Optimal Planning of Energy Storage Systems in Microgrids for Improvement of Operation Indices

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Abstract- The output of distributed generation resources depends on the weather conditions. This causes a fluctuation in the production of these resources and reduces the power quality. One of the solutions to overcome this problem is the use of energy storage systems. The use of these systems improves the operation indices of the grid. Energy storage systems, especially batteries, with all their technical capabilities, are high-cost systems. Therefore, installing them at any location with any random and non-optimum size can lead to higher cost. This research presents a method by which it can be possible to determine the optimal location, power and energy capacity of storage systems in a grid based on hour to hour data of the grid over a year (Includes variable output power of distributed generation and load). Since the effect of using the storage device on the operation indices depends more on the installation location than on the storage capacity by creating an independent objective function for the voltage profile and power losses the optimum location to install the storage device is determined. In this paper, the symbiotic organisms search algorithm has been used to solve the optimization problem. In the optimization process, in addition to improving the voltage profile, reducing losses and increasing network reliability, storage costs (Including the cost of investment, operation and maintenance) are minimized. The results obtained with Symbiotic organisms search algorithm are compared with other conventional algorithms such as particle swarm optimization (PSO) and genetic algorithms. Given that Symbiotic algorithm has no specific adjusting parameters, the convergence rate increases and a more appropriate answer is obtained.

Keywords Distributed Generation, Energy Storage Systems, Operation Indices, Symbiotic Organisms Search Algorithm.

1. Introduction

Nowadays, increasing population and diversity of consumers have increased energy consumption [1]. Considering the increase in energy consumption, demand energy will be double over the next thirty years [2]. Conventional power plants are not enough to respond to this demand. On the other hand, environmental degradation effects, such as pollution and reduction of fossil fuels, have led to a greater tendency to use renewable energy sources [3]. The imbalance between energy production and demand leads to grid instability and low quality of voltage and frequency. Therefore, a certain amount of energy must always be available to meet the demand.. In addition, power plants are usually located in non-consuming locations and require long transmission lines to transmit energy. Using long transmission lines lead to increase energy losses and costs [4]. On the other hand, the variable nature of distributed generation sources and the dependence of their output power on climate conditions reduce the quality of production power. One of the solutions to solving these problems is using of energy storage systems [5]. Storage systems are used in many applications in the network. some of these applications are: improvement stability of grid [6], frequency regulation [7, 8], improvement of reliability [9, 10], power loss reduction [11], voltage regulation [12] and active distribution network [13]. The greater storage capacity leads to greater improvement in each of the applications mentioned. However, because of the high investment cost, these systems cannot be used with very high capacity. Thus, the planning of storage systems requires the determination of optimum capacity and suitable installation location to achieve their maximum capabilities at the lowest cost [14] . In [15], the problem of optimal battery planning involves determining its location, capacity, and rating power to minimize the amount of objective function, which includes costs of investment, operation and reliability. In this plan, the planning problem involves short-term and long-term planning. In the short-term planning, optimal load flow is performed with the point estimation method. The long-term planning is based on short-term planning. The above problem is optimized with Tabu Search and PSO hybrid algorithm. Each energy storage system has its own technical and economic specifications, which makes it suitable for a particular application. In [16], the comparison between the different batteries, used in this scheme as a storage, is presented in order to find the best choice for applications in the distribution grid. The proposed planning method has a four-layer process and considers the uncertainty of battery specifications, load, and wind power. The long-term planning layer optimizes the location, capacity, and power of the battery with the genetic algorithm. The short-run programming layer performs the optimal probability load flow by considering the technical constraints with the simulated annealing algorithm. In the uncertainty modeling layer, the technical and economic characteristics of the battery and demand load are modeled using fuzzy values. Also, to consider the correlation of wind power profiles, in the classification layer, these profiles are divided into several categories by the factor analysis method. Reference [17] presents a method based on a genetic algorithm to determin the capacity of energy storage systems in a grid. The main purpose of this method is to find the power and energy of storage to minimize the cost of operation of the grid. In this paper, the energy management method which is based on the fuzzy system is used to control the power output of the storage. Another article that deals with the plan of optimal storage systems is [18]. This paper presents a method to determin the optimal size and location of storage systems in a power grid with wind turbine sources, taking into account uncertainty. The uncertainty of the output power of the wind turbine is modeled by tree theory. Because of the large relationships used in the design, they cannot be solved, therefore, the Benders decomposition algorithm is used to reduce computational burden. The plan shows that increasing the investment cost of storage systems can reduce the operating cost of the power system. Thus, a compromise is made between the investment cost and the daily operation cost. In [19], a new stochastic plan framework is proposed to determine the optimum battery capacity and year of installation in a grid. the plan is for islanding mode and uses battery energy chart. In this scheme, the uncertainty about wind speed and demand power is considered and solved by Monte Carlo simulation and Lain Hypercube sampling. Optimal decision making minimizes the expected costs in a perennial horizon. The method presented is solved with the linear integer programming in two steps. The optimal battery values in the first step and the optimal battery installation year in the second step will be determined. Determining the optimal location and size of battery is very important for minimizing cost and losses. Reference [20], describes an innovative way to find the optimal location and capacity of the battery in both transmission and distribution sectors. Determining the optimum location of the battery in the transmission section is done with the aim of controlling the frequency using complex valued neural networks as well as load flow in the time domain. Additionally, the optimum battery size is found by load flow and economic dispatch. storage planning in the distribution section is done with the aim of modifying the peak load and smoothing the load curve.[21] reviews recent developments in microgrids. It is intended to introduce the subject by reviewing the components level, structure and types of microgrid applications installed as a plant or modelled as a simulation environment. In [22] a hybrid Energy Storage Systems has been used to compensate microgrid instability caused by constant power loads. the hybrid energy storage system (HESS), with a battery unit as well as ultra-capacitor unit, is introduced to reduce the deficiency in the case of using either battery-only or ultra-capacitor-only storage system and offer the combined features with higher energy and higher power density. also a simple implementable algorithm has been presented to improve overall efficiency, cost effectiveness, life span; reduce the energy storage size and stress on the battery. One of the energy storage systems that has a lot of use in the grid is battery. In batteries, chemical energy is converted into electrical energy. The batteries are divided into two sets of primary and secondary batteries, which in the primary set, the battery is un-rechargeable and in the secondary set, the battery is rechargeable [23]. İn [24] the Zinc Bromide Battery and Li-ion Battery are delineated with the explanations on their performance and related simulations. Flow batteries are a two-electrolyte system in which the chemical compounds used for energy storage are in liquid state, in solution with the electrolyte. They overcome the limitations of standard electrochemical accumulators (lead-acid or nickel-cadmium for example) in which the electrochemical reactions create solid compounds that are stored directly on the electrodes on which they form. This is therefore a limited-mass system, which obviously limits the capacity of standard batteries. An example of secondary batteries is a vanadium redox flow battery. In this battery, unlike conventional batteries, that store energy in the electrodes, electrolytic solutions are responsible for storing of energy, which makes it possible to determine the power and energy capacity separately. This battery, despite its high investment cost and low energy density, has a flexible discharge time, power and energy, as well as high lifetime, which encourage the use of this type of battery [25]. Based on mentioned and regardless of the valuable research done in the field of energy storage systems, the issue of using these systems to develop performance indicators such as voltage profiles, system losses, and system reliability considering technical and economic aspects are less appealing by literatures.

In this paper, the optimal location, power and energy capacity of the storage system with the aim of improving the operation indices such as voltage profile, losses reduction and reliability are determined. In addition to these goals, an optimal energy management process is also proposed using energy storage system. Using the annual wind speed data, annual wind power production is calculated, and the variable nature of the distributed generation source is considered. Since network load varies, to get an optimal and practical answer, the energy storage system design takes into account the hourly variations of the load and the annual load curve as well as momentary wind turbine production. Considering the high cost of energy storage systems, the economic aspects , such as cost of investment, annual operation and maintenance, along with the technical aspects are considered. Since the effect of using the storage device on the operation indices depends more on the installation location than on the storage capacity, the problem of locating becomes more important. According to whatever was said about the vanadium redox flow battery benefits, the energy storage system used in this article is a vanadium redox flow battery. To solve the optimization problem, the symbiotic organisms search (SOS) algorithm is used. The main advantage of this method, compared with other meta-heuristic algorithms, is the need for no specific configuration parameters that cause faster convergence. The results obtained are compared with the results obtained from the genetic algorithms (GA) and the particle swarm optimization (PSO) algorithm to determine the efficiency of the SOS algorithm. The resource of the distributed generation used in this project is a wind power plant consisting of several wind turbines. The output power of each turbine is determined by a model dependent on wind speed. Therefore, the main innovation of this paper can be summarized as follows:

- The simultaneous increase of system performance indicators, including voltage profiles, loss reduction, and increased system reliability
- Considering economic aspects such as investment cost, annual maintenance cost, replacement cost, energy purchased from the main grid and the cost of energy not supplied and optimization of them.
- Considering hourly changes in annual load.
- Considering variations in wind power production using wind speed data over the course of the year.
- The use of the symbiotic organisms search (SOS) algorithm to optimize the design of the energy storage system
- Presenting an optimal energy management process

In the following, section 2 explains the wind turbine model. In Section 3, problem formulation, objective function and constraints are introduced. Section 4 explains the SOS algorithm. Section 5 explains the proposed method. Section 6 presents the results of the simulations carried out. Finally, Section 7 is dedicated to the conclusion.

2. Wind Turbine Model

Wind turbines cannot function properly for technical and economic reasons in storms. Therefore, in such cases it will be shut off and there will be no energy production. Therefore, according to the analysis presented in reference [26], the power produced by the wind turbine can be calculated by Equation (1). This relationship indicates that the output power of wind turbine reliant on wind speed and turbine characteristics.

$$P=\begin{cases} 0 & v < v_c \ or \ v > v_f \\ \alpha v^2 + \beta v + \gamma & v_c \le v \le v_r \\ P_r & v_r < v \le v_f \end{cases} \quad (1)$$

In this regard, v shows the wind speed. v_r is the mean value of wind speed at which this, turbine generating power is equivalent to the rated power. v_c or cut-in speed is the minimum wind speed, after which the power generation begins, and v_f or cut-off speed is the maximum wind speed after which the turbine motion is stopped to maintain the turbine's health and prevent its overturning and power is not generated. Also, P_r is the rated power of turbine. Thus for wind speeds between v_r and v_f, a wind machine produces its rated output, P_r, independent of wind speed. Furthermore, the values of α, β and γ can be expressed as a function of p_r, v_c, v_r and v_f [26]. A commercial horizontal axis wind turbine is employed in this paper [27]. The following parameters have been obtained for Equation (1) [17]:

α =0.144 kW s2/m2, β = -1.152 kW s/m, γ =2.268 kW.

Also in reference [28], the mathematical modelling of the permanent magnet synchronous generator wind turbine and simulation for the different aspects and cases of the system have been addressed.

3. Problem Formulation

3.1. Objective Function

The optimization aims that are considered in this paper include improving the voltage profile, reducing power losses, and reducing costs. Consequently, the objective function consists of three components as (2), each component being considered for one of the goals.

$$\mathrm{F} = \min[\mathrm{F}_1 + \mathrm{F}_2 + \mathrm{F}_3] \qquad (2)$$

In the objective function, to improve the voltage profile, the value of the voltage deviation is computed. For this purpose, first, a desired voltage level, V_{level}, with a value of 1 pu is considered. Then the deviation voltage of each bus at each hour from the desired level is determined. Then the bus voltage deviation index is calculated by equation (3):

$$F_1 = \sum_{j=1}^{8760} \sum_{i=1}^{33} \left| v_{level} - v_i^j \right| \qquad (3)$$

The active power losses in each branch are obtained by (4):

□□□□□ = □□□□$[(V_i - V_j) \times I_n^*]$ (4)

In this situation, V_i and I_n shows the voltage of bus i and current of the branch n, respectively. Then, the total amount of power losses is calculated at any hour in all branches.

$$F_2 = \sum_{j=1}^{8760} \sum_{i=1}^{37} (P_i^{loss})_j \qquad (5)$$

The costs that are considered in this plan include investment, operation, and reliability costs.

$$\mathrm{F}_3 = \mathrm{IC} + \mathrm{OC} + \mathrm{RC} \qquad (6)$$

The investment cost (IC) of a battery involves the installation cost and replacement cost, which are functions of the energy and power of the battery [15]. This cost is expressed in (7):

□□ = □□□ × □□□□□ + □□□ × □□□□□ + □□□ × □□□□□ + □□□ × □□□□□ (7)

In this case, □□□□□ (□□) is power and □□□□□(□□h) is energy capacity and C_{IP} (\$/kW) is installation cost factor related to the power of the battery and C_{IE} (\$/kWh) is installation cost factor related to the energy of the battery and C_{RP} (\$/kW) is replacement cost factor related to the power of the battery and C_{RE} (\$/kWh) is replacement cost factor related to the energy of the battery. The battery lifetime is typically modeled with a limited number of charging and discharging cycles. If the number of cycles exceeds this, the investment cost will increase as much as replacement cost.

Operation cost (OC) includes the costs of operation and maintenance of the battery and the cost of energy is bought from the main grid, which is dependent on battery power [15]. this cost can be determined as follows:

$OC = C_{OM} \times P$□□□□ $+ \sum_{i=1}^{8760} PE_i$ (8)

In (8), C_{OM} (\$ / kW) is the cost factor associated with the operation and maintenance of the battery, and PE_i is the energy cost which is bought from the main grid at any hour. When no battery is used and the amount of energy generated by the wind power plant is not enough to feed the load, energy is provided from the network. When using the battery, if the total energy produced by the wind power plant and the injectable energy of the battery is not sufficient to feed the load, the network provides energy shortages.

In this article, the cost related to the energy not supplied (ENS) is considered as reliability cost (RC). The important parameters in calculating the energy not supplied are the average failure rate (λ), mean outage time (r), and mean load (La) [29]. Here, the values of λ and r for all lines are considered to be 2 (failure per year) and 194.66 hours, respectively. The average load is calculated by (9).

$$L_a = \frac{E_d}{T} = \frac{Demand\ energy\ in\ the\ desired\ time}{desired\ time} \qquad (9)$$

$$\mathrm{U}_i = \lambda_i \times \mathrm{r}_i \qquad (10)$$

In this way, using (11) the energy not supplied can be calculated.

$$ENS = \sum_{i=1}^{33} L_a(i) \times U_i \qquad (11)$$

Then, using (12), the reliability cost will be obtained. In this regard, C_E (\$ / kWh) is the cost of unit energy.

$$RC = C_E \times ENS \qquad (12)$$

When the battery is installed in the grid, the demand energy decreases during the time the battery is discharged [9]. The (13) is used to calculate this energy value.

$$E_d = \begin{cases} E_{demand} - E_{discharge} & discharging\ time \\ E_{demand} & other\ times \end{cases} \qquad (13)$$

Given that all three objective functions are combined in a general objective function; they must have the same unit. Since the unit of two functions F_1 and F_2 is per unit and the unit of function F_3 is dollar, the function F_3 is multiplied by a weighting factor.

3.2. Constraints

In this plan, two categories of constraints are considered. One of the categories is related to the battery and another category related to the grid.

3.2.1 Battery constraints

□□□□□□□ ≤ □□□□□ ≤ □□□□□□□ (14)

□□□□□□□ ≤ □□□□□ ≤ □□□□□□□ (15)

In (14), C_{batt} is energy capacity of battery and in this paper the minimum and maximum values of it are 1500 and 2000. In (15), P_{batt} is power capacity of battery and in this paper the minimum and maximum values of it are 300 and 500. Maximum and minimum capacity of the battery are subject to several factors, including the use of battery targets. The battery can be used to control the frequency, control the stability, increase reliability, reduce losses and smooth the load curve and reduce the peak load. Each of these uses can define the battery capacity range .But an important factor in determining the capacity of the battery is economic aspects. As stated, the battery has investment and installation costs, annual operating costs and replacement costs. Therefore, due to the available budget and considering technical aspects, the maximum and minimum capacity of the battery can be estimated.

The stored energy in the battery should be restricted.

$$0 \le \square^{\square} \le \overline{\square} \tag{16}$$

$\overline{\square}$, is the energy capacity of the battery. The battery state of charge should be updated every hour. For this purpose, (17) and (18), which are used in charging and discharging mode respectively, are used [30].

$$\square\square\square^{\square} = \square\square\square^{\square-1} + \frac{\square^{\square}_{\square\square\square\square}\times\Delta\square\times\square_{\square}}{\square_{\square\square\square\square}} \tag{17}$$

$$\square\square\square^{\square} = \square\square\square^{\square-1} - \frac{\square^{\square}_{\square\square\square\square}\times\frac{\Delta\square}{\square_{\square}}}{\square_{\square\square\square\square}} \tag{18}$$

In (17) and (18), $\square_{\square}$ is charging efficiency and $\square_{\square}$ is discharging efficiency which in this paper both are considered 70%.

3.2.2 Grid constraints

$$\square_{\square\square\square} \le \square_{\square,\square} \le \square_{\square\square\square} \tag{19}$$

$$\square^{\square}_{\square\square} + \square^{\square}_{\square\square\square\square} = \square^{\square}_{\square\square\square\square} + \square^{\square}_{\square\square\square\square} + \square^{\square}_{\square\square\square\square} \tag{20}$$

Constraint (19) related to the voltage of buses at any hour. The minimum and maximum values of voltage are 0.9 and 1.1 pu. Constraint (20) shows the power balance. In this equation, $\square^{\square}_{\square\square}$ is the power of the wind power plant, $\square^{\square}_{\square\square\square\square}$ is grid power, $\square^{\square}_{\square\square\square\square}$ is the load power and $\square^{\square}_{loss}$ is the power losses per hour.

4. Symbiotic Organisms Search (SOS) Algorithm

The symbiotic organisms search algorithm is a new algorithm for numerical optimization problems. This algorithm inspires interactions between beings in nature. Due to the dependence of beings on nutrition and survival, they rarely live alone. This relationship based on dependence is called symbiosis. There are various symbiotic relationships in nature that are distinguished on the basis of the profit or harm of the two members that are related. If the symbiotic relationship results in two member profits, the relationship is *mutualism*. The other symbiotic relationship that benefits a member and doesn't affect another member is known as *commensalism*. If the symbiotic relationship causes one member's profit and another member's harm, it's called *parasitism* [31].

The SOS algorithm starts with an initial population called the *ecosystem.* In this initial population, a number of organisms are randomly generated. Each organism will provide a solution to the related issue, which is associated with a certain degree of compatibility and indicates the degree of compliance with the target. After creating the initial population and choosing the best organism among them, the solutions should be generated in the next iteration. For this purpose, three phases of *mutualism*, *commensalism* and *parasitism* are used. The completion criteria must be met to complete the algorithm.

4.1. Mutualism phase

X_i is the i-th member of the ecosystem, and X_j is another member that is randomly selected to interact with X_i. In this phase, a relationship is formed between the two members, which will benefit both. The new candidate solutions for X_i and X_j are modeled by (21) and (22).

$$X_{inew} = X_i + rand(0,1)\times(X_{best} - MV\times BF_1) \tag{21}$$

$$X_{jnew} = X_j + rand(0,1)\times(X_{best} - MV\times BF_2) \tag{22}$$

$$MV = \frac{X_i+X_j}{2} \tag{23}$$

In these equations, *rand* (0,1) is the vector of random numbers, and X_{best} is the member that has the highest amount of compliance with the ecosystem. Benefit factors (BF_1 and BF_2) randomly selected 1 or 2, determine the profit level of each member from the relationship. Finally, if the new compatibility value of members is more than the amount of compatibility in previous iterations, members will be updated.

4.2. Commensalism phase

In this phase, member X_j is randomly selected from the ecosystem for interacting with X_i. In this situation, the member X_i tries to benefit from the relationship. However, the member X_j will not benefit from this relationship and will not also be harmed. The answer to the new candidate X_i, which is calculated on the basis of the commensalism relation between the members X_i and X_j, is modeled in (24). The member X_j will be updated if the new compatibility value is greater than the compatibility level in previous iterations.

$$X_{inew} = X_i + rand(-1,1) \times (X_{best} - X_j) \quad (24)$$

4.3. Parasitism phase

In Parasitism phase, the member X_i creates a parasitic-like parasite by creating an artificial parasite called the parasitic vector. Then the member X_j is randomly selected from the ecosystem and feeds the parasite vector as the host. Parasite vector tries to replace the member X_j in the ecosystem. The compatibility value of both members are calculated. If the parasite vector has a better compatibility value, the member X_j will be destroyed and replaced by the ecosystem. If the X_j compatibility value is better, X_j is no longer a parasite, and the parasite vector will not be able to survive in this ecosystem any more.

5. The Proposed Method for Planning of Battery

Figure 1 shows the flowchart of the proposed method in the optimal planning of the battery. The details for each step will be as follow:

Step A: This step is about preparing and giving the initial value to the parameters of the algorithm. At this step, the number of organisms, the initial ecosystem and the number of iterations are determined.

Step B: At this step, one organism of the ecosystem will be selected. Each organism of the ecosystem is a vector that contains decision variables.

Step C: The decision variables include the location and capacity of the power and energy of the storage system. At this step, the value of each of these parameters is applied to the storage system.

Step D: At this step, the values of the output power of wind power plant and load, depending on each hour, are applied to these two parameters, respectively.

Step E: Charging and discharging the battery is based on a comparison of the output power of wind power plant and load. So, at any hour if the output power of wind power plant exceeds the load and battery capacity is not full, the battery will be charged, and if the capacity of the battery is full, the excess power generated than the power consumption will be sold to the grid. If the output power of wind power plant is less than load and the battery capacity is not completely empty, the battery will be discharged to supply the required power. In this case, if the capacity of the battery is empty, the power needed to feed the load is taken from the main grid.

Step F: This step is related to the calculation of the SOC. After performing step E, based on the amount of energy charged or discharged, SOC is calculated using relations (17) and (18).

Step G: At this step, the load flow is performed. In this plan, the preferred method for performing load flow is forward-backward method. Details of this method is given in [32].

Step H: After the load flow has been executed, the constraints must be checked. At this step, all constraints are examined, and if the value of each is exceeded the minimum or maximum values, the corresponding organism is removed from the ecosystem.

Step I: After performing steps D to H to the number of hours considered, the objective function is calculated.

Step J: All organisms of the ecosystem are evaluated and the objective function is calculated for each organism. Subsequently, from among all organisms, the organism with the lowest value of the objective function is selected.

Step K: At this step, all organisms of the ecosystem are updated in mutualism, commensalism and parasitism phases, respectively, using the relationships given in Section 4.

Step L: At this step, the termination criteria is examined. The termination criteria in this plan is to perform the number of iterations desired. After performing all the iterations, the execution of the algorithm is terminated and the optimal answer is obtained.

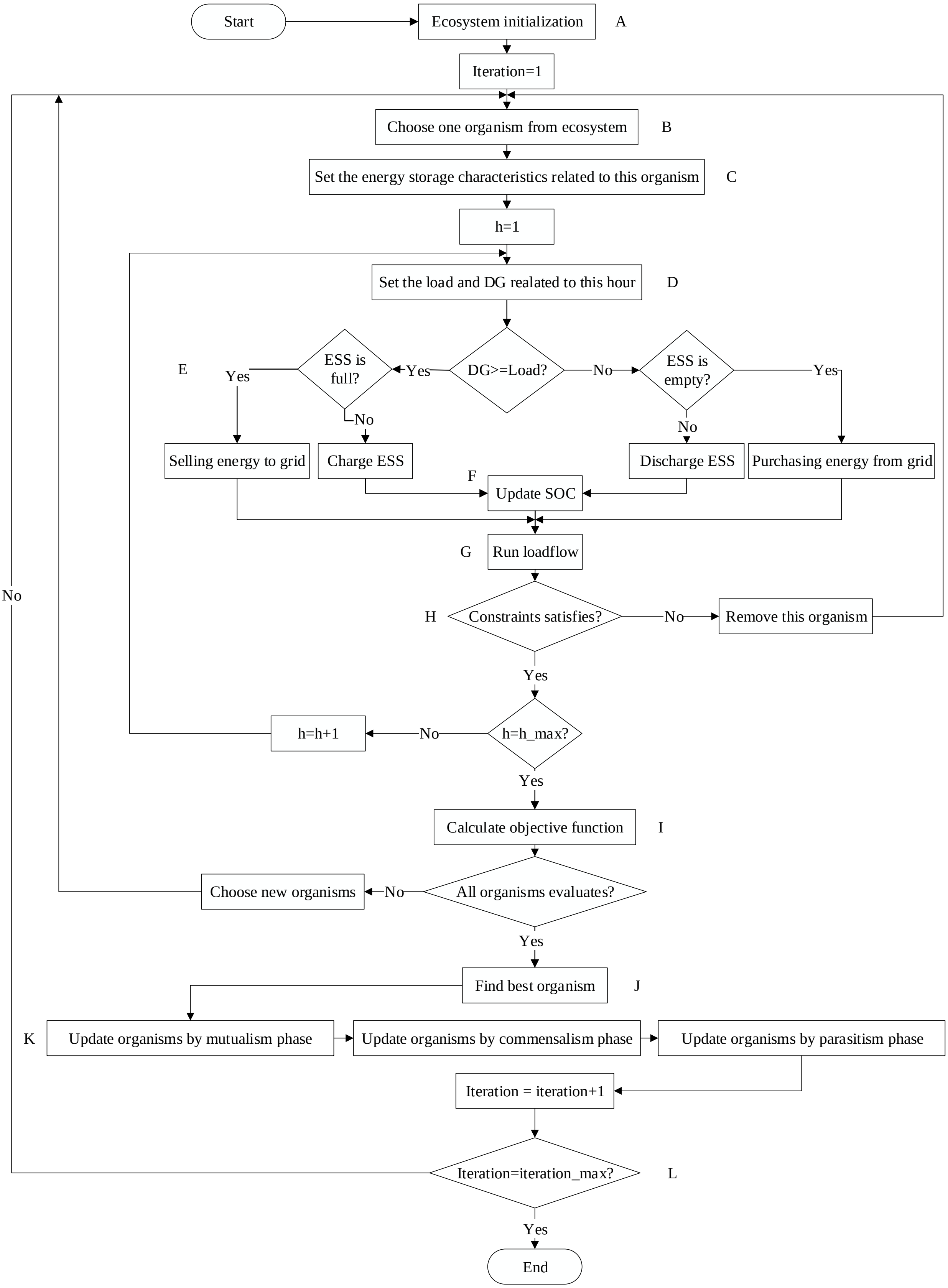

Fig. 1. Flowchart of the proposed method

6. Simulation and Results

The case study in this plan is standard IEEE 33 buses grid, which is selected to examine the proposed method. Figure 2 shows this grid. Information of this grid is presented in [33].

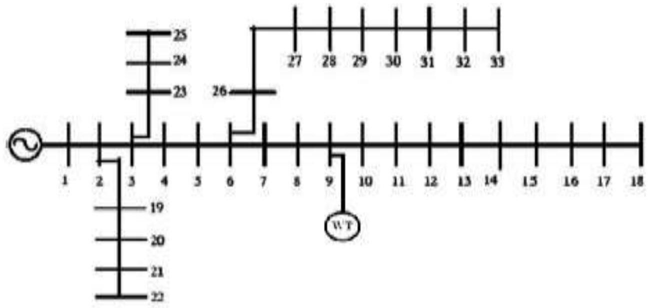

Fig. 2. The standard IEEE 33 buses grid

In this grid a wind power plant including 180 turbines is used that connected to the bus 9. Rated power of this power plant is 3.6 MW. Wind turbine power is reliant on wind speed. Figure (3) shows the variation in wind speed throughout the year.

Using the equation (1) and the wind speed values shown in Fig. 3, the output power of each wind turbine can be obtained. Finally, Fig. 4 shows the output power of wind power plant throughout the year.

There are three categories of domestic, commercial and administrative loads in this grid. The amount of these loads are based on real measurements in capital city of Tehran in Iran and for one year (8760 hours). In Table 1, the type of load and maximum power consumption on each bus is defined. The daily consumption curve for each of the domestic, commercial and administrative loads mentioned above is averaged based

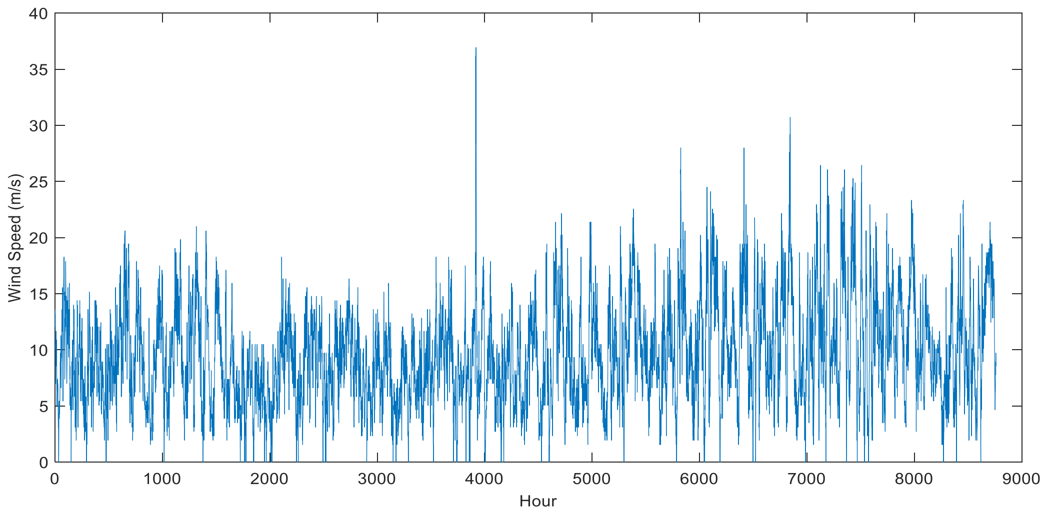

Fig. 3. Variation in wind speed throughout the year

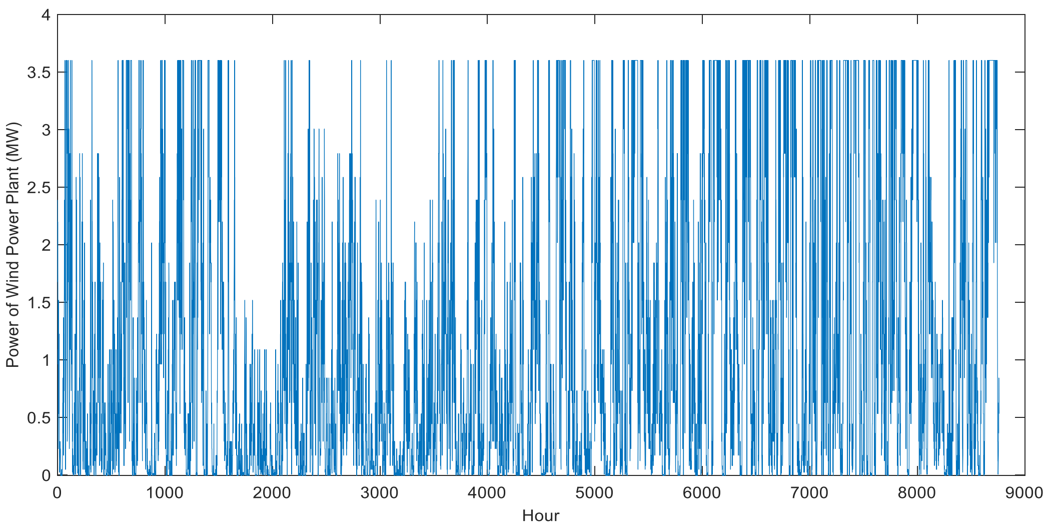

Fig. 4. Output power of wind power plant throughout the year

on the measured data in 365 days and, respectively, is shown in Figs. 5, 6 and 7.

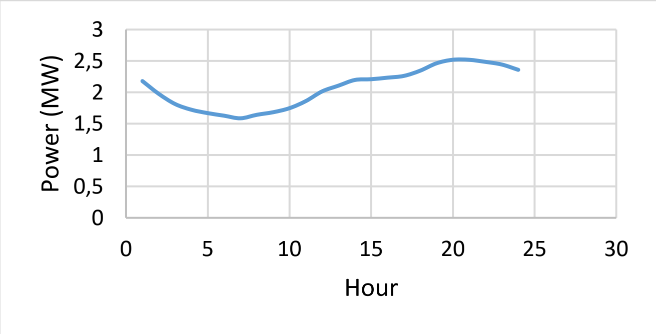

Fig. 5. Average Daily consumption curve for domestic load

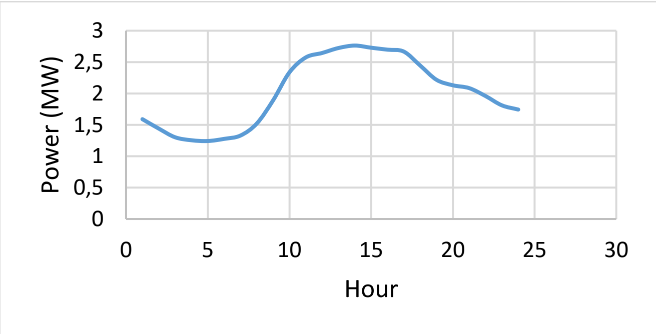

Fig. 6. Average Daily consumption curve for commercial load

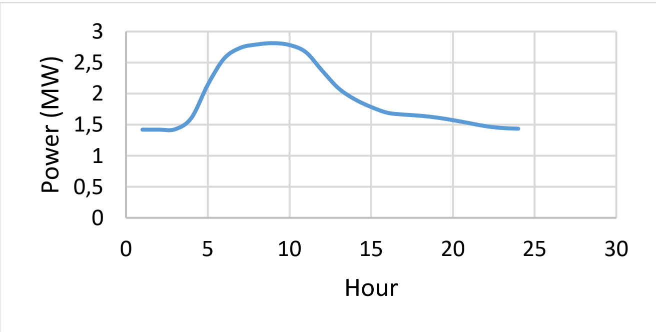

Fig. 7. Average Daily consumption curve for administrative load

Table 1. Load type and maximum power consumption on each bus

Bus Number	Type of Load	Active Power (kW)	Reactive Power (kVar)
1	-	0	0
2	Domestic	100	60
3	Commercial	90	40
4	Domestic	120	80
5	Domestic	60	30
6	Commercial	60	20
7	Domestic	20	100
8	Domestic	200	100
9	Commercial	60	20
10	Domestic	60	20
11	Domestic	45	30
12	Domestic	60	35
13	Domestic	60	35
14	Domestic	120	80
15	Administrative	60	10
16	Domestic	60	20
17	Domestic	60	20
18	Commercial	90	40
19	Domestic	90	40
20	Domestic	90	40
21	Domestic	90	40
22	Domestic	90	40
23	Domestic	90	50
24	Domestic	420	200
25	Domestic	220	100
26	Domestic	60	25
27	Commercial	60	20
28	Domestic	60	20
29	Domestic	120	70
30	Administrative	200	600
31	Domestic	150	70
32	Domestic	210	100
33	Domestic	60	40

The energy storage used in this grid is a vanadium redox flow battery and the characteristics of which are given in Table 2.

In this plan, the goal of optimization is to find the optimal location for installation and determine the optimal capacity of the battery in the target grid. The symbiotic organisms search algorithm is used to obtain optimal solutions. Finally, the results are compared with well-known and successful algorithms, i.e., GA and PSO.

The simulation is then carried out in four scenarios:

1- In the grid, no energy storage system is used
2- In the grid, optimized storage while GA algorithm is used.
3- In the grid, optimized storage while PSO algorithm is used.
4- In the grid, optimized storage while SOS algorithm is used.

Simulation is performed to optimize the objective function introduced in Section 3.1. Table 3 shows the location of installation, power capacity, and energy capacity of battery.

Also, the value of the adjusting parameters correlated to each of the algorithms is given in Table 4. The number of iterations for all algorithms is 100.

Table 2. Characteristics of vanadium redox flow battery [34]

Parameter	Cost of Power ($/kW)	Cost of Energy ($/kWh)	Replacement Cost ($/kWh)	Operation and Maintenance Cost ($/kW)	Efficiency (%)
Value	426	100	158	9	70

Table 3. Information of location and battery size

Algorithm Used	Location of Installation (Bus Number)	Energy Capacity (kWh)	Power Capacity (kW)
SOS	9	1536	304
PSO	10	1536	309
GA	10	1562	313

Table 4. Adjusting parameters correlated to each of the algorithms

Algorithm Used	Parameter	Value
SOS	Number of organisms	50
GA	Population	50
	Crossover	0.2
	Mutation	0.6
PSO	Population	50
	W	0.8
	C_1	1.5
	C_2	1.5

Figure (8) shows the value of voltage deviation for the four scenarios mentioned. The values obtained clearly indicate the very significant effect of the battery on improving the voltage profile and fixing it in the amount of 1 pu. Network losses are shown in Figure (9). Using the battery has significantly reduced the loss on the network. Algorithm SOS gives more reduction in network losses. Figure (10) shows the energy not supplied (ENS) in the four scenarios. The presence of the battery has caused a significant reduction in ENS. In comparison with PSO and GA algorithms, the results of SOS algorithm show a higher reduction in the ENS. The cost of the battery investment is shown in Figure 11. Due to the amount of battery capacity resulting from the optimization, the results of the SOS algorithm show lower cost for investment. Electricity tariff information for the two period (first and second six months) of the year is given in Figure (12). The cost of unit of energy should be used to calculate the costs of operation and reliability. Figure 13 shows the cost of operation in the four scenarios. As seen in this figure, by installing the battery and discharging energy at required times, the purchased energy from the grid is reduced, which decreases the operation cost. According to the results, operation costs in the fourth scenario (SOS) are less than other scenarios. The costs of reliability and network losses over a period of one year are shown in Figures (14) and (15), respectively. Using the battery has significantly reduced these costs. Algorithm SOS gives better results than other algorithms used in this regard. Finally, Figure (16) shows the savings on different network costs. Due to the results, the presence of battery in the network has been a significant savings in network costs. The savings from SOS algorithm are higher than other algorithms.

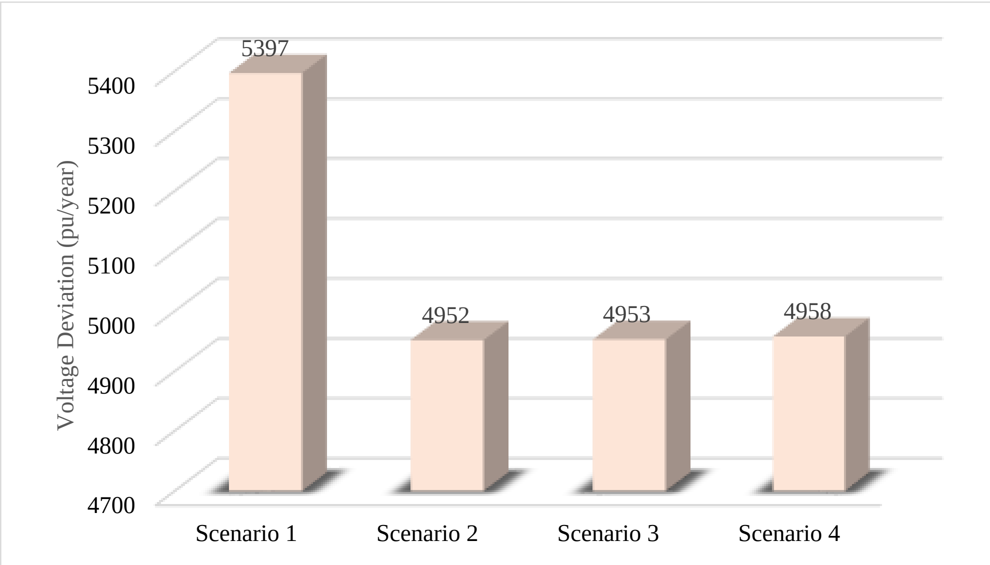

Fig. 8. Total values of voltage deviation (F_1) in the all scenarios

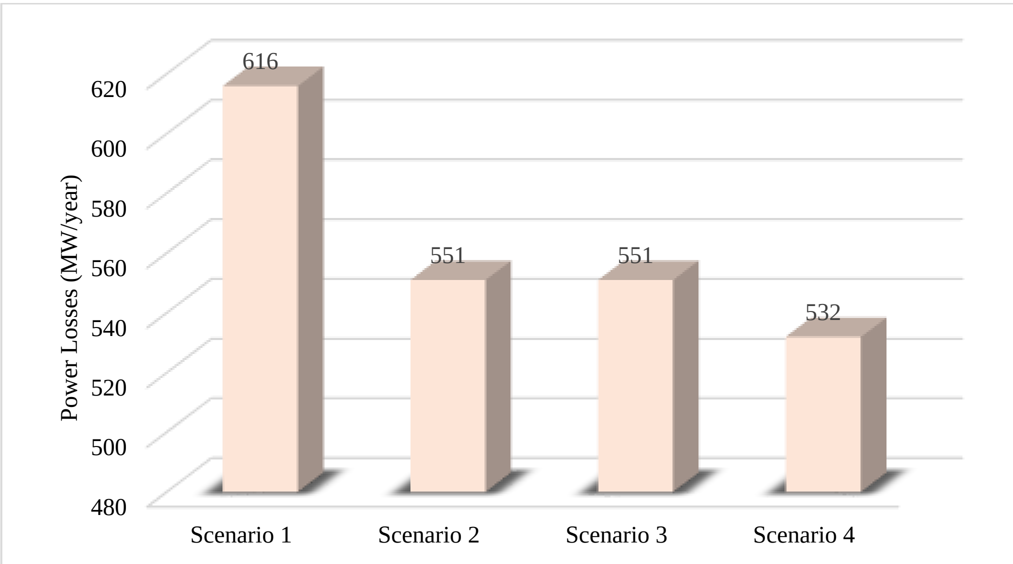

Fig. 9. Total values of power losses (F_2) in the all scenarios

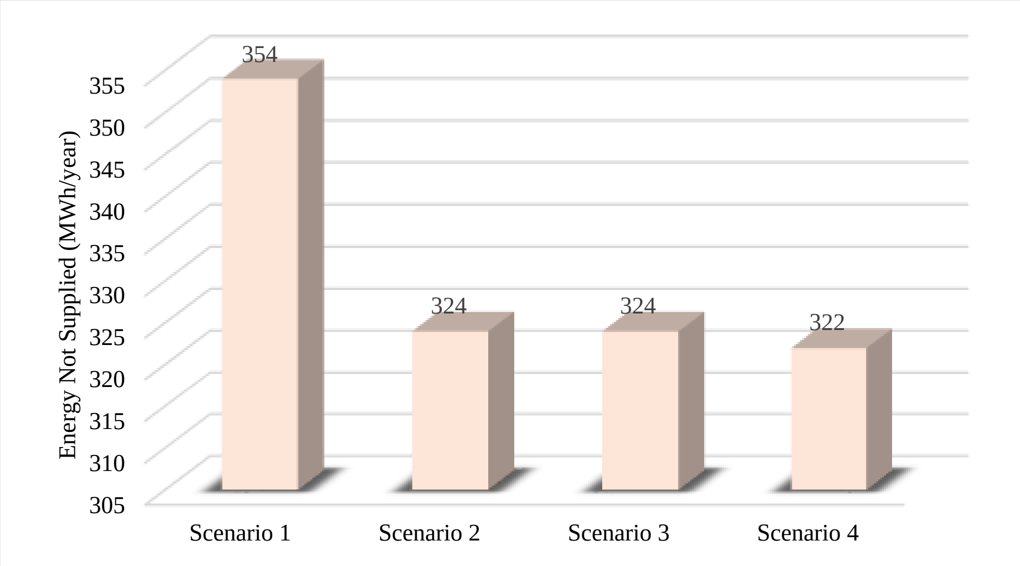

Fig. 10. Total values of energy not supplied (ENS) in the all scenarios

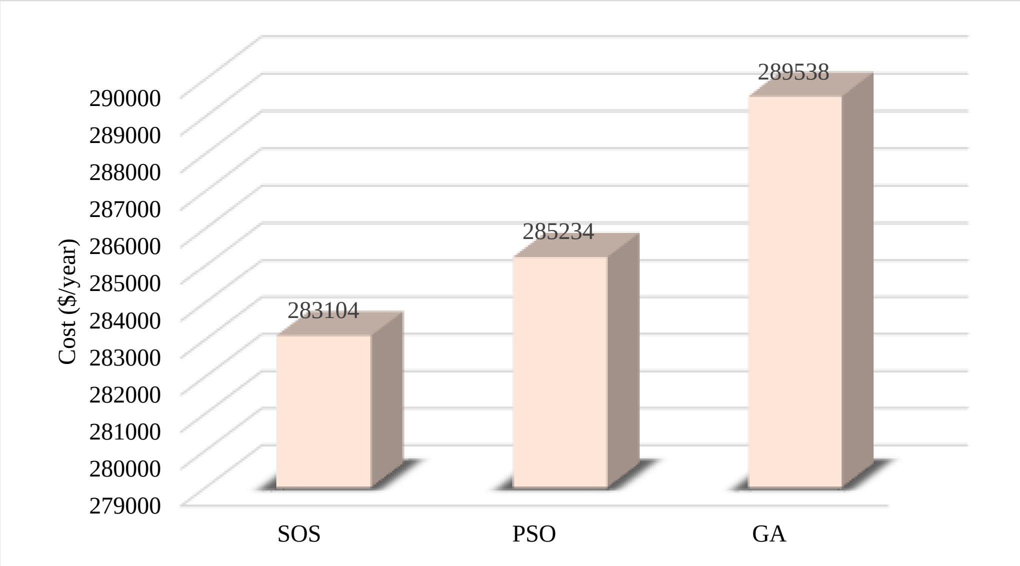

Fig. 11. Investment cost (IC) of battery

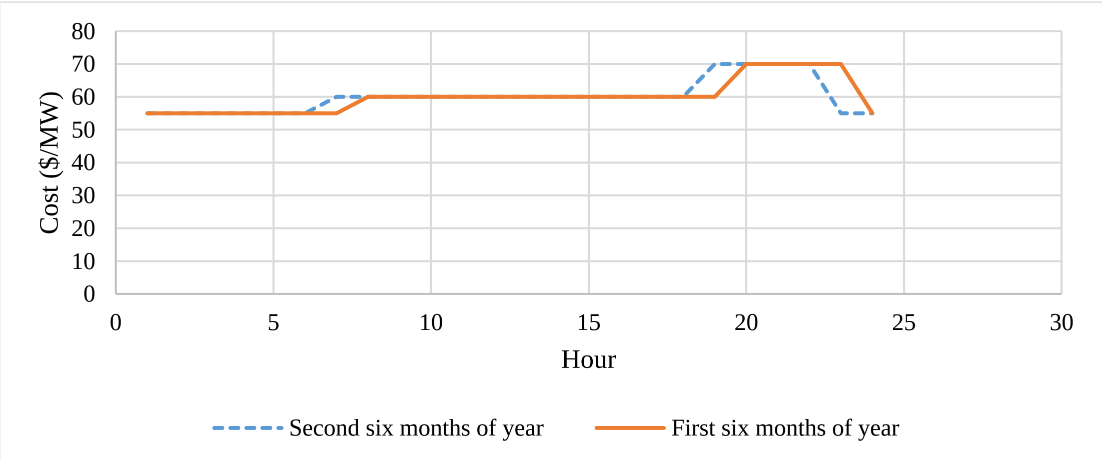

Fig. 12. Electricity tariffs for first and second six months of the year

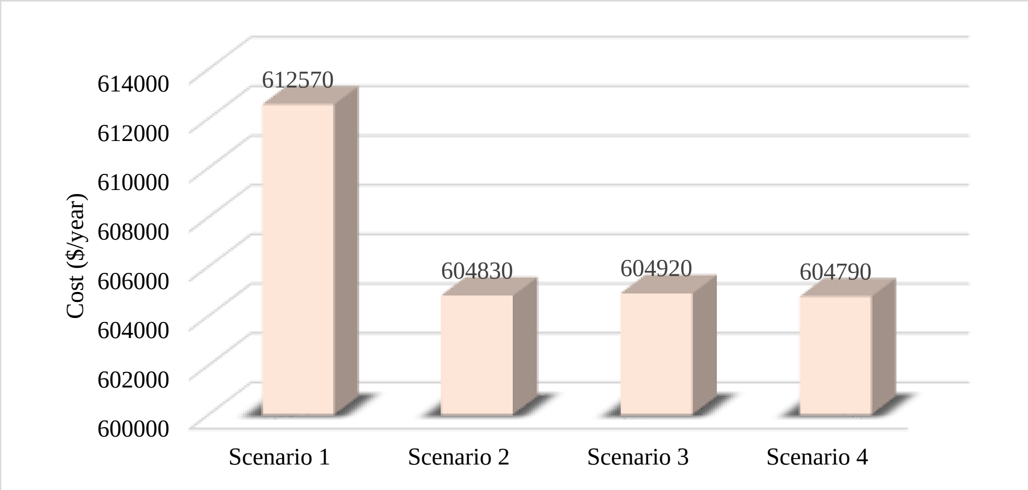

Fig. 13. Operation cost (OC) in the all scenarios

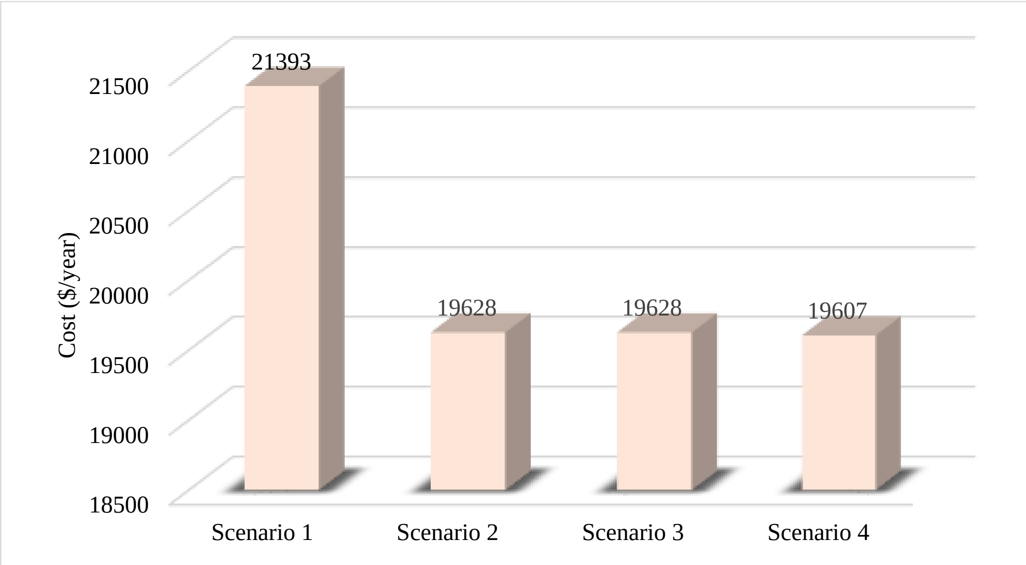

Fig. 14. Reliability cost (RC) in the all scenarios

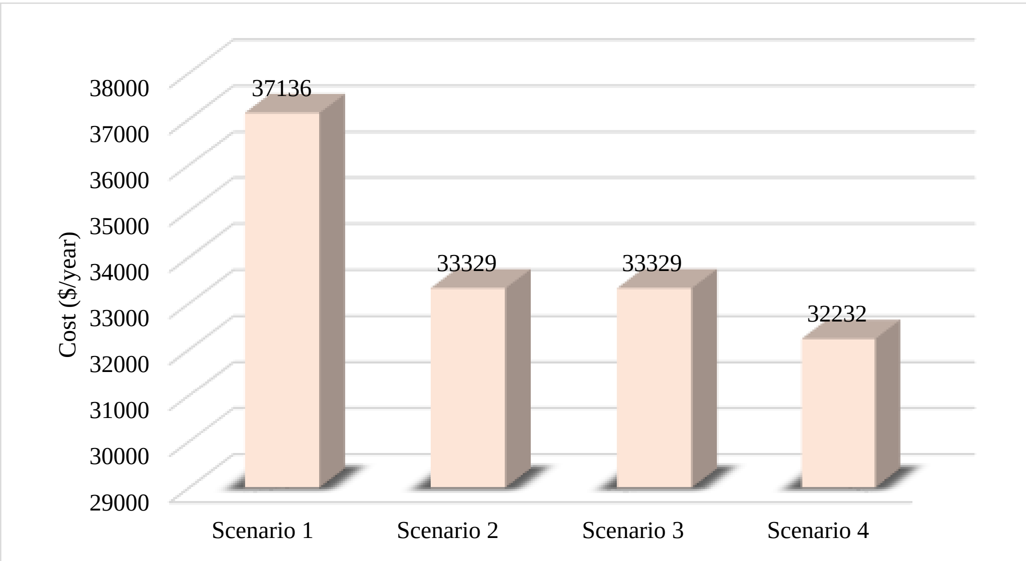

Fig. 15. Power losses cost in the all scenarios

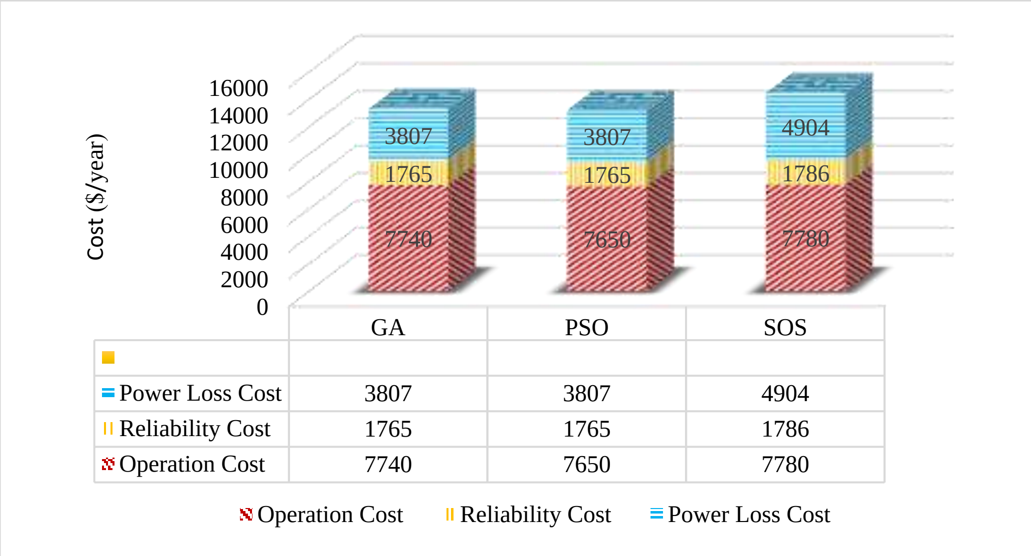

Fig. 16. Amount of saving in grid costs by using the battery

The cost savings in one year, in simulation with the genetic algorithm, is 13,312 $, with the PSO algorithm, 13,222 $ and with the SOS algorithm, 14,470 $. Due to the long lifetime of vanadium batteries, the cost saving from using the battery during the lifetime of this battery, in addition to returning the cost of investment, also brings major benefits to the system. As shown in Fig. 16, cost savings in the SOS algorithm are greater than the rest. This point, coupled with the lower cost of capital investment in SOS algorithm show the efficiency and effectiveness of the SOS algorithm.

7. Conclusion

In this research, the issue of the use of energy storage systems in grid has been investigated with the aim of improving the voltage profile, reducing power losses and improving reliability in the presence of a wind power plant with variable power generation. Due to some benefits, such as flexible discharge time, power and energy, as well as high lifetime, vanadium redox flow battery has been used to store energy. In order to provide real and practical conditions of the network, the annual load curve and hourly load changes of the network as well as the production of the net power of the wind power plant have been used throughout the year.

Because the batteries have high investment, operation and maintenance costs, their economic aspects have been considered along with the technical aspects. Using the proposed method, while the optimmal location of the installation, power and energy capacity of the energy storage system have been determined the costs of investment, repair and maintenance, replacement, energy not supplied, and the energy purchased from the main network have been also optimized. As a result, an optimal energy management is provided on the network.The SOS algorithm has been used to optimize the objective function and forward-backward method to calculate the load flow. The SOS algorithm, due to the simplicity and non-adjustment of the specific parameters, has a better convergence rate and more optimal results. The results show that the proposed method in compliance with the practical constraints of the network, in addition to achieving the objectives of the technical sector, also fulfills the objectives of the economic sector.

By examining the results, it can be seen that the effect of the location of the storage systems on improving the voltage profile and reducing power losses is greater than the storage size. Also, the amount of costs will be more dependent on the storage capacity. The costs in this project involved in investment, operation, and reliability. Cost savings due to the installation of the battery, including cost savings of operation, power losses and reliability, in addition to returning the cost of investment, will also generate major benefits to the system. In the end, the results of the SOS algorithm have been compared with the results of two well-known and successful algorithms, namely, GA and PSO, and the advantages of SOS algorithm have been discussed.

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