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# Symbiotic Organisms Search for Determining Optimal Generator Capacity

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*Abstract*—**This article proposes a method to optimize generation capacity (GC) according to the load diagram for a generator system by adopting the Symbiotic Organisms Search algorithm (SOS). In this paper, the generator system operates as an off-grid including Diesel Generator (DG), Solar Panels (PV), and Wind Turbine (WT). Regarding the applied algorithm, the SOS algorithm is used to solve the optimization problem to minimize electricity generation costs while still ensuring meeting load capacity according to demand within 24 hours with many other scenarios. Calculation results are performed with 3 cases, each corresponding to a specific generator system. They will be compared with DE-HS, DSM, and FO algorithms. The comparison results show the effectiveness of the SOS algorithm compared to the DE-HS, DSM, and FO algorithms. On the other hand, analyzing the obtained results, the convergence speed of the SOS algorithm in finding solutions achieves stability when increasing the number of iterations by ten times. However, the SOS algorithm still has some problems that need to be improved. That is to minimize the time to find the optimal solution because the algorithm has to perform many intermediate solution steps. Generator systems operating in off-grid mode are increasingly popular. In this system, generators have a variety of energy sources, including Diesel generators, solar power, and wind power. Many energy sources are integrated into a system, requiring a method to handle the optimal problem.**

*Keywords*— **Symbiotic organisms search algorithm; diesel generator; solar panels; wind turbine; optimal generator capacity.**

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## I. INTRODUCTION

Hybrid power systems (combining chemical energy sources and renewable energy sources) are not only a new trend but have become a part of today's life. With the development of technology, different models of hybrid power systems have been built in many areas. However, a problem with hybrid electric systems is how to operate to ensure optimal efficiency [1], [2], [3]. Optimal system operation involves many issues, but the problems revolve around arranging the energy sources to meet load needs. Energy sources must be positioned appropriately and optimally to ensure that generation capacity meets requirements and that economic factors and the safety of grid operation are met. That is the origin of many optimization problems. Each optimization problem is born with requirements, and finding their solution is to find a way to operate electrical systems optimally.

However, how to solve these optimization problems is a complex task. Because the hybrid power system is complex, with many input variables and different constraint functions, so conventional mathematical solution methods can only partially handle it. Over the years, researchers have developed and improved many algorithms to find the best solutions with the least time and resources. Algorithms considered adequate for solving optimization problems are algorithms based on the simulation of natural processes or algorithms based on artificial intelligence. Each algorithm created has different purposes, but the common goal is to find an effective solution to the problem of optimizing power distribution.

We can mention optimization algorithms applied in research, such as Jaya algorithm with self-adaptive multi-population and Lévy flight (Jaya-SML) [4], Modified harmony search (MHS) algorithm [5], Sine-Cosine Algorithm (SCA) [6], Improved Adaptive Harmony Search algorithm [7], Gray wolf optimization (GWO) [8], [9], Converged Barnacles Mating Optimizer Algorithm (CBMO) [10], Real-coded genetic algorithm (RCGAs) [11], [12], Modified harmony search (MHS) algorithm [5], [13], Social network search (SNS) algorithm [14], [15] Improved harmony search

(IHS) algorithm [16], Interior Search Algorithm (ISA) [17], [18], Greedy Sine-Cosine Non-Hierarchical Gray Wolf Optimizer (G-SCNHGWO) [19], Improved random drift particle swarm optimization (IRDPSO) [20].

This article is subject to solving the GC optimization value in the problem of a microgrid system with generators, including 3 cases: case 1, a microgrid system with 2 DG, 1 PV, and 1WT. In case 2, microgrid systems include 52 DG generators and 1 wind energy system with an external supply. In the case 3, microgrid systems, there are 10 DG generators, a hydroelectric system, a solar power system with storage batteries, and a wind power system. In all 3 cases, the SOS algorithm is used to find the optimal results. In case 3, we divide it into two instances: without the storage battery's participation and with the storage battery's involvement. To evaluate the effectiveness of the algorithm, the results will be analyzed and evaluated concerning the algorithm as a Genetic algorithm (GE) [21], [22], [23], Direct search method (DSM) [24], [25], Hybrid differential evolution and harmony search (DE-HS) [26], [27], [28].

## II. Materials and Method

### A. Objective Function Equation

The power system comprises many different power generation elements (turbine combination, diesel generator, photovoltaic, hydro system, battery system). Each device has distinct characteristics. Therefore, equipment operating cost variables will also follow the individual characteristics of the equipment. The operating cost function of each device will contribute to calculating the dispatching capacity of the entire system.

*1) Equation of fuel cost:* The fuel *cost* of N thermal generator is described by equation:

$$F_c(P_i) = \sum_{i=1}^{N} a_i + b_i P_i + c_i P_i^2 \quad (1)$$

In equation (1) $F_c$ is the fuel cost value that needs to be searched, N is the number of generators, each $i^{th}$ generator has fuel cost coefficients of $a_i$($/h), $b_i$($/MWh), $c_i$ ($/MW$^2$h) and the generating capacity is $P_i$

*2) Equation of available water:* The water content stored in the reservoir for electricity generation is calculated as follows:

$$X_j^{total} = \sum_{i=1}^{N} X_{jt} \quad (2)$$

where $X_j^{total}$ is the total amount of water forecast to serve the electricity generation of the j$^{th}$ generator.

*3) Wind power function:*

$$P_{wt} = \begin{cases} 0 V_{in} < V_t, V_t \geq V_{off} \\ P_{rated} \times (\frac{V_t - V_{in}}{V_{rated} - V_{out}})^3 V_{in} < V_t < V_{rated} \\ P_{rated} V_{rated} < V_t < V_{off} \end{cases} \quad (3)$$

Where: $V_t$ is the forecast wind speed at time t

$V_{in}$ is the cut-in wind speed

$V_{out}$ is the cut-out wind speed

$V_{rated}$ là is the rated wind speed

$P_{rated}$ is the rated generating capacity of the wind turbine.

*4) Solar power function:*

$$P_{PVt} = P_{STC} \times \frac{G_t}{G_{STC}} [1 + k \times (T_{ct} - T_r)] \quad (4)$$

Where: $P_{PVt}$ the solar electric energy produced at time t

$P_{STC}$ is the maximum capacity that can be generated by solar power at standard conditions (STC).

$G_t$ predicted radiation at time t

$G_{STC}$ is standard radiation calculated as 1000 W/m$^2$.

k is the temperature coefficient.

$T_{ct}$ is the PV panel temperature at time t.

$T_r$ is standard temperature of PV panels.

$$P_{PVt} = P_{St} + P_{bt} \quad (5)$$

$P_{St}$ is the solar power energy supplied to the load at time t.

$P_{bt}$: charge/discharge energy from the storage battery system at time t.

*5) Total cost of micro-grid system:*

$$F_c = \sum_{t=1}^{N} \sum_{i=1}^{M} F_{ct}(P_i) \quad (6)$$

$F_{ci}$ ($P_i$) is the fuel cost function of the i$^{th}$ generator at time t.

N is the number of times to be considered for selection.

M is the number of generators participating in providing power to the load.

$$F_c = \sum_{t=1}^{N} \left( \left( \sum_{i=1}^{M_{DG}} F_{ct}(P_i) \right) + d_w \times P_{wt} + d_s \times P_{St} \right) \quad (7)$$

Where: $d_w$ is the cost coefficient of the wind power system.

$d_S$ is the cost coefficient of the solar power system.

*6) Balance equations of power:*

$$\sum_{i=1}^{M} P_{it} + \sum_{j=1}^{J} P_{Hjt}(X_{jt}) + P_{wt} + P_{st} = P_{Dt} t = 1,2{:}N \quad (8)$$

Where: $P_{Hjt}$ is the hydropower capacity related to the amount of water stored at time t.

$X_{jt}$ is the volume of water used by generator j to generate electricity at time t.

J: number of hydroelectric generators.

$P_{wt}$: the electricity output of the wind power system at time t.

$P_{st}$ is the solar power output the solar power system generates at time t. This power output is determined by whether or not a storage battery is used.

$P_{Dt}$ load demand at time t

*7) Constraint function*

- Diesel generator capacity

$$P_i^{min_i^{max}}$$

- The amount of water supplied to generate electricity at a time t.

$$X_j^{min_{jt}^{max}_j}$$

- Charge/discharge capacity of storage battery

$$\left| P_{bt}^{min} || _{bt} | P_{bt}^{max} ||| \right|$$

*B. Symbiotic Organisms Search (SOS) Algorithm*

Symbiotic Organisms Search Algorithm, abbreviated as SOS Algorithm, is an algorithm built to process and find optimal values through 3 stages: *mutualism phase, commensalism phase, and parasitism phase* [29] [30] Using an initial population randomly generated with the number of organisms in a population clearly defined, SOS begins the process of transformation to create new populations. The transformation process of updating or changing each entity in the population with other, more suitable entities is carried out in three stages: the mutualism phase, the commensalism phase, and the parasitism phase.

Each stage is built on the interaction and relationship between two entities in the population. If their interaction is mutually beneficial during the mutualism phase stage, then through the *commensalism phase* stage, only one side will benefit and the other will be normal. During the parasitism phase, the relationship worsens when one party benefits and another is harmed. At the same time, it should be noted that this interaction is entirely random; the entities interact with each other, and the parties' interests will follow the phase to which they belong. This process occurs continuously and repeatedly until a satisfactory value is found or if the number of iterations reaches a critical level.

*1) The first phase (mutualism phase):* First, the vector ($X_i$) representing individual 'i' in the population will contact and exchange with the vector ($X_j$) representing some random individual 'j' that also belongs to the population ('i' and 'j' are equivalent). This interactive process will create new entities 'i', 'j' according to the equation below:

$$X_{inew} = X_i + \varepsilon * (X_{best} - \bar{X} * \beta_1) \tag{12}$$

$$X_{jnew} = X_j + \varepsilon * (X_{best} - \bar{X} * \beta_2) \tag{13}$$

$$\bar{X} = \frac{X_i + X_j}{2} \tag{14}$$

where $X_{best}$ is the vector representing the highest fitness in the population. In the value range [0,1] the value $\varepsilon$ is randomly selected and the $\beta_i$ benefit coefficient is also randomly selected in (1,2). If $X_{inew}$, $X_{jnew}$ achieves a better level than $X_i$, $X_j$ then they will be chosen instead.

*2) The second phase (commensalism phase:* In this phase, vector $X_i$ is also selected with the same principle as the case above. The selected value must be beneficial in the interaction and the new value will be calculated according to the equation below:

$$X_{inew} = X_i + \varepsilon' * (X_{best} - X_j) \tag{15}$$

Unlike the value $\varepsilon$ the value $\varepsilon'$ is randomly selected within the range [-1,1], If $X_{inew}$ achieves a better level than $X_i$ then they will be chosen instead.

*3) The third phase (parasitism phase):* During this stage, the value $X_i$ is selected through a parasitic process. The parasitic vector is created by replacing some elements in the existing vector. This vector will parasitize vector $X_j$. If $X_j$ does not meet the requirements, a parasitic vector will replace it. A parasitic vector will replace the value of Xj and, after that, be destroyed.

Combining the above cases, we get the algorithm flow chart as follows:

a. **Step 1:** Initial initialization:

Select the values of the parameters of the SOS algorithm (number of individuals (Eco_size), number of iterations ($max_{Iter}$). Identify input variables including: Number of generator types along with cost functions according to generation capacity for each generator type.

Boundary conditions of each input variable.

The function represents the correlation between generators.

Power loss function, transmission loss, line....

Load requirements (required capacity, required time...)

b. **Step 2:** Identify independent loops.

c. **Step 3:** Randomly initialize population X.

d. **Step 4:** Check boundary conditions, correlation constraints between generators, calculate objective functions, correlation functions, power loss functions for initial variables, determine the value of the objective function target for each individual. Set Iter = 0.

e. **Step 5:** start main loop, Iter = Iter + 1:

f. **Step 6:** Determine the best individual $X_{best}$, with the lowest/highest objective function value (depending on the choice of algorithm).

g. **Step 7:** Implement the mutualism phase

h. **Step 8:** Implement the commensalism phase.

i. **Step 9:** Perform the parasitism phase.

j. **Step 10:** Repeat step 6 until maximum loop.

## III. Results and Discussion

*A. Case 1*

The problem is carried out with 2 diesel generators (DG), 1 solar power set (PV), 1 wind power set (WT) with the total capacity needed to provide continuously every hour of the day. Details are listed in the Table I [31], performed with a number of iterations of 50. The results of the problem are compared with the results of the Hybrid differential evolution and harmony search (DE-HS) algorithm [26]. The objective function used is equation (7). The coefficients of the generators are given in [31] [32].

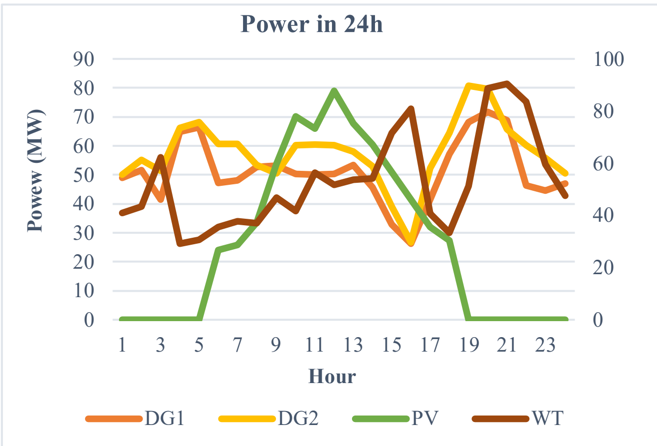


Fig. 1 Distribution of system capacity in 24 hours

The functions of solar power, wind power, and diesel engines are, respectively, equation (1) (3) (4) (5). Solve the optimization problem and find the results in Table II and Fig 1.

TABLE I
CAPACITY DEMAND IN HOURS PER DAY

| Time (hour) | Load (MW) | Time (hour) | Load (MW) |
|---|---|---|---|
| 1 | 140 | 13 | 240 |
| 2 | 150 | 14 | 220 |
| 3 | 155 | 15 | 200 |
| 4 | 160 | 16 | 180 |
| 5 | 165 | 17 | 170 |
| 6 | 170 | 18 | 185 |
| 7 | 175 | 19 | 200 |
| 8 | 180 | 20 | 240 |
| 9 | 210 | 21 | 225 |
| 10 | 230 | 22 | 190 |
| 11 | 240 | 23 | 160 |
| 12 | 250 | 24 | 145 |

TABLE II
DISTRIBUTION OF SYSTEM CAPACITY IN 24 HOURS

| Time (h) | DG 1 (MW) | DG 2 (MW) | PV (MW) | WT (MW) |
|---|---|---|---|---|
| 1 | 48.93 | 50.07 | 0 | 41 |
| 2 | 51.59 | 55.14 | 0 | 43.27 |
| 3 | 41.51 | 51.37 | 0 | 62.12 |
| 4 | 64.73 | 66.05 | 0 | 29.22 |
| 5 | 66.29 | 68.22 | 0 | 30.49 |
| 6 | 47.12 | 60.74 | 26.59 | 35.55 |
| 7 | 48.05 | 60.64 | 28.7 | 37.61 |
| 8 | 52.7 | 53.26 | 37.14 | 36.9 |
| 9 | 53.11 | 50.43 | 59.68 | 46.78 |
| 10 | 50.23 | 60.24 | 78.02 | 41.51 |
| 11 | 50.05 | 60.5 | 73.16 | 56.29 |
| 12 | 50.23 | 60.21 | 87.8 | 51.76 |
| 13 | 53.3 | 57.97 | 75.16 | 53.57 |
| 14 | 45.56 | 53.02 | 67.24 | 54.18 |
| 15 | 32.76 | 39.08 | 56.68 | 71.48 |
| 16 | 26.28 | 26.73 | 46.12 | 80.87 |
| 17 | 41.41 | 52.26 | 35.56 | 40.77 |
| 18 | 57.05 | 64.49 | 30.28 | 33.18 |
| 19 | 68.15 | 80.77 | 0 | 51.08 |
| 20 | 71.75 | 79.56 | 0 | 88.69 |
| 21 | 68.69 | 65.7 | 0 | 90.61 |
| 22 | 46.33 | 60.17 | 0 | 83.5 |
| 23 | 44.55 | 55.81 | 0 | 59.64 |
| 24 | 47.02 | 50.52 | 0 | 47.46 |

Fig 2 depicts the system's convergence speed. Table IV describes the cost values of DG PV and WT generators solved by SOS. Fig 3 describes the DG generators' response to load demand.

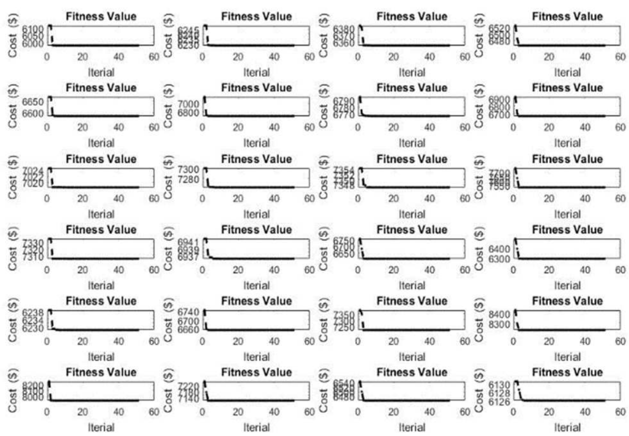

Fig. 2 Convergence speed of the objective function hourly

TABLE III
COMPARE RESULTS BETWEEN ALGORITHMS

| Item | Cost ($) | |
|---|---|---|
| | SOS | DE-HS [26] |
| DG 1 & 2 | 170,668.82 | 170,976.45 |
| PV | 26,793.28 | 28,750.71 |
| WT | 28,561.90 | 32,683.02 |
| Total | 228,909.52 | 232,410.18 |

TABLE IV
DISTRIBUTION OF SYSTEM COST IN 24 HOURS

| Time (h) | DG 1 (MW) | DG 2 (MW) | PV (MW) | WT (MW) |
|---|---|---|---|---|
| 1 | 3,531.92 | 3,175.13 | - | 1,017.21 |
| 2 | 3,633.34 | 3,368.45 | - | 1,073.53 |
| 3 | 3,258.67 | 3,224.10 | - | 1,541.20 |
| 4 | 4,161.11 | 3,805.54 | - | 724.95 |
| 5 | 4,226.73 | 3,895.92 | - | 756.46 |
| 6 | 3,463.96 | 3,589.21 | 1,014.67 | 882.00 |
| 7 | 3,498.77 | 3,585.20 | 1,095.19 | 933.10 |
| 8 | 3,676.20 | 3,296.04 | 1,417.26 | 915.49 |
| 9 | 3,692.11 | 3,188.65 | 2,277.39 | 1,160.61 |
| 10 | 3,581.26 | 3,569.19 | 2,977.24 | 1,029.86 |
| 11 | 3,574.40 | 3,579.59 | 2,791.79 | 1,396.55 |
| 12 | 3,581.26 | 3,567.99 | 3,350.45 | 1,284.17 |
| 13 | 3,699.50 | 3,479.06 | 2,868.11 | 1,329.07 |
| 14 | 3,406.06 | 3,286.85 | 2,565.88 | 1,344.21 |
| 15 | 2,954.69 | 2,777.43 | 2,162.91 | 1,773.42 |
| 16 | 2,742.30 | 2,365.40 | 1,759.94 | 2,006.38 |
| 17 | 3,255.08 | 3,257.87 | 1,356.97 | 1,011.50 |
| 18 | 3,847.23 | 3,741.28 | 1,155.48 | 823.20 |
| 19 | 4,305.78 | 4,440.94 | - | 1,267.29 |
| 20 | 4,461.33 | 4,386.73 | - | 2,200.40 |
| 21 | 4,328.90 | 3,791.08 | - | 2,248.03 |
| 22 | 3,434.56 | 3,566.39 | - | 2,071.64 |
| 23 | 3,368.90 | 3,394.46 | - | 1,479.67 |
| 24 | 3,460.23 | 3,192.03 | - | 1,177.48 |

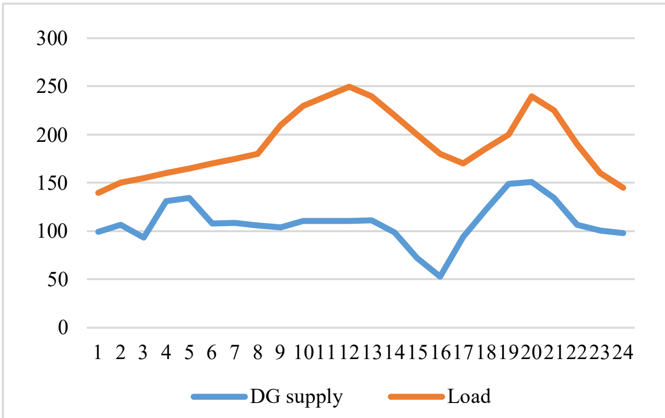


Fig. 3 Graph of the response of DG generators to load demand

The calculation results in Table III show that the SOS algorithm gives better results than the DE-HS algorithm in each DG, PV, and WT cost value.

## B. Case 2

The problem is solved with 52 diesel generators (DG) and 1 wind power set (WT). In this problem, wind energy will be purchased from another unit, with the most significant total energy being 3000 MW and the smallest being 1200 MW. The system provides a total load of 18,000MW. The problem is performed with many iterations of 50.

TABLE V
DISTRIBUTION OF SYSTEM CAPACITY IN 24 HOURS

| No | DG Power ($) | No | DG Power ($) | WT Power ($) |
|---|---|---|---|---|
| 1 | 898.36 | 27 | 19.88 | |
| 2 | 954.56 | 28 | 316.25 | |
| 3 | 982.60 | 29 | 26.91 | |
| 4 | 980.10 | 30 | 61.83 | |
| 5 | 143.84 | 31 | 36.93 | |
| 6 | 193.01 | 32 | 220.52 | |
| 7 | 280.02 | 33 | 269.86 | |
| 8 | 405.46 | 34 | 279.95 | |
| 9 | 455.17 | 35 | 466.16 | |
| 10 | 432.29 | 36 | 550.80 | |
| 11 | 407.04 | 37 | 55.41 | |
| 12 | 463.21 | 38 | 64.19 | |
| 13 | 489.49 | 39 | 272.27 | 2,575.07 |
| 14 | 818.83 | 40 | 277.89 | |
| 15 | 21.10 | 41 | 209.92 | |
| 16 | 37.49 | 42 | 411.22 | |
| 17 | 22.97 | 43 | 351.33 | |
| 18 | 6.01 | 44 | 468.54 | |
| 19 | 15.26 | 45 | 589.81 | |
| 20 | 34.32 | 46 | 437.63 | |
| 21 | 502.66 | 47 | 612.46 | |
| 22 | 16.99 | 48 | 437.20 | |
| 23 | 14.98 | 49 | 161.09 | |
| 24 | 15.82 | 50 | 58.85 | |
| 25 | 11.11 | 51 | 63.31 | |
| 26 | 19.22 | 52 | 74.91 | |

Solve the optimization problem and find the results in Table V and Figure 4. Table VI shows the fuel cost value of DG generators and the cost of the WT source. The problem results are compared with the direct search method (DSM) algorithm [24].

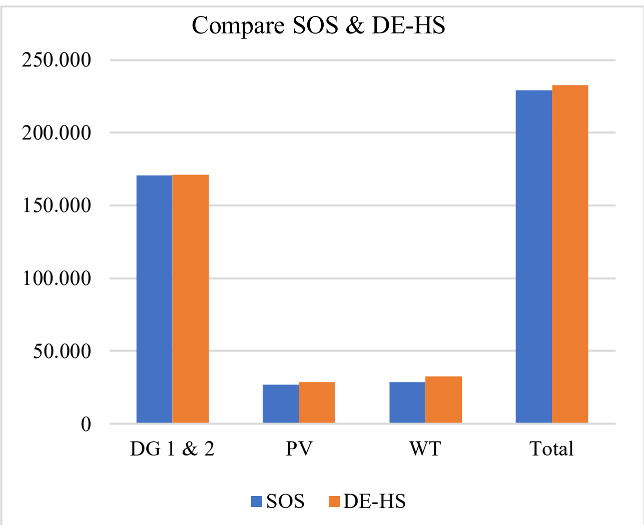


Fig. 4 Graph of response of DG generators to load demand

Table VII describes the values solved by the optimization functions (including SOS).

TABLE VI
AGGREGATE COST TABLE

| | DG | WT |
|---|---|---|
| **Cost ($)** | 8,198,148.59 | 3,746,450 |
| **Total cost ($)** | 11,944,598.59 | |

TABLE VII
COMPARE RESULTS BETWEEN ALGORITHMS

| | WT Power (MW) | Total cost ($) |
|---|---|---|
| **SOS** | 2,575.07 | 11,944,598.59 |
| **DSM** [24]. | 2,532.422 | 12,032,401.93 |

## C. *Case 3*

*1) The generator system does not have a reserve battery:* The problem is carried out with 10 diesel generators (DG), 1 hydroelectric generator system, 1 wind power set (WT), and 1 solar power system (PV), with the total capacity needed to provide over a 24-hour period, according to the load demand graph shown in Fig. 5, Fig. 6, Fig. 7, and Fig. 8.

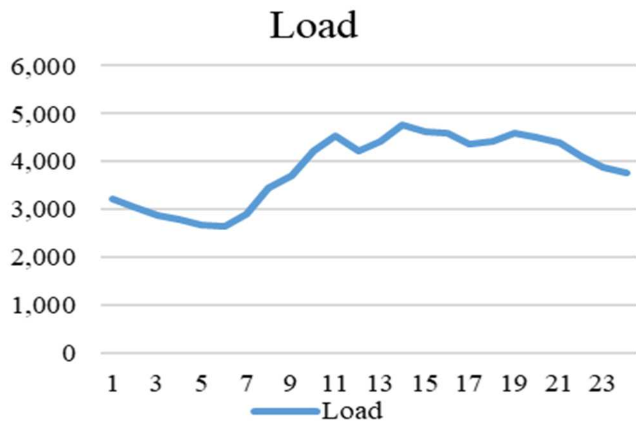


Fig. 5 Load demand graph

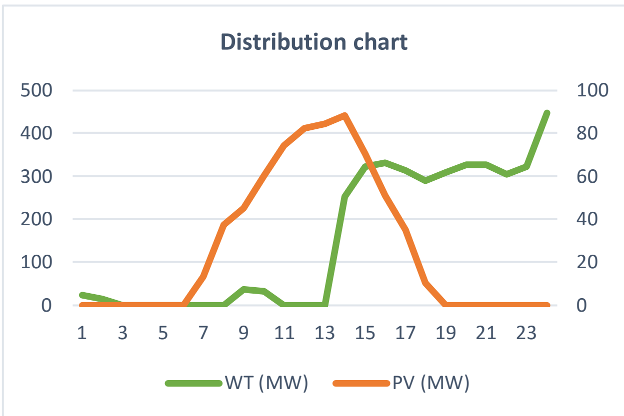


Fig. 6 Load PV and WT graph

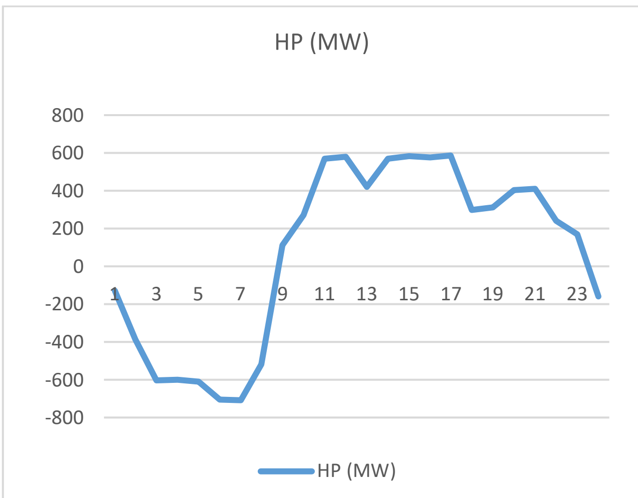


Fig. 7 Load Hydro power graph

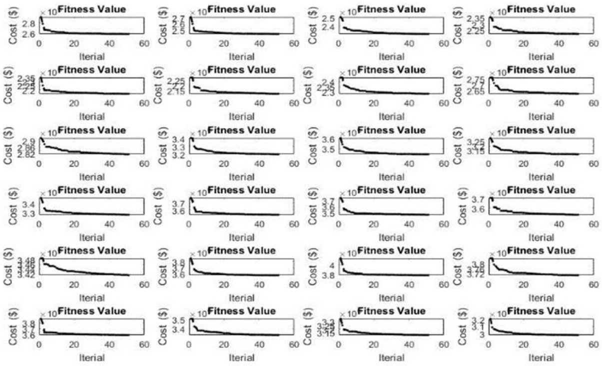


Fig. 8 Graph of response of DG generators to load demand

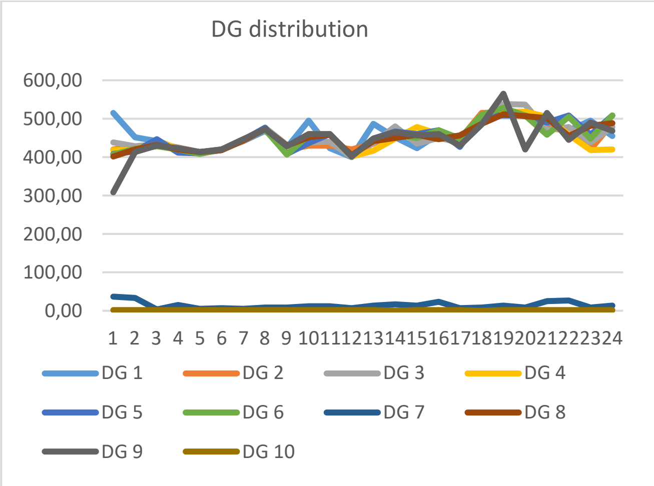


Fig. 9 Distribution of system capacity in 24 hours

TABLE VIII
COMPARE RESULTS BETWEEN ALGORITHMS

| | SOS | GA |
|---|---|---|
| Total DG cost ($) | 72,636,901.20 | 74,230,000 |

The problem is performed with several iterations of 50. The results of the problem are compared with the results of the Genetic algorithm (GE) [22]. The calculation results are shown in Fig. 9, Fig. 10, Fig. 11, Table VIII, and Table IX. Based on the spreadsheet, we see that SOS's results are much better than GA's.

TABLE IX
DISTRIBUTION OF SYSTEM CAPACITY IN 24 HOURS NO-BATTERY

| Load | Time(h) | Total DG (MW) |
|---|---|---|
| 3,230.00 | 1 | 3,355.53 |
| 3,045.13 | 2 | 3,428.83 |
| 2,890.63 | 3 | 3,495.93 |
| 2,781.23 | 4 | 3,382.93 |
| 2,689.62 | 5 | 3,299.92 |
| 2,653.46 | 6 | 3,357.96 |
| 2,916.20 | 7 | 3,556.60 |
| 3,457.19 | 8 | 3,791.19 |
| 3,714.08 | 9 | 3,370.91 |
| 4,218.42 | 10 | 3,639.29 |
| 4,541.30 | 11 | 3,600.70 |
| 4,231.75 | 12 | 3,239.35 |
| 4,416.53 | 13 | 3,574.23 |
| 4,762.20 | 14 | 3,699.60 |
| 4,618.14 | 15 | 3,619.64 |
| 4,590.69 | 16 | 3,694.12 |
| 4,378.95 | 17 | 3,552.92 |
| 4,420.44 | 18 | 4,013.07 |
| 4,590.12 | 19 | 4,218.02 |
| 4,509.89 | 20 | 4,042.16 |
| 4,390.29 | 21 | 3,914.36 |
| 4,120.03 | 22 | 3,818.86 |
| 3,891.17 | 23 | 3,656.17 |
| 3,758.26 | 24 | 3,829.26 |

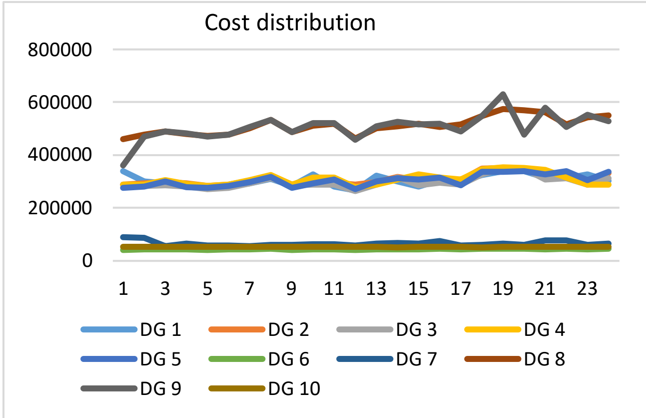


Fig. 10 Distribution of system cost in 24 hours

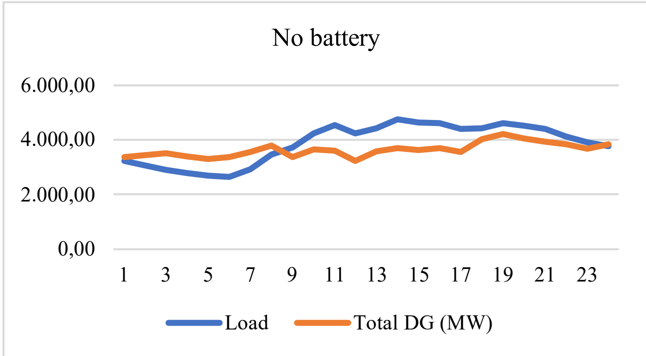


Fig. 11 Graph of response of DG generators to load demand

*2) The generator system has a reserve battery*

The problem is carried out with 10 diesel generators (DG), 1 hydroelectric generator system, 1 solar power system (PV), 1 wind power set (WT), and 1 battery system, with the total capacity needed to provide power over 24 hours according to the load graph in Fig. 5. The calculation results are shown in Fig. 12, Fig. 13, Fig. 14, Fig. 15, Table X, and Table XII. Based on the spreadsheet, we see that the SOS results are much better than those of GA. When the storage battery is involved, the electrical energy generated during low-load periods will be stored to supplement peak periods.

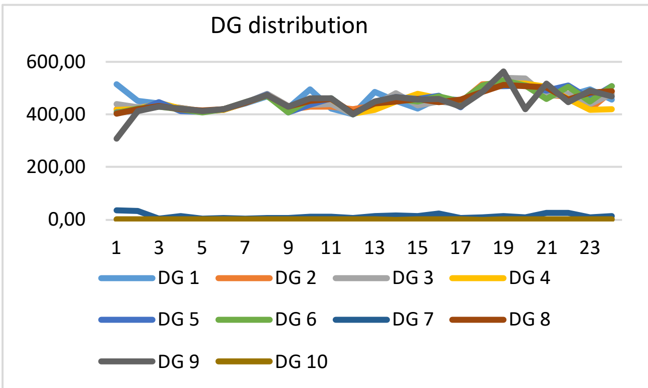


Fig. 12 Distribution of system capacity in 24 hours

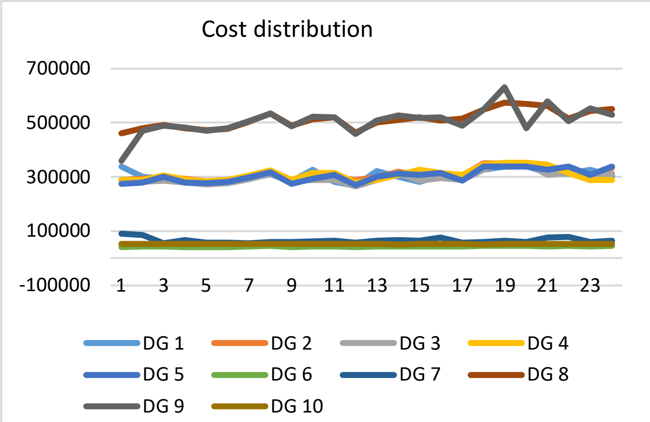


Fig. 13 Distribution of system cost in 24 hours

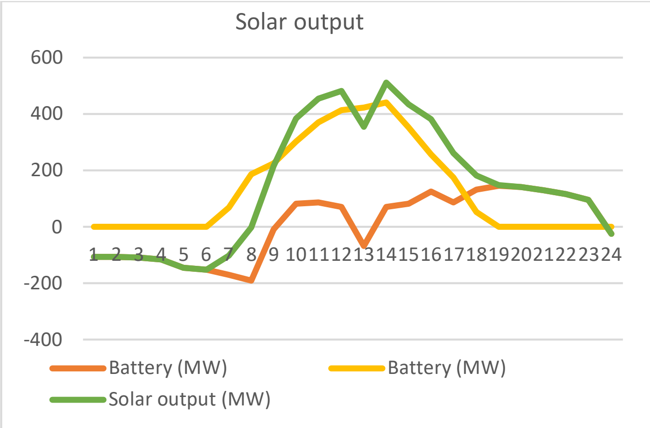


Fig. 14 Distribution of solar capacity in 24 hours

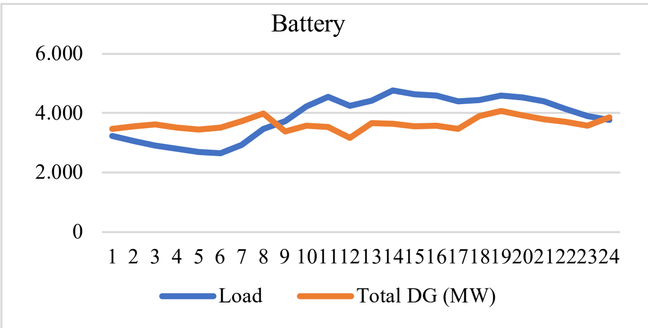


Fig. 15 Graph of the response of DG generators to load demand

TABLE X
COMPARE RESULTS BETWEEN ALGORITHMS

| | **SOS** | **GA** |
|---|---|---|
| Total DG cost ($) | 64,570,126 | 73,870,000 |

TABLE XI
COMPARE THE INCREASE OF THE SOS ALGORITHM IN TWO CASES WITH A BATTERY AND WITHOUT A BATTERY

| **No** | **Case** | **SOS** | **GA** |
|---|---|---|---|
| 1 | No reserve battery | 72,636,901 | 74,230,000 |
| 2 | Reserve battery | 64,570,126 | 73,870,000 |
| | Decrease ratio (%) | 11.11% | 0.48% |

TABLE XII
DISTRIBUTION OF SYSTEM CAPACITY IN 24 HOURS WITH BATTERY

| **Load** | **Time(h)** | **Total DG (MW)** |
|---|---|---|
| 3,230.00 | 1 | 3,463.03 |
| 3,045.13 | 2 | 3,537.43 |
| 2,890.63 | 3 | 3,605.23 |
| 2,781.23 | 4 | 3,498.73 |
| 2,689.62 | 5 | 3,445.52 |
| 2,653.46 | 6 | 3,510.66 |
| 2,916.20 | 7 | 3,727.20 |
| 3,457.19 | 8 | 3,981.69 |
| 3,714.08 | 9 | 3,381.41 |
| 4,218.42 | 10 | 3,558.89 |
| 4,541.30 | 11 | 3,516.20 |
| 4,231.75 | 12 | 3,169.15 |
| 4,416.53 | 13 | 3,642.63 |
| 4,762.20 | 14 | 3,630.30 |
| 4,618.14 | 15 | 3,538.24 |
| 4,590.69 | 16 | 3,569.32 |
| 4,378.95 | 17 | 3,467.22 |
| 4,420.44 | 18 | 3,882.67 |
| 4,590.12 | 19 | 4,072.12 |
| 4,509.89 | 20 | 3,901.76 |
| 4,390.29 | 21 | 3,786.06 |
| 4,120.03 | 22 | 3,704.16 |
| 3,891.17 | 23 | 3,561.87 |
| 3,758.26 | 24 | 3,856.06 |

TABLE XIII
COMPARE THE VALUE DIFFERENCE BETWEEN ALGORITHMS

| No | Case | Ratio |
|---|---|---|
| 1 | 10 generators | 2% |
| 2 | 52 generators | 1% |
| 3a | No reserve battery | 2% |
| 3b | Reserve battery | 13% |

## IV. CONCLUSIONS

Through surveys, we see that the SOS algorithm gives much better results than the compared algorithms. The results show that the cost of diesel generators is reduced when renewable energy systems are involved. Considering the results of Table XI and Table XIII, with the same SOS algorithm without the presence of a battery system, the fuel cost is much higher than the fuel cost with the presence of a battery system (11.11%). Meanwhile, for the GA algorithm, the difference between the two cases is insignificant (0.48%).

Considering the statistical results of the SOS algorithm's better rate compared to other algorithms, we see this rate is about 2%. However, in the case of the presence of a battery, this rate exceeds 13%, showing that the SOS algorithm has quite good stability, and the presence of storage helps significantly reduce costs. This also indicates that the proposed algorithm effectively implements the proposed requirements. However, the SOS algorithm still has many points that need improvement to achieve the required algorithm speed and efficiency.

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