

# Determining the Optimal Capacity of Renewable, Non-Renewable, and Storage Resources for the Microgrid Network Considering Certainty

## Abstract

This study aimed to determine the optimal capacity of renewable, non-renewable, and storage resources for the microgrid network considering certainty. The studied system consisted of eight main parts, a DC busbar and an AC busbar. These components include wind turbine units, solar arrays, fuel cells, hydrogen tank, electrolyzer, energy storage, DC/CA converter, and consumed load. The improved particle clustering algorithm was selected as the solution method in this research. The proposed model was a mixed-integer nonlinear programming model (MINLP). Because the objective functions and constraints were nonlinear, the proposed model will be solved using the meta-heuristic method. This problem was solved through MATLAB software. The results indicated that the peak load per month was 66.67 kW. The cheapest way to supply this load is to use wind turbines, so the answer to the problem considered six wind turbine units.

Moreover, due to the difference between the peak generation time of the wind resource and the storage load in fuel cells and hydrogen tanks, it is required to store the excess generation of wind in low load hours and use it to supply load in peak load hours. For this purpose, the capacity of three fuel cells and three hydrogen tanks was determined. Although the diesel generator source can improve the objective function of operation reliability, its capacity has not been determined as a solution due to its higher average investment and operating costs compared to renewable sources. On the other hand, the diesel generator source causes pollution, which leads to the failure of two equivalent objective functions in the operation process.

**Keywords:** *Wind Turbine, Solar Arrays, Fuel Cell, Hydrogen Tank, Microgrid Network.*

## Javid Habibi Aghzariat

*Electrical engineering of power systems, Shabestar Branch, Islamic Azad University, Shabestar, Iran*

## Sima Shah Mohammadi

*Faculty member, Electrical engineering of power systems, Shabestar Branch, Islamic Azad University, Shabestar, Iran  
Email: javidhabibi92@gmail.com*

## Introduction

The electric power industry has been restructured for many reasons over recent years. Restructured the electric power industry changed the philosophy of power system operation. The power company supplied customers' total electric energy needs in the conventional system, and designs were done to reduce customers' blackouts. However, this policy was changed in the new structure whereby the increase in the power system productivity and efficiency and maximizing the profit were introduced as restructured power system's objectives. Intelligent distribution networks were developed with production, measurement, and communication amenities and equipment. The scattered renewable generation resources are the most important in today's microgrid networks because environmental concerns and uncertainty in fossil fuel resources have interested grid designers and users in maximum uses of renewable resources. The most common renewable resources in these grids are wind and solar resources.

Wind energy has been increasingly used to generate electric energy. The installation capacity of the wind units exceeded 30 GW at the end of 2002 [1]. Nevertheless, the nature of the wind energy variable makes its operation problematic. The generation power of wind units varies due to uncertainty in wind blow and its stochastic speed rate. Such uncertainty reduces control of wind power plants and has different effects on power systems, including their reliability [2]. A solution must be provided for problem modeling due to its uncertainty. Stochastic programming is a solution used to solve problems

with uncertainty [3]. This problem solution requires producing enough scenarios for parameters with uncertainty; hence, there are sometimes too many scenarios that prevent the problem solution. In such cases, the number of scenarios must be minimized [4].

Moreover, salient reliability indicators must be used in the problem's constraints to determine the reliability constraint. Optimization of these constraints depends on the system's spinning reserve capacity. Evaluation of spinning reserve adequacy is usually done based on definitive techniques [5]. These methods usually lead to indefinite solutions due to the high number of generators and coverage of a minor part of probabilistic space [6]. Therefore, probabilistic methods have been developed to overcome such problems [7]-[8]. On the other hand, storage resources can support storing the surplus power per hour and supply the power shortage over other hours. Accordingly, it is possible to minimize the cost of development and exploitation, reliability (using storage), and reduce environmental pollutants in this problem.

Some studies have been conducted on this topic. Paper [9] presented a framework for demand response and shared adaptation in a smart grid. In particular, this study used congestion pricing through internet traffic to show that pricing information can help to regulate user demand and balance network load. According to the definition proposed by research [10], DER resources consist of two aspects: scattered generations that are installed in distribution network close to the consumption area, and demand-side resources that include

demand management programs, including demand shift from overload to underload, reduction of losses by minimizing peak load, etc. Some researchers consider consumption management a method comprising energy efficiency (EE) and demand response (DR).

In contrast, others have used a stochastic programming framework to coordinate renewable units considering uncertainties [11-12]. Paper [13] has developed a microgrid considering load (or demand) uncertainty, wind, and radiation to develop wind, solar, fuel cell, diesel, and storage resources. The robust optimization technique has been used in this study to overcome uncertainty.

Moreover, network connection basic was considered to provide a solution for developing isolated microgrids (separated from the network). The fuel cell was used regarding the considered resources for development. On the other hand, units' programming problem in a microgrid is an optimization problem within the exploitation and operation studies' scope; hence, it requires a powerful method for solution in the required time. Solution methods for this problem are generally divided into iteration-based traditional methods and heuristic methods [5]. Traditional methods include the priority list technique [6-7], dynamic programming [14], mixed integer programming [15], and the Lagrange release method [16].

$$(1) \quad F = f_1 + f_2 + f_3$$

$$\begin{aligned} f_1 = Cost &= \sum_t \sum_{i \in \{G, W\}} k_t C C_{it} \cdot P_i^{max} \cdot x_i + \sum_t \sum_{i \in S} k_t (C P_{it} P_i^{max} + C E_{it} P_i^{max}) x_i \\ &+ \sum_t \sum_h \sum_b \sum_{i \in G} k_t C_i P_{ibht} \\ &+ \sum_t \sum_h \sum_b k_t \rho_{bht} P_{M, bht} \\ f_2 &= \sum_t \sum_h \sum_b \sum_{i \in G} k_t C e m_i \cdot C P E \cdot P_{ibht} \\ f_3 &= \sum_t \sum_h \sum_b k_t v_{bht} L S_{bht} \end{aligned}$$

The first objective function, which is the objective function of cost, comprises existing costs. The second objective function includes the pollution function. The third objective is the reliability function, which must minimize the total annual load outage. To make the proposed mathematical model robust against the stochastic variables of the problem, the model presented for objective function (1) has been divided into two core problems in the investment phase and the subproblem of operation. In the operation phase, the worse state is found based on the existing scenario (disambiguation), and the

Some new smart methods include metals plating [17], colonial algorithm [18], and genetic algorithm [8]. Regarding developing rural and military areas far away from the main network access, it is essential to develop microgrid networks, especially renewable resources-based networks. Therefore, the extant study aimed to determine the optimal capacity of renewable, non-renewable, and storage resources for microgrid networks with certainty.

### Modeling Problem

In this research, the accurate mathematical model of determining the optimal capacity of greeting resources in the microgrid has been proposed by considering principles of operation at the bottom of the independent microgrid. Robust optimization is a suitable solution for solving the optimization problem. This study was conducted to determine generation resources that meet these objectives: minimizing costs, increasing reliability, and reducing environmental pollutants. According to Equation (1), the objective function of development covers development cost, operation cost, pollution, and distributed energy as a reliability index in the objective function. Hence, we have a multi-objective optimization.

objective function' amount is added as the penalty to the phase objective function of programming [19].

The development problem determines the number of dispersed generation resources, and its goal is cost minimization. Two first components of the objective function include the cost of resource development, and the third variable represents the operation cost, measured by optimality cut-off values.

$$\begin{aligned}
& \sum_t \sum_{i \in \{G, W\}} k_t C C_{it} P_i^{max} x_i \\
& + \sum_t \sum_{i \in S} k_t (C P_{it} P_i^{max} + C E_{it} P_i^{max}) x_i + \sum_t k_t \Lambda_t
\end{aligned} \tag{2}$$

The extant study aimed to develop a network-independent microgrid; hence, Equations (3) and (4) place  $l=z$  to ensure network independence and production exceeding consumption.

$$D_i^{max} - \sum_{i \in \{G, W, S\}} P_i^{max} x_i \leq k(1-z) \tag{3}$$

$$x_i \leq z \leq \sum_i x_i \tag{4}$$

The operation subproblem has been proposed for each year of a prospect based on the equations (5)-(13).

$$\begin{aligned}
& \max_U \min_P \sum_h \sum_b \sum_{i \in G} c_i P_{ibht} + \sum_h \sum_b \\
& + \sum_h \sum_b v_{bht} L S_{bht}
\end{aligned} \tag{5}$$

$$\sum_{i \in \{G, W\}} P_{ibht} \sum_{i \in S} (P_{ibht}^{dch} - P_{bht}^{ch}) + P_{M, bht} + L S_{bht} \tag{6}$$

$$= D_{bht} \quad \forall b, \forall h \tag{6}$$

$$-P_M^{max} u_{M, bht} \leq P_{M, bht} \leq P_M^{max} u_{M, bht} \quad \forall b, \forall h \tag{7}$$

$$0 \leq P_{ibht} \leq P_i^{max} \hat{X}_i \quad \forall i \in G, \forall b, \forall h \tag{8}$$

$$P_{ibht} = \hat{P}_{ibht} \hat{x}_i \quad \forall i \in W, \forall b, \forall h \tag{9}$$

$$0 \leq P_{ibht}^{dch} \leq P_i^{dch, max} \hat{x}_i \quad \forall i \in S, \forall b, \forall h \tag{10}$$

$$0 \leq P_{ibht}^{ch} \leq P_i^{ch, max} \hat{x}_i \quad \forall i \in S, \forall b, \forall h \tag{11}$$

$$0 \leq \sum_{k \leq b} (P_{ikht}^{ch} - P_{ikht}^{dch} / \eta_i) \leq C_i^{max} \hat{x}_i \quad \forall i \in S, \forall b, \forall h \tag{12}$$

$$0 \leq L S_{bht} \leq D_{bht} \quad \forall b, \forall h \tag{13}$$

The operation subproblem aims to minimize microgrid costs. This objective function is maximized to find the worse microgrid scenario. Equation (6) indicates power balance, and equation (7) determined the power derived from the upstream grid it is connected to (this capacity equals ... because the study examines independent microgrid), (8) determines constraint on the production of traditional units, (9) represents production capacity of renewable units, input or output power of storage is limited by (10) and (11). The energy in the storage

per hour is measured based on the energy in the previous hour and its net production power in the present hour by (12). Finally, (13) expresses maximum outage load, which must not exceed the consuming load. Regardless of network constraints, all resources are installed on the DC bus in the microgrid.

A wind turbine's power distribution can be measured based on the wind speed distribution and speed-to-power conversion function. The generation speed-to-power conversion function has been shown in this research [1]:

$$\begin{aligned}
(14) \omega = \{ & 0, & & \text{for } v < v_i \text{ and } v > \\
& v_o \omega_r (v - v_i) / (v_r - v_i), & & \text{for } v_i \leq v \leq \\
& v_r \omega_r, & & \text{for } v_r \leq v \leq v_o
\end{aligned}$$

where  $\omega$ ,  $\omega_r$ ,  $v_i$ ,  $v_r$ , and  $v_o$  represent the output power of the wind turbine (kW), nominal power, minimum win speed, nominal wind speed, and maximum wind speed, respectively. The power distribution of solar arrays (PV) can be calculated based on radiation distribution and radiation-to-power conversion function. Following radiation-to-power conversion function has been used in this research [2]:

$$(15) p = \eta^{PV} S^{PV} g$$

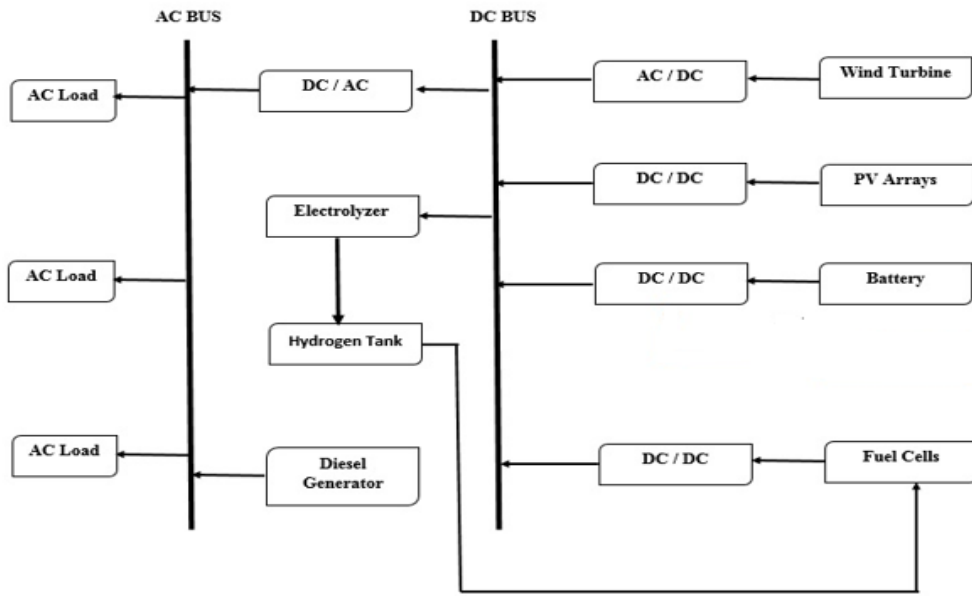
where  $p$  indicates output power PV (kW),  $\eta^{PV}$  represents efficiency (%), and  $S^{PV}$  shows total area based on cubic meter PV ( $m^2$ ).

The hydrogen tank model has two differences from other storage systems. First, it requires minimum power for charge or discharge; second, hydrogen flow is its constraint, which is a function of the internal pressure of the tank. This functionality, however, has been neglected in this research, and the flow constraint has been considered based on the tubes' size standard [20].

This study used an improved particle swarm algorithm as a solution method. The proposed model is a Mixed Integer Non-Linear Programming (MINLP). The objective functions and constraints are nonlinear; the proposed model is solved using the metaheuristic method. This problem is solved through MATLAB software. This software includes various solvers that each can solve specific models. Because the model presented in this research is an MINLP model, an MINLP solver is suggested.

## Findings

The studied system comprises eight main parts, a DC Bus Bar, and an AC Bus Bar. These components include wind turbine units, solar (PV) arrays, fuel cells, hydrogen tank, electrolyzer, energy storage system (diesel generator), DC-AC converter, and studied load consumption.



**Figure 1. Diagram block of the hybrid system comprising a fuel cell, electrolyzer, hydrogen tank, diesel generator, PV arrays, wind turbine, and battery**

The consumed powers over 24 hours were entered, and characteristics of the consumed load were analyzed through software reported in Table 1.

**Table 1. Initial monthly AC load peak**

| Month | Coefficient |
|-------|-------------|
| Jan   | 0.6         |
| Feb   | 0.6         |
| Mar   | 0.7         |
| Apr   | 0.8         |
| May   | 0.9         |
| Jun   | 1           |
| Jul   | 1           |
| Aug   | 1           |
| Sep   | 0.9         |
| Oct   | 0.8         |
| Nov   | 0.7         |
| Dec   | 0.7         |

**Table 2. Average daily clearness and radiation [AIPV]**

| Month | Clearness Index | Average Radiation         |
|-------|-----------------|---------------------------|
|       |                 | (kWh/m <sup>2</sup> /day) |
| Jan   | 0.517           | 2.530                     |
| Feb   | 0.524           | 3.270                     |
| Mar   | 0.503           | 4.070                     |
| Apr   | 0.506           | 5.000                     |
| May   | 0.522           | 5.790                     |
| Jun   | 0.556           | 6.420                     |

|                       |       |                            |
|-----------------------|-------|----------------------------|
| Jul                   | 0.540 | 6.100                      |
| Aug                   | 0.551 | 5.680                      |
| Sep                   | 0.547 | 4.750                      |
| Oct                   | 0.546 | 3.700                      |
| Nov                   | 0.519 | 2.690                      |
| Dec                   | 0.491 | 2.200                      |
| Scaled annual average |       | 4.35 kWh/m <sup>2</sup> /d |

The turbine model Generic 10KW was used in this study. The nominal power of this turbine equals 10KW. The output power feature ( $P_{WG}$ ) of this turbine is based on the wind speed ( $v_w$ ). The wind speed information was extracted from the Meteorological Department of Dammghan and reported in Table 3.

**Table 3. Average wind speed in different months (AIW)**

| Month | Wind Speed |
|-------|------------|
|       | (m/s)      |
| Jan   | 4.6        |
| Feb   | 4.4        |
| Mar   | 7.8        |
| Apr   | 10.2       |
| May   | 9.1        |
| Jun   | 10.5       |
| Jul   | 12.6       |
| Aug   | 9.6        |
| Sep   | 8.5        |

|     |     |
|-----|-----|
| Oct | 9.6 |
| Nov | 8.5 |
| Dec | 6.2 |

The battery must be chargeable and dischargeable. Table 4 reports the features of the battery used in this study.

**Table 4. Battery features**

|                         |            |
|-------------------------|------------|
| Quantities to consider: | 0, 40, 60  |
| Voltage:                | 4 V        |
| Nominal capacity:       | 1,900 Ah   |
| Lifetime throughput:    | 10,569 kWh |
| Min battery life:       | 4 yr       |

The investment and operation phases were separated; hence, operation costs were calculated for the first year in the objective function. Programming and operation were two parts

**Table 5. Load Scenarios**

| Hour       | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Scenario 1 | 17.73 | 16.47 | 15.20 | 16.47 | 12.67 | 19.00 | 25.33 | 30.40 |
| Scenario 2 | 19.60 | 18.20 | 16.80 | 18.20 | 14.00 | 21.00 | 28.00 | 33.60 |
| Scenario 3 | 21.47 | 19.93 | 18.40 | 19.93 | 15.33 | 23.00 | 30.67 | 36.80 |
| Scenario 4 | 23.33 | 21.67 | 20.00 | 21.67 | 16.67 | 25.00 | 33.33 | 40.00 |
| Scenario 5 | 25.20 | 23.40 | 21.60 | 23.40 | 18.00 | 27.00 | 36.00 | 43.20 |
| Scenario 6 | 27.07 | 25.13 | 23.20 | 25.13 | 19.33 | 29.00 | 38.67 | 46.40 |
| Scenario 7 | 28.93 | 26.87 | 24.80 | 26.87 | 20.67 | 31.00 | 41.33 | 49.60 |
| Hour       | 9     | 10    | 11    | 12    | 13    | 14    | 15    | 16    |
| Scenario 1 | 35.47 | 39.27 | 43.07 | 44.33 | 43.57 | 43.57 | 43.57 | 42.31 |
| Scenario 2 | 39.20 | 43.40 | 47.60 | 49.00 | 48.16 | 48.16 | 48.16 | 46.76 |
| Scenario 3 | 42.93 | 47.53 | 52.13 | 53.67 | 52.75 | 52.75 | 52.75 | 51.21 |
| Scenario 4 | 46.67 | 51.67 | 56.67 | 58.33 | 57.33 | 57.33 | 57.33 | 55.67 |
| Scenario 5 | 50.40 | 55.80 | 61.20 | 63.00 | 61.92 | 61.92 | 61.92 | 60.12 |
| Scenario 6 | 54.13 | 59.93 | 65.73 | 67.67 | 66.51 | 66.51 | 66.51 | 64.57 |
| Scenario 7 | 57.87 | 64.07 | 70.27 | 72.33 | 71.09 | 71.09 | 71.09 | 69.03 |
| Hour       | 17    | 18    | 19    | 20    | 21    | 22    | 23    | 24    |
| Scenario 1 | 40.53 | 45.60 | 50.67 | 48.13 | 40.53 | 35.47 | 30.40 | 25.33 |
| Scenario 2 | 44.80 | 50.40 | 56.00 | 53.20 | 44.80 | 39.20 | 33.60 | 28.00 |
| Scenario 3 | 49.07 | 55.20 | 61.33 | 58.27 | 49.07 | 42.93 | 36.80 | 30.67 |
| Scenario 4 | 53.33 | 60.00 | 66.67 | 63.33 | 53.33 | 46.67 | 40.00 | 33.33 |
| Scenario 5 | 57.60 | 64.80 | 72.00 | 68.40 | 57.60 | 50.40 | 43.20 | 36.00 |
| Scenario 6 | 61.87 | 69.60 | 77.33 | 73.47 | 61.87 | 54.13 | 46.40 | 38.67 |
| Scenario 7 | 66.13 | 74.40 | 82.67 | 78.53 | 66.13 | 57.87 | 49.60 | 41.33 |

**Table 6. Wind Scenarios**

of the system's costs. Moreover, objective functions of pollution and reliability were considered in addition to operating costs within the operation phase. The costs consisted of Net Present Value (NPV), investment, repair, maintenance, and replacement of equipment during the 20-year lifetime of the system. Because only one stochastic variable (load) was used in this research, samples were not classified and presented herein.

|            |      |      |      |      |      |      |      |      |
|------------|------|------|------|------|------|------|------|------|
| Hour       | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    |
| Scenario 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Scenario2  | 1.88 | 1.69 | 1.60 | 1.60 | 1.60 | 1.79 | 1.88 | 2.07 |
| Scenario 3 | 5.17 | 4.89 | 4.75 | 4.75 | 4.75 | 5.03 | 5.17 | 5.45 |
| Scenario 4 | 8.46 | 8.08 | 7.90 | 7.90 | 7.90 | 8.27 | 8.46 | 8.84 |
| Scenario 5 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 |
| Hour       | 9    | 10   | 11   | 12   | 13   | 14   | 15   | 16   |
| Scenario 1 | 0.00 | 0.00 | 0.00 | 0.00 | 4.23 | 0.47 | 0.56 | 0.52 |
| Scenario2  | 2.44 | 2.82 | 3.48 | 4.23 | 9.40 | 5.64 | 5.83 | 5.73 |
| Scenario 3 | 6.02 | 6.58 | 7.57 | 8.70 | 9.40 | 9.40 | 9.40 | 9.40 |
| Scenario 4 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 |
| Scenario 5 | 9.40 | 9.40 | 9.40 | 9.40 | 0.00 | 9.40 | 9.40 | 9.40 |
| Hour       | 17   | 18   | 19   | 20   | 21   | 22   | 23   | 24   |
| Scenario 1 | 0.47 | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Scenario2  | 5.64 | 5.36 | 4.70 | 3.76 | 2.82 | 1.88 | 1.69 | 1.60 |
| Scenario 3 | 9.40 | 9.40 | 0.00 | 7.99 | 6.58 | 5.17 | 4.89 | 4.75 |
| Scenario 4 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 8.46 | 8.08 | 7.90 |
| Scenario 5 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 | 9.40 |

**Table 7. Radiation Scenarios**

|            |       |      |      |     |      |      |       |      |
|------------|-------|------|------|-----|------|------|-------|------|
| Hour       | 1     | 2    | 3    | 4   | 5    | 6    | 7     | 8    |
| Scenario 1 | 0     | 0    | 0    | 0   | 0    | 0    | 0.004 | 0.02 |
| Scenario2  | 0     | 0    | 0    | 0   | 0    | 0    | 0.008 | 0.04 |
| Scenario 3 | 0     | 0    | 0    | 0   | 0    | 0    | 0.012 | 0.06 |
| Scenario 4 | 0     | 0    | 0    | 0   | 0    | 0    | 0.016 | 0.08 |
| Scenario 5 | 0     | 0    | 0    | 0   | 0    | 0    | 0.02  | 0.1  |
| Hour       | 9     | 10   | 11   | 12  | 13   | 14   | 15    | 16   |
| Scenario 1 | 0.06  | 0.12 | 0.16 | 0.2 | 0.16 | 0.12 | 0.06  | 0.02 |
| Scenario2  | 0.12  | 0.24 | 0.32 | 0.4 | 0.32 | 0.24 | 0.12  | 0.04 |
| Scenario 3 | 0.18  | 0.36 | 0.48 | 0.6 | 0.48 | 0.36 | 0.18  | 0.06 |
| Scenario 4 | 0.24  | 0.48 | 0.64 | 0.8 | 0.64 | 0.48 | 0.24  | 0.08 |
| Scenario 5 | 0.3   | 0.6  | 0.8  | 1   | 0.8  | 0.6  | 0.3   | 0.1  |
| Hour       | 17    | 18   | 19   | 20  | 21   | 22   | 23    | 24   |
| Scenario 1 | 0.004 | 0    | 0    | 0   | 0    | 0    | 0     | 0    |
| Scenario2  | 0.008 | 0    | 0    | 0   | 0    | 0    | 0     | 0    |
| Scenario 3 | 0.012 | 0    | 0    | 0   | 0    | 0    | 0     | 0    |
| Scenario 4 | 0.016 | 0    | 0    | 0   | 0    | 0    | 0     | 0    |
| Scenario 5 | 0.02  | 0    | 0    | 0   | 0    | 0    | 0     | 0    |

In the case of non-considering uncertainty, responses have been determined for mean values of uncertain parameters. In other words, uncertainty has not been considered in load, wind,

and radiation values. Responses of this model include the number of resources based on its basic capacity, which has been calculated as shown in Table 8.

**Table 8. Results of study without considering uncertainty**

| Equipment           | The initial price of unit price (\$/unit) | Number of unit capacity (\$/unit - yr) | Total price |
|---------------------|---|--|-------------|
| Wind turbine (10KW) | 8000                                      | 6                                      | 48000       |
| PV array (1KW)      | 1250                                      | 0                                      | 0           |

|                             |      |   |       |
|-----------------------------|------|---|-------|
| Battery (4V, 1900Ah, 7.6KW) | 1299 | 0 | 0     |
| Fuel cell                   | 800  | 3 | 2400  |
| Hydrogen tank               | 110  | 3 | 330   |
| Diesel generator            | -    | 0 | 0     |
| DC/AC converter (10KW)      | 818  | 7 | 5726  |
| AC/DC converter (10KW)      | 818  | 6 | 4908  |
| DC/DC converter (10KW)      | 1400 | 1 | 1400  |
| Sum                         |      |   | 62764 |

Load peak in consumption peak month equals 66.67KW. The cheapest way to meet this demand is through wind turbines; hence, the problem-solution considered six wind turbines. Moreover, due to the time difference between wind resource' production peak and storage load as fuel cell and hydrogen tank, it is essential to store the extra wind generation in low-load hours to supply load in peak hours. For this purpose, the capacity of 3 fuel cells and three hydrogen tanks was determined. Although diesel generators can improve the objective function of reliability, their capacity was not

determined as a solution due to average investment cost and high operation cost compared to renewable resources. This generator creates pollution that causes failure in two equivalent objective functions in operation.

Table 9 reports the results of the objective investment function or high-level objective function. It is worth noting that reliability equaled 100% because uncertainty was not considered in this research. In this lieu, pollution equals zero because renewable resources are used.

**Table 9. Operation objective functions in research without considering uncertainty**

| Equipment                   | Objective function of reliability | Objective function of pollution | Objection function of cost |
|-----------------------------|-----------------------------------|---------------------------------|----------------------------|
| Wind turbine (10KW)         | 0                                 | 0                               | 300                        |
| PV array (1KW)              | 0                                 | 0                               | 0                          |
| Battery (4V, 1900Ah, 7.6KW) | 0                                 | 0                               | 0                          |
| Fuel cell                   | 0                                 | 0                               | 75                         |
| Hydrogen tank               | 0                                 | 0                               | 3                          |
| Diesel generator            | 0                                 | 0                               | 0                          |
| DC/AC converter (10KW)      | 0                                 | 0                               | 280                        |
| AC/DC converter (10KW)      | 0                                 | 0                               | 210                        |

|                        |   |   |     |
|------------------------|---|---|-----|
| DC/DC converter (10KW) | 0 | 0 | 70  |
| Sum                    | 0 | 0 | 938 |

## Conclusion

The extant study aims to determine the optimal capacity of renewable non-renewable, and storage resources for microgrid networks considering certainty. The system studied in this research was isolated from the global power network despite the possible connection. Because the climate conditions of two wind and photovoltaic (PV) resources are almost complementary, both resources have been considered in the renewable category. These two energies cannot generate energy continually; hence, integrating these two resources in addition to the fuel cell, hydrogen tank, and electrolyzer has been used to generate energy continuously. Moreover, a diesel generator is considered the core supporter besides these resources. The battery has also been used as the energy storage system (ESS) in this project. The battery can be used in both network-isolated and network-connected systems. It stores the energy surplus when generating the fuel cell, PV, and wind turbine exceed the load. When there is no sunlight or wind or when the energy generation of solar or wind systems is less than the load (demand), the battery enters the circuit to cover the energy shortage. Therefore, this battery must be chargeable and dischargeable repetitively. The programming problem has been solved by a genetic algorithm (GA), while the operation subproblem has been solved by the RDPSO algorithm within the multi-objective technique.

The results indicated a load peak of 66.67KW in the month of consumption peak. The most inexpensive way to meet this demand is using a wind turbine. Hence, the problem-solution considered six wind turbine units for this purpose. Moreover, due to the difference between the peak generation time of the wind resource and the storage load in fuel cells and hydrogen tanks, it is required to store the excess generation of wind in low load hours and use it to supply load in peak load hours. For this purpose, the capacity of 3 fuel cells and three hydrogen tanks was determined. Although the diesel generator source can improve the objective function of operation reliability, its capacity has not been determined as a solution due to its higher average investment and operating costs compared to renewable sources. On the other hand, diesel generator source causes pollution, which leads to the failure of two equivalent objective functions in the operation process.

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## Conflict of interest

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## Ethics statement

None

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