Journal of Artificial Intelligence in Electrical Engineering, Vol. 12, No. 48, March 2024

# Designing an Optimized Hybrid Renewable Energy System in North-West of Iran to Reach High Efficiency

Leila Mohammadian
Department of Electrical Engineering, Shabestar Branch, Islamic Azad University, Shabestar, Iran
Email:Le.mohammadian@gmail.com

Receive Date:02 November 2024 Revise Date: 31 December 2024 Accept Date:28 January 2025

## Abstract

*Nowadays, the use of renewable energy sources is increasing rapidly due to the fatalities of fossil fuels and the numerous barriers to the expansion and development of centralized power plants and the creation of transmission lines. Among renewable energies, wind and solar energy are sources of high potential for power generation. A hybrid energy system is preferable for isolated and remote systems such as villages in desert areas that are far away from a power system. Hybrid energy systems are one of the most suitable options for reducing fossil fuel dependence, which are available through various sources of energy production such as wind and solar radiation. In this paper, after introducing the system components, modeling and simulation of hybrid system are carried out. For this purpose, the simulation of a hybrid system with the use of information on wind turbines, solar cells, micro turbines, hydrogen storage and converters and the cost per kilowatt of energy is accomplished and the best combination economically and reliably to provide continuous energy is provided according to load specifications in Sambaran Area in Marand- East Azarbaijan, Iran . In this paper, an evolutionary algorithm of particle swarm is used to perform optimization.*

**Keywords:** Algorithm of Particle Swarm, Renewable Energy, Wind Turbine, Hybrid Energy System, Photovoltaic.

## 1. Introduction

With the world's industrial development and the increasing demand for energy on one hand and the need to preserve the resources of fossil fuels for future generations as well as preventing environmental damage caused by their burning on the other hand, the only alternative is turning to renewable energies such as the sun and wind. In recent decades, wind and solar energy have gained more and more attention among renewable energy sources. In addition, energy production near the consumption centers eliminates the need to create voltage transmission lines near cities and villages.

A group of power generation systems powered by different sources of energy that work together and complement each other, are known as hybrid systems. Since these systems are powered by two or more different sources of energy, they are more reliable than systems that have a source for power generation. Different modes of hybrid systems could be selected based on the characteristics of the installation area (radiation intensity, ambient temperature, wind speed, etc). Moreover, one of the most important concerns in remote areas apart from the network around the world is the provision of electricity generation resources for these areas. Connecting these areas to network is costly, and in some cases, physically impossible. The use of wind and solar resources together and the use of storage improve the performance of these resources and increase reliability, thereby reducing the cost of the power system [1].

Various methods and solutions have been proposed to reduce the cost of wind and solar power plants. In some articles, these sources have been used in the hybrid and off - grid systems to provide electricity, and in some others; these resources have been used in the micro - grid connected to the grid to provide electricity or to sell electricity to upstream networks. An off - grid hybrid system consists of wind / solar / fuel cells in which the fuel cell along with the electrolyzer and hydrogen tank is considered as a storage medium for improving the performance of wind and solar resources [2]. In [3], a nonlinear planning method has been used to select the location and optimal capacity of networked wind power plants to maximize energy density and minimize costs. In [4], Determination of the optimal size of solar and wind units along with the battery considering wind uncertainty and the index of ELU has been studied. Using the differential evolutionary algorithm (DE), the optimal resource size in a network - independent micro - grid was studied taking into account the reliability indices in [5]. Reliability and pollution levels are considered as limiting factors for determining the size of resources in a hybrid system independent of the network such as wind / solar and diesel generators taking the wind and sun uncertainty into account in [6]. Emergency exit of solar cells in network-independent micro - grid production planning was also studied in [7]. In this paper, determination of the optimal size of resources in an interconnecting micro - grid with the electricity market has been investigated for charging electricity. Simulation was carried out in both separate and network-connected modes followed by results comparison. Reliability index was considered as a limiting factor.

Section 2 presents the structure of the micro - grid and the mathematical model of the elements used in it. The reliability model in the problem solving is dealt with in Section 3. Section 4 explains the goal of the micro - grid and the way of exploiting resources to provide electricity and heat, and section 5 is dedicated to explanation of the problem formulation and expression of the objective function and its constraints. Section 6 goes through the mechanism of particle swarm algorithm and how software is developed with this algorithm. In section 7, the results are presented and finally, the conclusion is drawn from this study.

## 2. Proposed Micro - Grid Structure and Its Element Model

Figure 1 illustrates the structure of the sample micro – grid. The hybrid system of wind and solar power sources are used as the main electric power generators and fuel cell system with electrolyzer and hydrogen tank are used as a storage device. In the event that the hydrogen tank is not sufficiently capable of storing hydrogen, the dump power of wind and solar resources will be given to the upstream network with regard to sales restrictions. Given that the micro – grid is autonomous, and the loads are often provided only by the grid makers themselves, therefore, decentralized control is used to manage the micro-network. In this figure, MGCC is the central controller and MC and LC stand for local controller [8]. This is followed by the description of the model of system components.

## 2.1. Wind Turbine Model

Power characteristic – The turbine speed is as follows:

$$\begin{cases} 0 & ; V_W \le V_{cutin}\ ,\ V_W \ge V_c \\ P_{wT\max} \times \left( \dfrac{V_W - V_{cutin}}{V_{rated} - V_{cutin}} \right)^m & ;\ V_{cutin} \le V_W \le V_{rated} \\ P_{wT\max} + \left( \dfrac{P_{furl} - P_{WT\max}}{V_{cutout} - V_{rated}} \right) & ;\ V_{rated} \le V_W \le V_{cutout} \\ \quad \times (V_W - V_{rated}) & \end{cases} \tag{1}$$

Where $V_{cutin}$, $V_{cutout}$, and $V_{rated}$ are cut – in speed, cut – out speed, and rated speed of the turbine respectively. In addition, $P_{wTmax}$ and Pfurl(KW) are maximum turbine output power and its power in cut – in speed respectively. In this paper, $m$ was considered to be 3. The turbine used in this paper is a BWCExcel-R/48. Figure 2 shows the wind turbine power output in terms of wind speed.

**Table. 1.**Technical Specifications of Wind Turbine

| | |
|---|---|
| Rated Power (Kw) | 7.5 |
| Installation Cost ($) | 19,400 |
| Replacement Cost ($) | 15,000 |
| Maintenance Cost ($/yr) | 75 |
| Lifespan (yr) | 20 |

## 2.2. Photovoltaic Panel Model

The electrical power equivalent to each photovoltaic panel is obtained by equation (2).

$$P_{PV} = G/_{1000} \times P_{PV,rated} \times \eta_{PV,rated} \tag{2}$$

where $G$ represents the radiation power perpendicular to the array surface (W/m$^2$), and $P_{pv.rated}$ is the rated power of each array per $G$ = 1000. η$PV.rated$ is equal to the efficiency of the DC / DC converter installed between each array and the DC bus. The power radiated (vertically) on the surface of the array installed at the angle θ_pv is calculated according to equation (3):

$$G(t,\theta_{PV}) = G_H(t) \times \sin(\theta_{PV}) + G_V(t) \times \cos(\theta_{PI} \tag{3}$$

where GH(t) and GV(t) are the rates of horizontal radiation and vertical radiation in t time step (w/$m^2$) respectively [9].

**Table.2.**Technical Specifications of Wind Turbine

| | |
|---|---|
| Rated Power (Kw) | 1 |
| Installation Cost ($) | 7,000 |
| Replacement Cost ($) | 6,000 |
| Maintenance Cost ($/yr) | 20 |
| Lifespan (yr) | 20 |

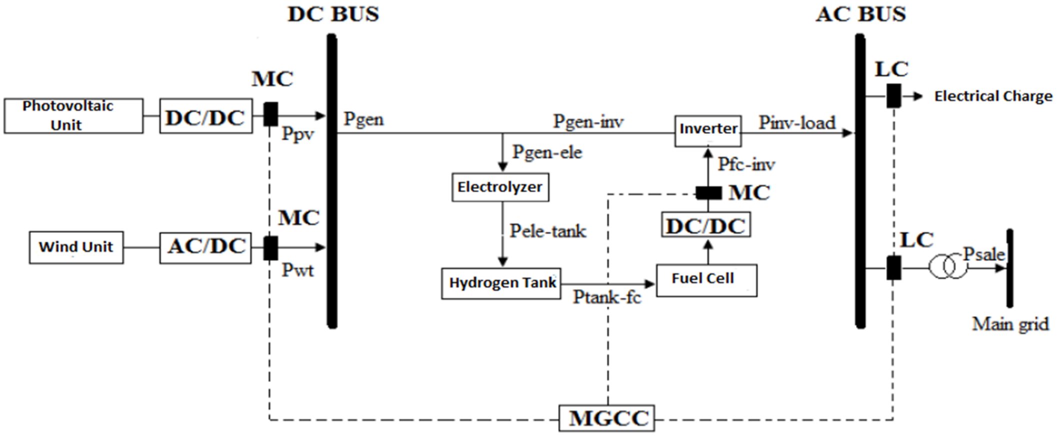

**Fig. 1.** Structure of the sample micro – grid

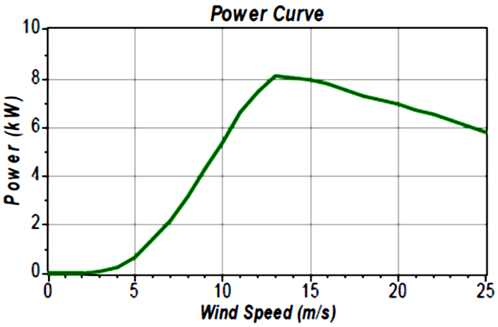

**Fig. 2.** Wind turbine power output in terms of wind speed.

The model for the evaluation of the SOC variations in the station and EV batteries is described by Eq. (10).

### 2.3. Electrolyzer Model

The output of the electrolyzer is obtained from (4):

*Pele*□tank □□*PGen*□*ele* □□*ele* (4)

where *PGen-ele* is the deliverable power from sources to the electrolyzer for hydrogen production. □*ele* is the electrolyzer efficiency, which, in this paper, was considered constant during the operation time.

### *2.4. Hydrogen Tank*

The energy stored in the tank for each t time step is calculated through the following equation:

$$E_{\tan k}(t) = E_{\tan k}(t-1) + P_{ele-\tan k} \times \Delta t - (P_{\tan k-fc}(t)) \times \Delta t / \eta_{storage} \quad (5)$$

where $\Delta t$ represents the length of each time step, $P_{ele-\tan k}$ is the transmission power from the electrolyzer to the hydrogen tank, and $P_{\tan k-fc}$ refers to the transmission power from hydrogen tank to the fuel cell. $\eta_{storage}$ is the representative of storage system efficiency.

### 2.5. Fuel Cell

The fuel cell used in this paper was a proton membrane PEM) that is commercially available. This type of fuel cell can be used to generate energy simultaneously and in small sizes. The electrical power output of this type of hydrogen fuel cell is obtained from (6):

$$P_{fc-inv} = P_{\tan k-fc} \times \eta_{fc} \quad (6)$$

Where $P_{fc-inv}$ is the electrial power in terms of kilowatt. $\eta_{fc}$ represents the efficiency of the fuel cell unit. The fuel cell used in this paper was a BCS PEMFC [7, 10].

2.6.Converter

The effect of converter losses can be modeled by its efficiency.

$$P_{inv-load}(t)=(P_{fc-inv}(t)+P_{Gen-inv}(t))\times\eta_{inv} \tag{7}$$

where $\eta_{inv}$ is the converter efficiency, and $P_{inv-load}$ represents the power of resources after the converter.

## 3. Reliability

The index of ELF was considered for the evaluation of system reliability, which includes other indices such as hope to cut off the load, hope to lose load, and the hope of non-provided energy. ELF would be obtained through the following equation:

$$ELF=\frac{1}{N}\sum_{t=1}^{N}\frac{Q(t)}{D(t)} \tag{8}$$

where $Q(t)$ and $D(t)$ respectively show the amount of the interrupted load and the total electrical charge in $t$ time in terms of kilowatt hours. $N$ is the number of simulation hours per year.

## 4. How to Exploit the Micro-Grid in Dealing with the Electricity Market

The proposed micro -grid in the present paper includes wind / solar and fuel cells. If we add the production, due to sales constraints, the additional power is given to the upstream grid.

At first, the powered produced by wind and solar resources (according to the information about wind speed and sound radiation) are calculated as follows:

$$P_{Gen}(t)=N_{WT}\times P_{WT}+N_{PV}\times P_{PV} \tag{9}$$

where $N_{WT}$ , $N_{PV}$ , $P_{WT}$ , and $P_{PV}$ are the number of wind resources, the number of solar resources, production capacity of each wind unit, and production capacity of each solar unit respectively. With regard to (9) and micro –grid load, any of the following 3 conditions may occur:

- $P_{Gen}(t)=P_{load}(t)/\eta_{inv}$:

In this case, production equals the load.

$$\begin{cases} P_{Gen}(t)=P_{load}(t)/\eta_{inv} \\ P_{fc-inv}(t)=0 \\ P_{ele-\tan k}(t)=0 \\ P_{\tan k-fc}(t)=0 \\ P_{sale}(t)=0 \end{cases} \tag{10}$$

- $P_{Gen}(t)>P_{load}(t)/\eta_{inv}$:

In this case, production is more than load, and and there is a possibility to sell to the upstream network.

$$\begin{cases} P_{Gen}(t)=P_{load}(t)/\eta_{inv} \\ P_{fc-inv}(t)=0 \\ P_{Gen-ele}(t)=(P_{WT}(t)+P_{PV}(t))-P_{Gen-inv}(t) \\ P_{ele-\mathrm{tank}}(t)=P_{Gen-ele}\times\eta_{ele} \\ E_{\mathrm{tank}}(t)=E_{\mathrm{tank}}(t-1)+P_{ele-\mathrm{tank}}(t) \end{cases} \tag{11}$$

If the hydrogen tank has no capacity for storage:

$$\begin{cases} E_{\tan k}(t)=E_{\tan kMax} \\ P_{ele-\tan k}(t)=E_{\tan k}(t)\ -E_{\tan k}(t-1) \\ P_{ele-\tan k}(t)=P_{Gen-ele}\times\eta_{ele} \\ P_{Gen-ele}(t)=(P_{WT}(t)+P_{PV}(t)) \\ \qquad -P_{Gen-inv}(t) \end{cases} \tag{12}$$

- $P_{Gen}(t)<P_{load}(t)/\eta_{inv}$

In this case, the production is less than load, and the remainder of the load is provided by the storage medium and is interrupted if forced:

$$\begin{cases} P_{Gen}-inv(t)=P_{Gen}(t) \\ P_{Gen-ele}(t)=0 \\ P_{ele-\tan k}(t)=0 \\ P_{fc-inv}(t)=\dfrac{P_{load}(t)}{\eta_{inv}}-P_{Gen-inv}(t) \\ P_{\tan k-fc}(t)=P_{fc-inv}(t)/\eta_{fc} \\ E_{\tan k}(t)=E_{\tan k}(t-1)+P_{\tan k-fc}(t) \end{cases} \tag{13}$$

If the demand for load is not met despite the availability of fuel cell, the load will be cut off:

$$\begin{cases} E_{\tan k}(t) = E_{\tan kMin} \\ P_{\tan k-fc}(t) = E_{\tan k}(t-1) - E_{\tan k}(t) \\ P_{fc-inv}(t) = P_{\tan k-fc}(t) \times \eta_{fc} \\ P_{shed}(t) = P_{load}(t) / \eta_{inv} - P_{Gen-inv}(t) \\ \qquad - p_{fc-inv}(t) \end{cases} \tag{14}$$

Where $P_{shed}$ is the amount of the discontinued load of the micro – grid at *t*.

## 5. Objective Function and Problem Constraints

The purpose of this paper is to determine the optimal size of resources in an interconnected micro-grid with the electricity market to provide electricity for the purpose of reducing the network's dependence on fossil fuels. system costs include installation costs, replacement costs, maintenance costs, and power outage costs. Earnings from residual value and sales to the upstream network reduce these costs.

To calculate costs and determine the objective function, the net present cost method (NPC) was used.

### 5.1.Equipment cost

Given the above costs, the objective function of the problem is defined as follows:

$$NPC_i = N_i \times (CC_i + RC_i + K_i + (O\&MC_i \times PWA(ir,R)) \tag{15}$$

where $N$ is the number of units, $CC$ represents the cost of initial investment cost ($\$.unit^{-1}$), $RC$ is the cost of each alternate load ($\$.unit^{-1}$), and $O\&M$ is the cost of annual maintenance ($\$.unit^{-1}.yr^{-1}$), and $R$ represents the lifespan of the project (which was considered 20 years in this article). $ir$ is the real interest rate taking inflation into account. Moreover, $PWA$ and $K$ are respectively the current value factor of annual payments and the number of replacements, which are determined through the following equations:

$$PWA(ir,R) = \frac{(1+ir)^R - 1}{ir(1+ir)^R} \tag{16}$$

$$K_i = \sum_{n=1}^{y_i} \frac{1}{(1+ir)^{n \times L_i}} \tag{17}$$

y and L represent the number of replacements and lifespan respectively.

### 5.2.The cost of Power Failure

The cost of power failure equals the cost imposed by losses caused by power failure on consumers. If the hoped annual lost load is defined by the following equation,

$$LOEE = EENS = \sum_{t=1}^{8760} E[LOE(t)] \tag{18}$$

the NPC of the load loss will be obtained as follows:

$$NPC_{loss} = LOEE \times C_{loss} \times PWA(ir,R) \tag{19}$$

where $C_{loss}$ is equal to the average loss caused by cutting – off of every kilowatt hour of time consumed ($KWh)

### 5.3.Residual Value

The residual value of equipment is the sale price of that equipment at the end of its useful life; in economic calculations the residual value is considered as a negative cost; (20) shows how to calculate the residual value at the beginning of the project:

$$NPSV_i = N_i \times (P/F(ir,r) \times RC_i \times \frac{L_{rem,i}}{L_i}) \tag{20}$$

In the above equation, $NPSV_i$ is the present residual value of equipment I, $N$ represents the number of the equipment, $RC_i$ is the replacement cost of i<sup>th</sup> equipment ; $L_{rem.i}$ is the remaining lifespan of ith equipment. And $P/F(ir,r)$ is the present value factor which is equal to a future sum, which could be obtained as follows:

$$P/F(ir,r)=\frac{1}{(1+ir)^{R}} \tag{21}$$

5.4.Revenue from Electricity Sales to The Upstream Network

The revenue from electricity sales to the upstream network is determined by the amount of sales and its price. Equation (22) shows the current value of electricity sales to the upstream network:

$$NPC_{sale}=PWA(ir,R)\times\sum_{t=1}^{8760}P_{sale}(t)\times C_{sale} \tag{22}$$

where $C_{sale}$ is the revenue from sales per kilowatt hours of electricity to the upstream network ($/KWH$^{-1}$).

### *5.5. Objective Function*

With regard to the costs mentioned above, the objective function of the problem is defined as follows:

$$J=\min_{x}\left\{\begin{array}{l}(\sum_{i} NPC_{i})+NPC_{loss}\\ -(\sum_{i} NPSV_{i})-NPCsale\end{array}\right\} \tag{23}$$

where I is the given equipment, and $X=[N_{PV},N_{WT},N_{ele},N_{\tan k},N_{fc}]$ is a vector of optimization variables, which are representatives of the number photovoltaic arrays, the number of wind turbines, the number of electrolyzers, the number of hydrogen tanks, and the number of fuel cells respectively.

5.6.Problem Constraints

The constraints which must be considered in problem solving are:

$$ELF\le ELF_{mxx} \tag{24}$$

$$E_{\tan kMin}\le E_{\tan k}(t)\le E_{\tan kMax} \tag{25}$$

$$E_{\tan k}(0)\le E_{\tan k}(8760) \tag{26}$$

$$P_{sale}\le P_{saleMax} \tag{27}$$

The third constraint implies that the energy stored in the tank at the end of the year should not be less than the energy stored in at beginning of the year. The constraint ensures that reliability calculations are carried out for the worst possible situation [4,7,8].

## 6. Particle Swarm Algorithm(PSO)

An algorithmic particle pool is a group in which a set of particles search the possible space of the problem in order to find the optimal response of an objective function. In this algorithm, the position of each particle is changed by the velocity vector of the same particle. The direction and size of the velocity vector of each particle is determined through combination of its previous velocity vector following the best personal and group experience, which causes each particle to tend to follow both its own experience and the experience of the best particle of the population. This is mathematically expressed in (28):

$$\begin{aligned}V_{i}^{k+1}&=w\times V_{i}^{k}+C_{1}\times rand_{1}\times(P_{best}-X_{i}^{k})\\&+C_{2}\times rand_{2}\times(g_{best}-X_{i}^{k})\end{aligned} \tag{28}$$

$V_{i}^{k+1}$ is the modified velocity vector of the i$^{th}$ particl in the iteration of k+1$^{th}$; $V_{i}^{k}$ is the velocity vector of the i$^{th}$ particle in the iteration of k$^{th}$; $rand_{1.2}$ shows the random numbers between 0 and 1; $P_{best}$ is the spot vector of the best personal experience of the i$^{th}$ particle; $g_{best}$ is the spot vector of the group experience; w represents the weighting factor of each particle's velocity vector; $C_1$ and $C_2$ are coefficients of experiences of themselves and others [7, 12, 13].

Using (28), a specific velocity is calculated for each particle, and at the next iteration stage, the current position of each particle is corrected by (29):

$$X_{i}^{k+1}=X_{i}^{k}+\chi\times V_{i}^{k+1} \tag{29}$$

In this equation, $X$ stands for the shrinkage coefficient which has been entered in (29) to limit the effect of velocity vector. In many references, $C_1$ and $C_2$ were considered both constant and equal to 2. As we know, $C_1$ is the person's own learning coefficient and $C_2$ is the coefficient of learning from others. If each person at the beginning of the algorithm has a high coefficient of learning and is less affected by others, and tries to interact with and learn from others at the end of the algorithm, this may prevent the algorithm from falling in the local optimum which leads to the increased accuracy and speed of convergence. The coefficients of learning in this dissertation are dynamically changed; in that, the initial value of $C_1$ is set to 2.5, and as the iterations increase at the end of searching, it closes to 1.5. On the other hand, the value of $C_2$ is increased from 1.5 up to 2.5 on the reverse direction. Moreover, the X – factor was used to limit the vector effect and fall in the local optimum, and its value was considered 0.7.

## 7. Simulation Results

In order to determine the optimal capacity of the units to provide the charge in the system, the software is provided under the MATLAB programming environment using a mass particle algorithm. The problem data includes the economic data of the units, the annual charge curve, the radiation data, the wind data, and the parameters of the mass particle algorithm, all of which are given in the appendices. Simulation was performed to determine the size of the micro - grid sources in both off - grid and grid-connected modes, and the results were presented in Tables (3) and (4) respectively; and also the problem of optimization with genetic algorithm was carried out and its results were compared to the massive algorithm. It should be noted that the continuous genetic algorithm was used to solve the optimization problem. The results show that for both off – grid and connected modes, using fuel cells reduces the total cost of the micro – grid. In addition, the results indicate that selling power to upstream network with its consequent revenue in network connected mode led to decreased total cost.

**Table 3-**Simulation Results in off – Grid mode

| | Results |
|---|---|
| Number of wind turbines | 40 |
| Number of photovoltaics | 590 |
| Number of electrolyzers | 415 |
| Number of hydrogen tanks | 456 |
| Number of fuel cells | 220 |
| Total Cost ($) | $8.12 \times 10^{6v}$ |

By comparing the results obtained from both off – grid and connected modes, it becomes clear that the total cost reduces in network – connected mode. The reason is that in this mode, the micro – grid sells its dump power to the upstream network and prevents power loss, which reduces the system costs.

**Table 4-**Simulation Results in Network – Connected Mode

| | pso Results | (GA) Results |
|---|---|---|
| Number of wind turbines | 42 | 54 |
| Number of photovoltaics | 580 | 630 |
| Number of electrolyzers | 430 | 540 |
| Number of hydrogen tanks | 450 | 470 |
| Number of fuel cells | 225 | 360 |
| Total Cost ($) | 7.82 × 106 | 8 × 106 |

In addition, results show that PSO algorithm gives more satisfying responses compared to GA algorithm in terms of reducing the total cost of the micro – grid.

## 8. Conclusion

In this paper, the objective function was dealt with taking into account the costs in order to determine the optimum size of micro – grid production units interconnected with electricity market to supply electrical charge. The obtained objective function was optimized in both the off – grid mode and the network – connected mode using PSO algorithm in MATLAB software. The results showed that with proper management (proper utilization strategy throughout the year) and the use of fuel cells, the dependence of the micro - grid on fossil fuels was reduced. Moreover, some of the produced power was given to the upstream network, which, in addition to income generation for the micro – grid, prevents power loss as well as reducing the micro – grid costs. Furthermore, the results show that the mass particle algorithm has more accuracy than the genetic algorithm in achieving the optimal response.

In order to expand the model presented in this article, the following items could be added:

- Considering load growth and providing an appropriate optimization method to manage the high dimensions caused by the expansion of the model,
- Modeling the purchase of electricity from the national grid and its impact on resource size,
- Considering the uncertainty of wind and solar resources.

Appendix

The input data of the problem is presented in the following tables:

**Table 5-**Technical and economic specification used Technical and Economic Specification used in the proposed micro-grid

| Equipment | Initial Cost ($.unit$^{-1}$) | Replacement Cost ($. unit$^{-1}$) | Annual maintenance Cost ($.unit$^{-1}$.yr$^{-1}$) | Lifespan (yr) | Efficiency (%) |
|---|---|---|---|---|---|
| Wind Turbine | 19,400 | 15,000 | 75 | 20 | - |
| Solar Array | 7,000 | 6,000 | 20 | 20 | - |
| Electrolyzer | 2,000 | 1,500 | 25 | 20 | 75 |
| Hydrogen Tank | 1,300 | 1,200 | 15 | 20 | 95 |
| Fuel Cell | 3,000 | 2,500 | 175 | 5 | 50 |
| DC/AC Converter | 800 | 750 | 8 | 15 | 90 |

**Table 6-**Other technical characteristic of wind turbine

|  | Rated Power (KW) | Maximum Output Power (kW) | Output Power at high cut – off speed | High speed Cut (m.s$^{-1}$) | Rated Speed (m.s$^{-1}$) | Low cut – off speed (m.s$^{-1}$) |
|---|---|---|---|---|---|---|
| Wind Turbine | 7.5 | 8.1 | 5.8 | 25 | 11 | 3 |

Table 7-Parameters of PSO algorithm

| Number of Population | Number of Iterations | $W_{max}$ | $W_{min}$ | $C_{1\ first}$ | $C_{1\ end}$ | $C_{2\ first}$ | $C_{2\ end}$ |
|---|---|---|---|---|---|---|---|
| 200 | 200 | 0.9 | 0.4 | 2.5 | 1.5 | 1.5 | 2.5 |

## References

[1] Ekren, O., Ekren, B.Y., "*Size Optimization of a PV/Wind Hybrid Energy Conversion System with Battery Storage Using Simulated Annealing*", Applied Energy, Vol.87,pp. 592–598, 2010.

[2] Koutroulis, E., Kolokotsa, D., Potirakis, A., Kalaitzakis, K., "*Methodology for Optimal Sizing of Stand-Alone Photovoltaic/Wind Generator Systems Using Genetic Algorithms*", Science Direct, Solar Energy, Vol. 80, No. 9, pp. 1072-1088, 2006.

[3] Giraud, F., Salameh, Z.M., "*Steady State Performance of a Grid-Connected Rooftop Hybrid Wind-Photovoltaic Power System with Battery Storage*", IEEE Transactions on Energy Conversion, Vol. 16, pp. 1-7, 2001.

[4] Navaeefard , A., Tafreshi, S.M.M, Barzegari, M., JalaliShahrood, A., "*Optimal Sizing of Distributed Energy Resources in Microgrid Considering Wind Energy Uncertainty with Respect to Reliability*", EnergyConference and Exhibition (Energy Con) IEEE, pp. 820- 826, 2010.

[5] Abedi, S., Ahangar, H.G., Nick, M., Hosseinian, S.H., "*Economic and Reliable Design of a Hybrid PV-Wind- Fuel Cell Energy System Using Differential Evolutionary Algorithm* ", ICEE Conference, pp. 1-6, 2011.

[6] Hong, Y.Y., Lian, R., "*Optimal Sizing of Hybrid Wind/PV/Diesel Generation in a Stand-Alone Power System Using Markov-Based Genetic Algorithm*", IEEE Transactions on Power Delivery, Vol. 27, pp. 640 647, No. 2, 2012.

[7] KashefiKaviani, A., Riahy, G.H., Kouhsari, SH.M., "*Optimal Design of a Reliable Hydrogen-Based Stand- Alone Wind/PV Generating System, Considering Component Outages*", Renewable Energy, Vol. 34, pp. 2380-2390, 2009.

[8] Katiraei, F., Iravani, R., "*Power Management Strategies for a Microgrid with Multiple Distributed Generation Units*", IEEE Transactions on Power System, Vol. 21, No. 4, 2006.

[9] Lambert, T., "*Micropower System Modeling with Homer*", Integration of Alternative Sources of Energy, John Wiley & Sons, Inc, 2006.

[10] Shabani, B., Andrews, J., "*An Experimental Investigation of a PEM Fuel Cell to Supply both Heat and Power in a Solar-Hydrogen RAPS System*" Science Direct, Hydrogen Energy, Vol 36, pp. 5442-5452, 2011.

[11] Oskuinejad, Mohammad, "*Engineering Economics Evaluation of Industrial Projects*", Amirkabir University Press, 17th print, 2003.

[12] Yuhui , Sh., "*Particle Swarm Optimization*", IEEE neural Networks Society, 2004.

[13] Chaturvedi, K.T., Pandit, M., Srivastava , L., "*Particle Swarm Optimization with Time Varying Acceleration Coefficients for Non-Convex Economic Power Dispatch*", Elsevier, Journal of Electrical Power and Energy Systems, Vol. 31.

[14] Website https://weatherspark.com/

[15] M. J. Mokarram, M. Gitizadeh, T. Niknam, and K. E. Okedu, "A decentralized granular-based method to analyze multi-area energy management systems including DGs, batteries and electric vehicle parking lots," *Journal of Energy Storage,* vol. 42, p. 103128, 2021.

[16] B. Sheykhloei, T. Abedinzadeh, L. Mohammadian, and B. Mohammadi-Ivatloo, "Optimal co-scheduling of distributed generation resources and natural gas network considering uncertainties," *Journal of Energy Storage,* vol. 21, pp. 383-392, 2019.

[17] J. Junga, M. Villaran, "Optimal planning and design of hybrid renewable energy systems for microgrids ", *Journal of Renewable and Sustainable Energy Reviews,* In Press.