Research Article – Vol. 01, Issue 03, No. 04

Advanced in Engineering and Intelligence Systems

Journal Web Page: https://aeis.bilijipub.com

Determining appropriate strategy for managing the energy production system in the presence of renewable energy sources and improved intelligence method

Amır Sohel[1,*] , Md Faisal Bin Ashab [1]

[1] *College of Electrical engineering and new energy, China three gorges University*

Highlights

- Planning for the best growth of the energy supply system is an important issue
- It is difficult to plan for evolving systems under novel circumstances
- According to the results, the optimal capacity of other power plants has a direct relationship
- Determining the optimal wind and hydropower plant capacity is crucial for lowering costs and environmental damage
- PSO and GSA are both employed in the combined PSOGSA optimization technique

Article Info

Received: 10 August 2022
Received in revised: 24 September 2022
Accepted: 24 September 2022
Available online: 01 October 2022

Keywords

Stochastic programming,
Renewable energy,
Distributed generation,
Reliability,
Optimal capacity,
Particle swarm algorithm,
Gravitational search algorithm

Abstract

In recent years, changing the structure and decentralizing management of energy systems have been started as a serious movement in many countries and past experience in this field has demonstrated that relying on market mechanism to ensure the adequacy of energy production and supply in the long run lacks efficiency. Hence, the issue of planning for the optimal development of the energy supply system is one of the key issues in the restructured condition. Planning for developing systems in new conditions is much more complicated than the classical systems. In the present study, the development planning of electric power production system with the collaboration of thermal, wind, hydro and solar power plants is reviewed. A multi-level model for electric charge, wind and hydro power plants is introduced. By specifying the optimal capacity of wind and water units and reducing the contribution of thermal units as well as environmental pollution, the total cost of developing the production system is decreased. The presented method is carried out for IEEE 24 busbar network and the combined particle swarm optimization and gravitation search algorithm optimization process, which includes two methods for optimization process.

Nomenclature

DG	*Distribution generation*	*PSO*	*Particle swarm optimization*
DLR	*Dynamic line rating*	*PV*	*Photovoltaic*
GPD	*Gross domestic production*	*RES*	*Renewable energy sources*
GSA	*Gravitational search algorithm*	*WT*	*Wind turbine*
NREL	*National Renewable Energy Laboratory*		

1. Introduction

Nowadays, electricity plays an important role in economy and influences sustainable development and welfare of communities. Besides, it has a direct impact on gross domestic production (GPD) and one of the most important indicators of development of any country is reflected in its per capita electricity consumption. Nowadays, producing electricity from renewable energy sources plays an important role in the energy portfolio of developed countries. Air pollution, which is increasing every year in different parts of the world, is somehow

* Corresponding Author: Amır Sohel
Email: Amirsohels126@gmail.com

associated with uncontrolled development of fossil power plants. The development of renewable electricity reduces emissions and global warming, energy stability and security, crisis management and economic resilience of countries when there is lack of fossil fuel resources and, hence, finding effective policies in the development of renewable energy is of great importance [1]. The amount of production costs and the competitiveness ability of electricity production technologies depend on the conditions of each country. Renewable power plants, in which hydropower plants play a key role, have advantages over non-renewable power plants, including fossil fuels conservation, helping environmental protection due to near zero air pollutant and greenhouse gases emission, producing clean and environmentally friendly electricity in accordance with the Kyoto Protocol (per 4 MW of capacity, about 4 ton of carbon dioxide in the environment is reduced), significant reduction in water consumption, eliminating fuel costs and competitiveness of the cost of electricity (about 300 m^3 of natural gas produced per MW of energy and about 75 billion Rial saved per MW of capacity), diversification of energy resources through using other potentials of the country so as to enhance the electricity production, helping in peak shaving, as well as compensating for the limitation of natural gas production capacity in the country [2]–[4]. In addition to the aforementioned advantages, small renewable power plants have some other benefits, such as less causalities in the transmission and distribution network due to production in the vicinity of the consumption site, reducing the need to build new transmission and distribution networks, possibility of using any type of energy source in the place and less need to transfer energy sources, emergency power supply in case of blackout in the network (compensation of network instability), improving the security of electricity supply and resilience of the power system in the situation of war, destructive actions and the occurrence of natural disasters such as flood, earthquakes and dust, greater reliability given the reliance on a large number of decentralized independent generators, the possibility of providing sufficient and quality electricity in remote parts of the network, possibility of investment by a large number of individuals and small companies, breaking the monopoly of electricity supply and, consequently, more competition, higher productivity, lower costs and cheaper electricity for the final consumer, the possibility of developing local energy and electricity markets, social alterations in deprived areas and helping in creating new jobs [5]–[7].

Over the last decades, wind energy has grown faster than other energy sources. The development of technology in this area has allowed the construction of turbines with 5 MW capacity. However, given the random nature of this energy, using it is somehow limited. Increasing the costs of fossil fuels and enacting clean air regulations have necessitated a wider use of this energy. For this reason, the development plan of production units has no alternatives, but to consider the new energies, especially wind energy. Increasing the application of wind energy-based capacities in a power system requires numerous analyses such as the analysis of cost and reliability. Traditionally, the development plan of production units so as to provide load while maintaining the reliability of the system is done to an acceptable level.

Concerning the changes in wind speed and surface and water flow, arrangements should be made in planning the production system in the presence of renewable sources. In this regard, stochastic programming is adopted and uncertainty is taken into account in variables such as wind speed and water flow. In [8] _ [9], energy sustainability is dealt with as one of the main issues in power system planning in the Indonesian archipelago system and, therefore, the planning process of sustainable development is considered based on local energy sources. The [10] presented a multi-stage sustainable development planning model, which took into account the uncertainty of electricity demand and renewable energy production through limited distance. Owing to the growing proportion of renewable and variable energy sources in the power system, in [11], the development of rational production while considering the uncertainties was highly required. The present study proposed a three-stage heat production planning model that encompassed the uncertainties of wind and load power and possible reliability criteria. In [12], special attention was paid to planning production development in power systems and it was declared that, in traditional systems, investment in production development was done by the electricity company. But, when the electricity industry renovated, the owners of various parts of the system send their suggestions to the standalone system operator and the standalone system operator selects the optimal design. The gradual increase in energy production from renewable sources can face the grid with some challenges. Increasing the influence of renewable resources given the uncertainty in their production can reduce network reliability and, thus, increase system costs. For this purpose, a multidimensional structure of production development planning is addressed based on increasing the influence of distributed generation resources (renewable and non-renewable) as well as the usage of load management and demand response. In [13], countries require long-term plans so as to continue with the global pace of transition from fossil fuels to clean and renewable energy. Renewable energy development plans can be centralized, decentralized or a combination of both. This paper presents a new method for obtaining an optimal multi-cycle program to produce any type of renewable energy (solar, wind, hydro, geothermal and biomass) through multifunctional mathematical modeling. The proposed model is integrated with an econometric method in order to predict the country's demand along the planning horizon. The [14] addressed production development planning as one of the topics discussed in universities and by energy sector decision-makers in order to avoid the emission of greenhouse gasses. Every country, with the aim of improving its economy, focuses on implementing policies that can increase the influence of renewable energy sources (RES) in the combination of its electricity capacity. The [15] represented random energy management in a smart micro grid in the presence of alternating sources such as wind turbine (WT) and photovoltaic (PV). Finally, the photovoltaic system renders fuel cell to the appropriate and optimal size of the wind turbine and reduces the cost. The [16] scrutinized the optimum timing of hybrid micro grid in the presence of renewable energies as well as considering the dynamic line rating (DLR). DLR is a practical constraint that can potentially affect the ampacity of lines, particularly in the island state, where the lines reach their maximum capacity in the absence of the main production source at the point of connection with their usefulness. The [17] stated that using various types of renewable energy sources, while taking into account their uncertainty, caused different challenges for minimizing operating costs and maximizing system reliability. As a result, stochastic programming is an essential tool for considering system uncertainty. To this end, it provides an energy management system in order to reduce operating costs and increase reliability by considering a number of challenges to support electrical and thermal charges. In the proposed method, renewable energy sources, boiler system and energy storage system are all responsible for supplying electrical and thermal charges. In [18], an improved energy hub consisting of different types of renewable energy-based DG units was proposed, owing to the storage and heating systems, which model system performance and planning aspects. Moreover, the optimal programming and planning of the multi-carrier energy hub system was modeled by considering the random behavior of wind and photovoltaic units. By scrutinizing various factors such as type of wind turbine, the average wind speed of wind sites and the cost of installing wind turbines, [19] suggested the proper selection of wind turbines for planning the installation of wind generator turbines. Using load duration curve and display curves for power plants, [20] economically analyzed the use of wind energy, instead of fossil fuels, and the extent of optimal use of traditional units.

Stochastic programming is performed in two general ways: based on scenario and based on sampling. Scenario-based stochastic programming for production and transmission systems has been conducted in the presence of wind and thermal power plants. Although the number of scenarios has been decreased, solving the important issue of mixed integer programming model with a large number of constraints is difficult and time-consuming. But, in sampling-based stochastic programming, the problem is solved at various levels and there is no need to put the scenarios in the form of a large-scale problem.[21], [22]

Owing to the uncertainty in the production of hydro and wind power plants, evaluating reliability should be considered in production planning and the presence of these power plants. Scrutinizing reliability in the articles is done through mathematical models, methods which are based on equipment output scenarios and innovative methods. Equipment output can be considered by creating scenarios in the problem.

The contributions of this paper are summarized as follows:

- In the present study, the optimal combination of hydropower, wind, solar, thermal and gas power plants is considered.
- Effective factors in determining the optimal capacity of wind and hydropower plants, which have been not gathered in previous studies, are included in this article.
- Simultaneous multilevel models for wind and hydroelectric power plants are introduced and, hence, reduce the number of scenarios in stochastic programming.
- The expected level of reliability in the presence of wind and hydro power plants is considered.

Besides, recovery time for lost production is considered so as to specify the optimal capacity of hydro and gas power plants. Accordingly, the optimal reserve power of power plants is determined at peak load and, with the exit of part of the production, its recovery is performed at the desired time. Consequently, the frequency range of the system is reduced. Environmental pollution fines are also mentioned in the equation so as to increase the optimal capacity of wind and hydropower plants.

2. Participation of hydropower plants

Hydropower plants produce approximately 24% of the world's electricity (in other words, the electricity needed for more than 1 billion people). According to National Renewable Energy Laboratory (NREL), the world's hydropower plants totally produce 675,000 MW of power, which is equivalent to 3.6 billion barrels of oil. There are more than 2,000 hydropower plants in the United States, which makes the hydropower the country's largest source of renewable energy. Hydropower plants use gravity and solar power to produce electricity. Water evaporates due to ambient heat, the main cause of which is the sun, and rises in the atmosphere. Subsequently, it falls down as rain and snow. Water pours on the heights and flows in the form of small streams and, then, larger rivers. After passing some distance, gravitational potential energy is converted into kinetic energy. Generally speaking, hydropower plants are one of the clean and cheap sources of electricity supply, constructed along the river or behind dams.

In the first case, kinetic energy is used and, in the second case, water potential energy is used. The output power of the water unit with dam storage and along the river is presented in Eqs (1) and (2), respectively.

$$P = \eta \rho g h Q \quad (1)$$

$$\mathrm{P} = \frac{1}{2} \eta \rho \mathrm{Q} \mathrm{V}_{\mathrm{h}}^{2} \quad (2)$$

where η is the efficiency of a water turbine, ρ is the density of water, g is the acceleration of gravity, h is the height of dam, Q is the flow of water and V_h is the velocity of water. Typically, uncertainty in the production of hydropower plants is considered using flow and water level scenarios.

In reliability studies, the output of power plant units is considered, but production recovery time is not taken into account. Production recovery time is really important in the frequency stability of the system and increasing the participation of power plants with higher response rates, such as hydropower plants, is effective in reducing production recovery time. Suppose, for instance, that a unit with the power of P_g, suddenly goes out of the circuit. The recovery time of the output is obtained according to Eq (3), where H, G and S are the sum of water, gas and heating units, respectively, and the rate of increase in their production is rr_h, rr_g and rr_s, respectively. m_h, m_g and m_s are the number of waters, gas and heating units, respectively, and T_d is the expected production recovery time.

$$T_d = P_g / \left(\sum_{u \in H} rr_h m_h + \sum_{g \in G} rr_g m_g + \sum_{s \in S} rr_s m_s \right) \quad (3)$$

Production recovery time should be within an acceptable range. In case it is high, we will observe fluctuations in the system. The minimum reservation power of water and heating units to provide the desired recovery time is presented in Eqs (4) and (5). The reservation power of the hydropower plant at time (h) is obtained according to Eq (6), which is associated with the water flow balance.

$$rr_u T_d < res_u \quad (4)$$

$$rr_u T_d < res_h \quad (5)$$

$$\mathrm{res_h} = \mathrm{res_h^{initial}} + \mathrm{P_h^{in}} + \mathrm{P_h^{out}} \quad (6)$$

where $\mathrm{res_h^{initial}}$ is the initial reservation power, $\mathrm{P_h^{in}}$ is the input power and $\mathrm{P_h^{out}}$ is the output power of the hydropower plant at time h. Also, $\mathrm{res_h}$ and $\mathrm{res_u}$ are the reservation power of water and heating units.

2.1. Clustering electric charge, wind and hydro power plants

Given various advantages of wind plants, the use and interest in using wind energy are increasing in different countries. In this paper, the participation of wind plants to reduce environmental pollution caused by fossil fuels is taken into account and a new clustering model for wind plants is introduced. In this method, a single model is obtained for all the wind farms. Diverse clustering methods have been used in previous articles. It has also been adopted in clustering in order to model wind farms in transmission network planning.

In the present paper, clustering is used to simultaneously consider uncertainties in hydro and wind power plants and the electrical load in the planning of the production system. By significantly reducing the number of scenarios in the present method, the speed of problem solving is remarkably enhanced. However, accuracy is maintained to an acceptable level. In this method, recording the data of wind speed, water flow and electric charge must be done simultaneously.

So as to cluster data, the following steps are considered:

(1) The recorded values of the hourly load are arranged in a descending order and the load duration curve is obtained.

(2) The load duration curve is divided into several levels and each level is considered as a load block.

(3) Using wind speed and water flow data, the output power of wind plants is calculated according to the reference and the output power of hydropower plants is calculated according to Equations (2) or (3).

(4) The output power of wind, hydro and electric power plants related to each load block is clustered at diverse levels. Besides, the values of each level and its probability are given in Tables 1 to 3. In this table, multi-level models of electric charge, wind and hydro power plants are obtained.

Table 1. Multi-level model for electric charge

cluster	Division interval (MW)	Output power of wind Turbine (MW)	Possibility of occurrence

s_1	$P_{di,t}^{s_1} \le \frac{P_{di,m}}{n}$	$\frac{\sum_{s_2} P_{di,t}^{s_1}}{n_{di}^{s_1}}$	$\frac{n_{di}^{s_1}}{Nd_i}$
s_n	$\frac{(n-1)P_{di,m}}{n} < P_{di,t}^{s_n} \le P_{di,m}$	$\frac{\sum_{s_n} P_{di,t}^{s_n}}{n_{di}^{s_n}}$	$\frac{n_{di}^{s_n}}{Nd_i}$

In the i-th load block, $P_{di,m}$ is the maximum data of the electric charge, $P_{di,t}^{s_n}$ is the random variable of t-th load in the s_n cluster and $n_{di}^{s_n}$ is the number of random electric charge variables in the s_n cluster. $Nd_i$is also the number of random load variables in the i-th block.

Table 2. Multi-level model for wind plant.

cluster	Division interval (MW)	Output power of wind Turbine (MW)	Possibility of occurrence
s_1	$P_{wi,t}^{s_1} = 0$	0	$\frac{nw_{si_1}}{Nw_i}$
s_2	$0 < P_{wi,m}^{s_2} \le \frac{P_{di,m}}{n}$	$\frac{\sum_{s_2} P_{wi,t}^{s_2}}{n_{wi}^{s_1}}$	$\frac{nw_{si_2}}{Nw_i}$
s_n	$\frac{(n-1)P_{wi,m}}{n} < P_{wi,t}^{s_n} \le P_{wi,m}$	$\frac{\sum_{s_n} P_{wi,t}^{s_n}}{n_{wi}^{s_n}}$	$\frac{nw_{si_n}}{Nw_i}$

In the i-th load block, $P_{wi,m}$ is the maximum data of the output power of wind plants, $P_{wi,t}^{s_n}$ is the random variable of t-th the output power of wind plants in the s_n cluster and $n_{wi}^{s_n}$ is the number of random variables of the output power of wind plants in the s_n cluster. Nw_i is also the number of random variables of the output power of wind plants in the i-th block.

Table 3. Multi-level model for hydro power plant

cluster	Division interval (MW)	Output power of wind Turbine (MW)	Possibility of occurrence
s_1	$P_{di,t}^{s_1} \le \frac{P_{hi,m}}{n}$	$\frac{\sum_{s_2} P_{hi,t}^{s_1}}{n_{hi}^{s_1}}$	$\frac{n_{hi}^{s_1}}{Nh_i}$
s_n	$\frac{(n-1)P_{hi,m}}{n} < P_{hi,t}^{s_n} \le P_{hi,m}$	$\frac{\sum_{s_n} P_{hi,t}^{s_n}}{n_{hi}^{s_n}}$	$\frac{n_{hi}^{s_n}}{Nh_i}$

In the i-th load block, $P_{wi,m}$is the maximum data of the output power of hydro power plants, $P_{wi,t}^{s_n}$ is the random variable of t-th the output power of hydro power plants in the s_n cluster and $n_{wi}^{s_n}$ is the number of random variables of the output power of hydro power plants in the s_n cluster. Nh_i is also the number of random variables of the output power of hydro power plants in the i-th block.

2.2. Probabilistic model of photovoltaic system

In the present study, the beta probability density function is used so as to model the power of the photovoltaic system.

$$f(I_r^t) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \times I_r^{t(\alpha-1)} \times (1-I_r^t)^{\beta-1} for \\ 0 \le I_r^t \le 1, \alpha \ge 0, \beta \ge 0 \\ 0 \quad otherwise \end{cases} \tag{7}$$

Concerning the distribution of the predicted radiation intensity in each area and the function of converting radiation to power, the output power of the photovoltaic system can be calculated for each radiation intensity at any time.

$$P_{pv} = \eta^{pv} \times S_r^{pv} \times I_r^t\big(1 - 0.005 \times (T_a - 25)\big) \tag{8}$$

2.3. Demand response plan

In the demand response plan, the main load capacity should be less than its maximum value and it is represented in Eq. (9). Moreover, the total load is obtained from the sum of the essential and non-essential loads and is in accordance with Eq. (10).

$$P_d^{reponsive}(t) \le PL \times P_d(t) \tag{9}$$

$$P_d^{reponsive}(t) + P_d^{non.reponsive}(t) = P_d(t) \tag{10}$$

The power associative load model is represented as Eq. (11).

$$P_d^{flexible\_TIME}(t) = \begin{cases} P^{nom} & t \in \{t_a^b + T_{delay}, \ldots, t_a^b + T_a + T_{delay} - 1\} \\ 0 & otherwise \end{cases} \quad (11)$$

The time associative load model is represented as Eq. (12).

$$P_d^{flexible\_POWER}(t) = \begin{cases} \leq P^{nom} & t \in \{t_a^b, \ldots, t_a^b + T_a + 1\} \\ 0 & otherwise \end{cases} \quad (12)$$

2.4. Scrutinizing reliability

According to the multilevel model presented in Section 3, we should go through the following steps so as to scrutinize reliability:

(1) Output modes of thermal power plants are taken into account. Accordingly, the maximum output of the two thermal units is considered together since, in case there is an increase in the output modes, solving the problem would be difficult.

(2) Electricity charge scenarios, wind power generation capacity and hydropower plants are determined based on multilevel models presented in Section 3.

(3) Considering the scenarios in the first and second steps, the scenarios related to equipment output and uncertainty of variables are considered.

(4) According to the scenarios of the third step, the mathematical expectation of unsupplied energy is figured.

2.5. Problem equations

The objective function of the problem is mentioned in Eq. (13), where the first, second and third items respectively represent investment cost of thermal, hydro and wind power plants, and the fourth, fifth and sixth items show the exploitation cost of power plants, pollution fines and unsupplied energies, respectively. Coefficient A is for converting the annual value into the present value, which is obtained based on Eq (14). m_{wi}, m_{hi} and m_{ui} are the binary decision variables for wind, hydro and thermal power plants, respectively. If they are 1, unit i is selected; otherwise, unit i is not opted.

$$Min \left(\sum_{i \epsilon U} Cl_{ui} m_{ui} + \sum_{k \epsilon H} Cl_{hj} m_{hj} + \sum_{k \epsilon W} Cl_{wk} m_{wk} + A \times \left(\sum_{i \epsilon U} \left(CO_{ui,s} + PE_{ui,s}^{con} \right) + PE_{EENS} \right) \right) \quad (13)$$

$$A = \frac{[(1+q)^w - 1]}{q(1+q)^w} \quad (14)$$

where H, U and W are hydro, thermal and wind power plants, respectively. Cl_{ui}, Cl_{hj} and Cl_{wk}, are the investment cost of thermal unit of i, hydro unit of j, and wind unit of k, respectively and $CO_{ui,s}$, PE_{ui}^{con} and PE_{EENS} are respectively the operating costs, pollution fines and unsupplied energy of heating unit of i. q and w are also the interest rate and life of the power plant, respectively. In the BD method, the problem is divided into two parts: main and secondary, as explained below:

2.6. Secondary problem

The number of power plant units specified in the main problem is assumed to be constant in the secondary problem. Hence, in this problem, reliability is evaluated per specific unit. For this purpose, the scenarios of section 4 are taken into account in the secondary problem. The s represents the variables in the s scenario. According to Eq. (15), the objective function of the secondary problem includes the exploitation cost of the units, the pollution penalty fines and the unsupplied energy. Eq (16) guarantees the balance between the production and consumption. The operating cost of the units generally consists of two parts: variable and fixed. The variable cost is related to the cost of fuel and the fixed cost is related to the cost of repair and maintenance. The exploitation costs of the units and the pollution fines are represented according to Eqs. (17) and (18), with a first-order linear equation. Unsupplied energy is calculated according to unsupplied load based on Eq (19) and its fines are obtained based on Eq. (20). The production recovery time of P_g is calculated based on Eq. (21). Moreover, Equations 22 and 23 represent the minimum reservation capacity of water and heating units in order to provide the desired recovery time of production. As in Eq. (20), wind farms are not considered for reservation capacity. Eqs. (24) and (25) show the production limit of thermal and water units, respectively. The limitation of unsupplied load per scenario is represented in Eq (26).

$$SP = Min \left(\sum_{i \epsilon U} \left(CO_{ui,s} + PE_{ui,s}^{con} \right) + PE_{EENS} \right) \quad (15)$$

$$\sum_{i \epsilon U} P_{ui,s} + \sum_{k \epsilon W} m_{wk} P_{wk,s} + \sum_{j \epsilon H} P_{hj,s} + ls_s = P_{d,s} \quad (16)$$

$$CO_{ui,s} = a_{ui} \times P_{ui,s} + b_{ui} \quad , \forall s \in S, \forall i \in U \quad (17)$$

$$PE_{ui,s}^{con} = c_{ui} \times P_{ui,s} + d_{ui} \quad , \forall s \in S, \forall i \in U \quad (18)$$

$$EENS = \sum_{s \epsilon S} (ls_s \, T_s \, P_s) \quad (19)$$

$$PE_{EENS} = CE \times EENS \quad (20)$$

$$P_g / \left(\sum_{i \epsilon U} m_{ui} \, rr_{ui} + \sum_{j \epsilon H} m_{hj} \, rr_{hj} \right) < T_d \quad (21)$$

$$T_d rr_{ui} m_{ui} < \overline{P}_{ui} - P_{ui,s} \quad \forall i \in U, \forall s \in S \quad (22)$$

$$T_d rr_{hj} m_{hj} < \overline{P}_{hj} - P_{hi,s} \quad \forall i \in H, \forall s \in S \tag{23}$$

$$m_{ui} P_{ui,min} < P_{ui,s} < m_{ui} \overline{P}_{ui} \quad \forall i \in U, \forall s \in S \tag{24}$$

$$m_{hj} P_{hj,min} < P_{hj,s} \leq m_{hj} \overline{P}_{hj} \quad \forall i \in H, \forall s \in S \tag{25}$$

$$0 \leq ls_s \leq P_{d,s} \quad \forall s \in S \tag{26}$$

where SP is the answer to the minor problem. $P_{ui,s}$, $P_{wk,s}$ and $P_{hj,s}$ are the production of the thermal unit of i, wind unit of k and hydro unit of j, respectively, and $\overline{P}_{ui}$ and $\overline{P}_{hj}$are the nominal power of the thermal unit of i and hydro unit of j, respectively. Also, $P_{hj,min}$ is the minimum production of the thermal unit of i and hydro unit of j.

a_{ui} , b_{ui}, c_{ui} and d_{ui} are the variable and fixed costs of exploitation and pollution of the thermal power plant of i, respectively. ls_s is the unsupplied load, T_s is the time continuity of unsupplied load and P_s is the possibility of occurring the s scenario.

EENS is the mathematical expectation of unsupplied energy and CE is its fine coefficient. rr_{ui} and rr_{hj} are the rate of increase in production of the thermal unit of i and hydro unit of j. T_d is the production recovery time of Pg. $P_{d,s}$ is the amount of electric charge in the s scenario.

2.7. The main problem

According to Equation 27, the objective function of the main problem includes the investment cost of thermal, hydro and wind power plants. Equation 28 is the optimality of the feedback which is added to the main problem per repetition. In this equation, the unsupplied energy is obtained from Eq (19) in the secondary problem, and $\beta_{si}$and δ_{sk} are the Lagrange multiplier for Eqs (24) and (25). By applying the optimality of the feedback in Equation 28, the expected level of reliability is provided, together with communicating the main and secondary issues.

$$Min\left(\sum_{i\epsilon U} Cl_{ui} m_{ui} + \sum_{k\epsilon H} Cl_{hj} m_{hj} + \sum_{k\epsilon W} Cl_{wk} m_{wk}\right) \tag{27}$$

$$ENS + \sum_{s\epsilon S}(ls_s\, T_s\, P_s)\left(\begin{array}{c}\sum_{i\epsilon U}\beta_{si} \times (ls_s\, T_s\, P_s) \\ \times (m_{ui} - \widehat{m}_{ui}) + \sum_{j\epsilon H}\delta_{sj} \times (m_{hi} - \widehat{m}_{hi})\end{array}\right) < \alpha \tag{28}$$

where $\widehat{m}_h$ and $\widehat{m}_u$ are the number of water and thermal units in the previous repetition, respectively, and α shows the mathematical expectation of the unsupplied energy.

3. PSOGSA optimization algorithm

Suppose a system with n mass where the location of the i-th mass is as follows:

$$X_i = (x_i^1, x_i^2, x_i^3, \ldots, x_i^n) \tag{29}$$

In PSOGSA, the two methods of PSO and GSA do not work one after the other; rather, they work in parallel. The main idea of PSOGSA comes from combining the best position for particle aggregation (gbest) in the PSO algorithm with the local search capability of the GSA algorithm. The combination of these two methods is as the following equation:

$$\begin{aligned} V_i(t+1) = w \times V_i(t) + c_1' \times rand \times ac_i(t) \\ + c_2' \times rand \times \left(gbest - X_i(t)\right) \end{aligned} \tag{30}$$

where $V_i(t)$ is the velocity of the i factor in the t- th repetition, c_1' is the weight vector, W is the weight vector, rand is a random number between zero and one, $ac_i(t)$is the acceleration of i-th factor in the t- th repetition and gbest is the best possible answer. In each repetition, the position of the particles is updated as follows:

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{31}$$

In the PSOGSA algorithm, first, an initial population is created. Then, each factor is considered as a response candidate.

The total force applied by factor i to factor j at time t is calculated by the following Eq.(32):

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t) M_{aj}(t)}{R_{ij}(t) + \varepsilon}\left(x_j^d(t) - x_i^d(t)\right) \tag{32}$$

where $M_{aj}$is the active gravitational mass of the factor j andM_{pi} is the passive active gravitational mass of factor i. $G(t)$is gravitational constant at time t. ε is a small constant and the Euclidean distance is between i and j. It is calculated based on the following Eq.(33):

$$G(t) = G_0 \times exp(-\alpha \times iter/\max iter) \tag{33}$$

where α andG_0 are coefficient and the initial value, repetition counter and the maximum number of repetitions of the algorithm. The total force applied by a group of mass exerted to a factor is figured according to Newton's law as follows:

$$F_i^d(t) = \sum_{j\in Kbest\ j\neq i} rand_j F_{ij}^d \tag{34}$$

where $rand_j$is a random number between zero and one for the j-th factor. Based on the Newton's laws of mechanics, the acceleration of each factor is equal to:

$$ac_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \tag{35}$$

where $M_{ii}$is the mass of i.

The best answer is updated in each repetition.

Afterwards, the velocity of all factors is calculated according to Equation 30.

In the PSOGSA algorithm, the propriety is involved in the process of updating the velocity and location of the factors. Factors close to better answers try to attract other factors. This improves and expands the searching space. When all the factors approach an optimal answer, their velocity is reduced. In this case, each factor, which has seen the best factor so far, is attracted to it and, finally, moves to the optimal answer.

4. Results of simulation

In this section, the proposed method is implemented for the IEEE 24-busbar network. It is assumed that each power plant has 5 units and the specifications of different types of power plant units are given in Table 4

Table 4. Specifications and characteristics of types of power plant units

Type of power plant	Change of production rate ((MW / min	Exploitation cost (USD/MWh)	Investment cost (thousand USD/ MW)	Pollution cost (USD/ MWh)
Heating	6	20	980	13
gas	12	25	900	10
Combined cycle	12	15	1140	11
wind	–	0	1600	0
hydro	100	0	2000	.
Photovoltaic	–	0	1400	0

4.1. Comparing the implementation and number of scenarios for the Monte Carlo method and the proposed new method

One of the important advantages of the proposed method is the high speed of implementation, when facing with practical and large issues. If the problem equations are solved by creating a scenario in the usual Monte Carlo method, the implementation time and number of scenarios will increase remarkably. Concerning the large aspects of practical problems, using Monte Carlo method in evaluating reliability in the presence of variables with uncertainty is time consuming and, hence, the suggested method offers a great advantage.

4.2. Determining new power plants without considering hydro, wind and solar units

In this section, wind and hydro power plants are not taken into account and the limitation of unsupplied energy is assumed to be 700 MWh per year. Accordingly, new power plant lines and units are obtained based on Table 6. It can be seen that since the exploitation cost of combined cycle power plants is lower than gas and heating power plants, more capacity is obtained from combined cycle power plants. Indeed, the limitation of reliability greatly influences the choice of units. The larger the number of units, the more is lost the producing capacity and, consequently, reliability indicators such as unsupplied energy are enhanced.

4.3. Taking the wind power plant into account

In this section, based on Table 5, two candidate wind power plants are considered. The wind is indicated in the candidate areas. It can be seen that wind speed is an important factor in determining the optimal direction of wind power plants. As the wind speed increases, the participation of wind power plants will increase remarkably. Fig 1 represents the total cost of developing the production system and the cost of pollution for various amounts of optimal participation of wind power plant. As the optimal participation of wind power plants increases, the total cost and the amount of environmental pollution are reduced. Hence, in areas where the wind speed is high, the construction of large wind farms seems necessary since it reduces the cost of the entire system, as well as pollution.

Table 5. Specifications and characteristics of candidate wind power plants

Number of busbar	Capacity of candidate power plant (MW)	Average wind speed (m/s)	Standard deviation of wind speed (m/s)

16	1250	9/5	3/2
18	1250	8/5	2/5

Table 6. New power plants without wind, hydro and solar units

Number of busbar	Type of power plant	Capacity of candidate (MW)	Selected capacity (MW)	Total cost (million dollars)
1	steam	576	0	0
2	steam	576	576	1/816/473/600
7	steam	900	900	2/838/240/000
13	Cycle	1773	1180	4/174/556/800
15	Gas	645	0	0
16	Gas	465	0	0
18	cycle	1200	800	2/830/208/000
21	cycle	1200	1200	2/901/312/000
22	steam	900	900	2/838/240/000
22	cycle	2000	1000	3/537/760/000

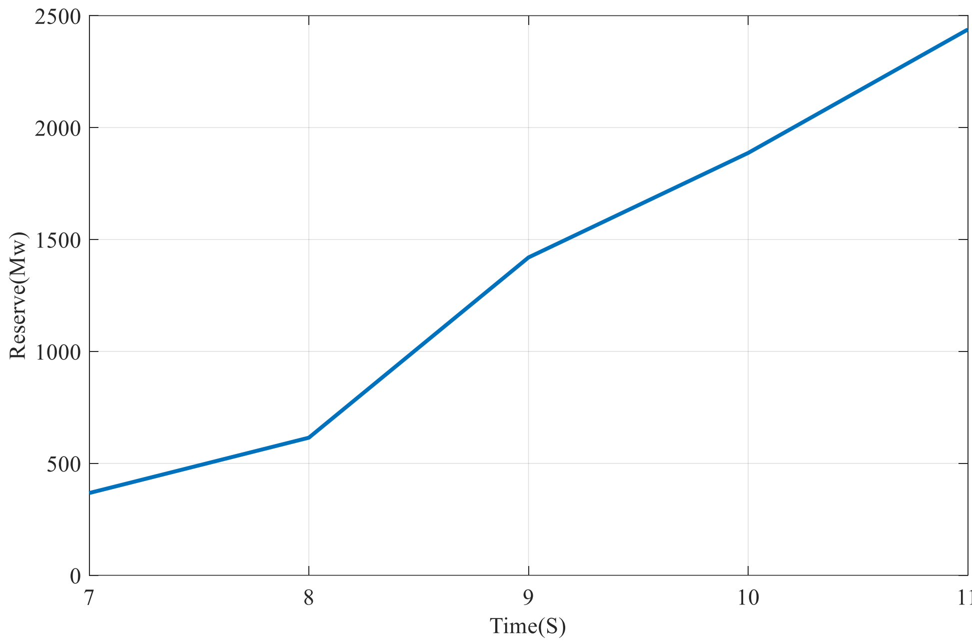

Fig. 1. Optimal capacity of wind power plants at different wind speeds

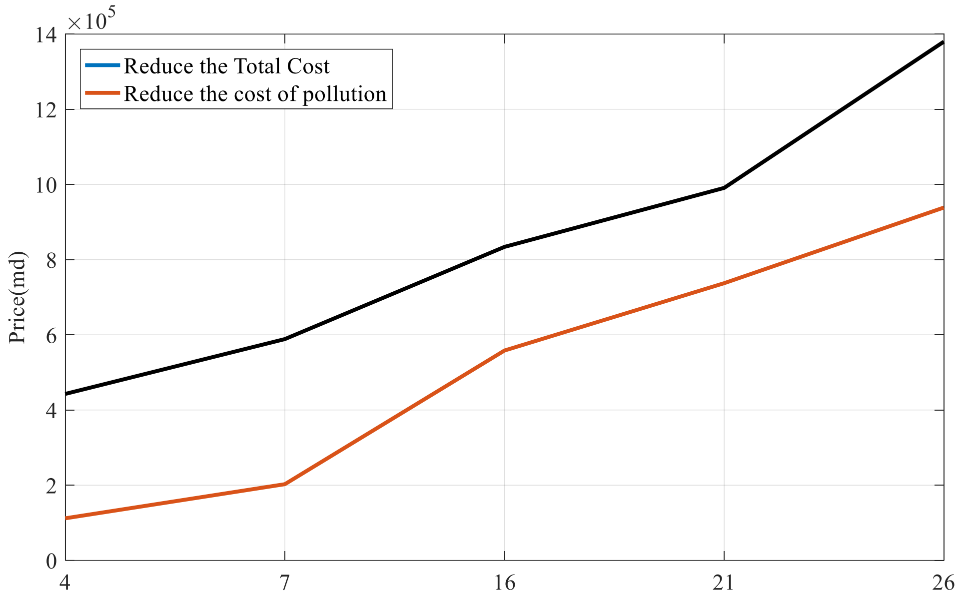

Fig. 2. Reducing the total cost of developing the production system and pollution with the participation of wind power plants.

4.4. Considering hydropower plants

In this section, in addition to wind power plants, a 2000 MW candidate hydropower plant with the standard deviation of 3.2 m3 / s for water flow is considered at busbar 6. Production output is assumed to be 10% of the total load and production recovery time is assumed to be 2 min. For different values of average water flow, the optimal capacity of different power plants is shown in Fig. 3. To perform better evaluation, the capacity of power plants is represented as a percentage of candidate capacity.

As the average water flow increases, the optimal capacity of hydropower plants enhances significantly and, for large amounts of average water flow, the participation of hydropower plants is even higher than thermal power plants.

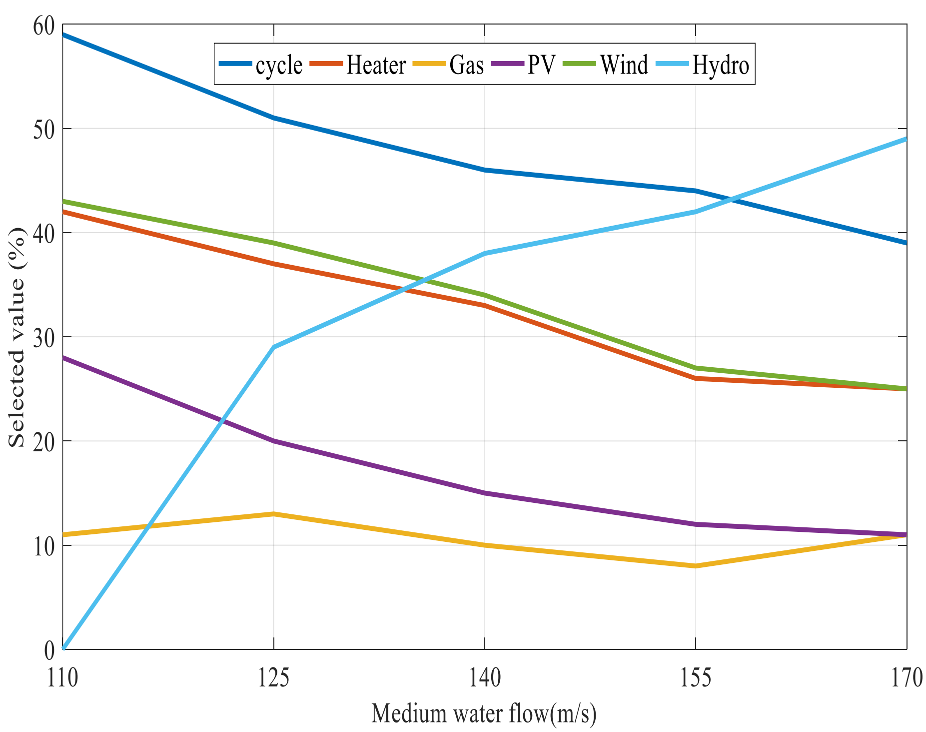

Fig. 3. Optimal capacity of power plants for different amounts of average water flow

4.5. Impact of reliability level

As the level of reliability decreases, the need for reservation power also decreases. On the other hand, owing to the uncertainty of hydro and wind power plants, the participation of these power plants enhances with decreasing level of reliability. Fig 4 represents the optimal power of power plants for diverse levels of reliability. In this regard, the optimum capacity of wind and hydro power plants increases, but the capacity of other power plants decreases.

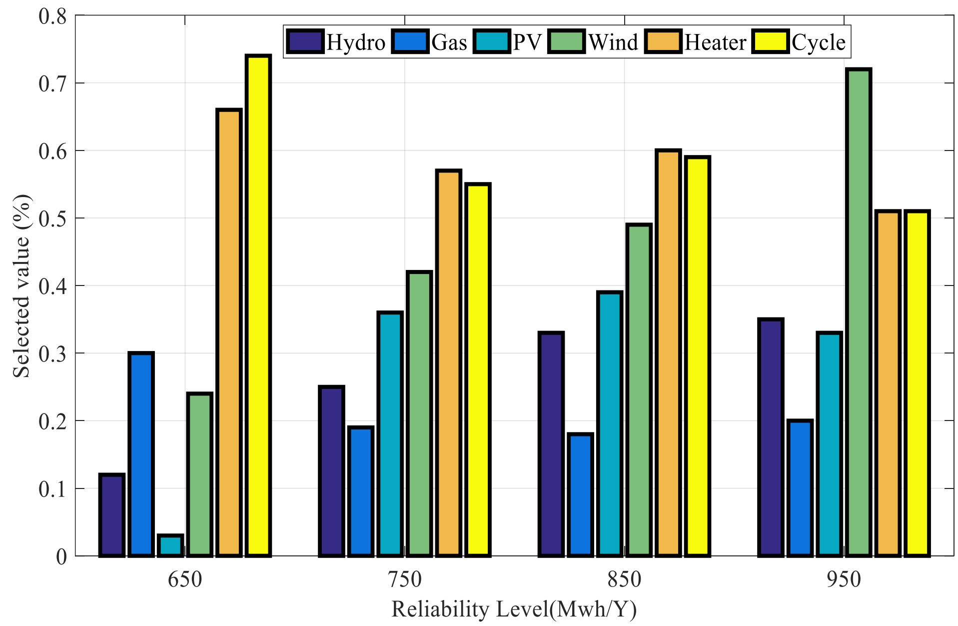

Fig. 4. Optimal power of power plants for diverse levels of reliability

4.6. Reservation power and various types of power plants at peak loads

In this section, the impact of the expected production recovery time on the optimal capacity of power plants is assessed. Figure 4 shows the optimal capacity of power plants for different amounts of production recovery time. The optimal capacity of heating power plants, which have a slower response, is reduced. In case the rapid production recovery is desirable, more capacity of hydropower, gas and combined cycle power plants is required and, generally speaking, there is greater need for more production capacity.

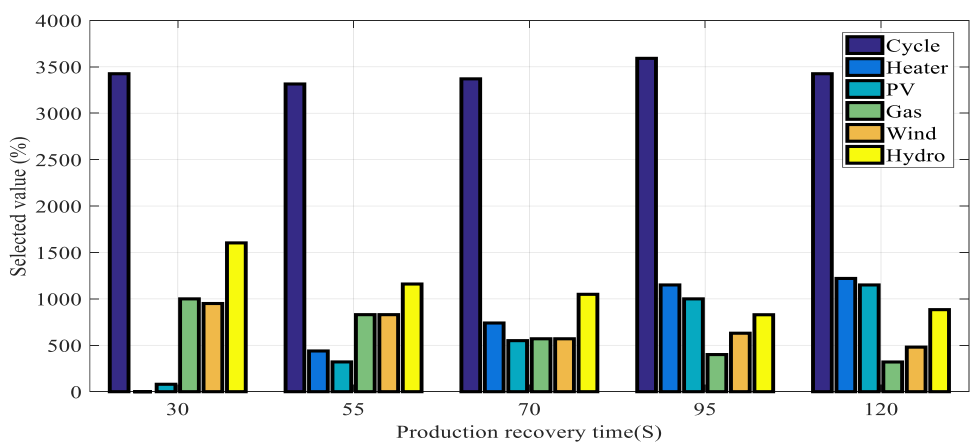

Fig. 5. Optimal capacity of power plants for different values of production recovery time in the production system planning

In the present article, the optimal reservation power of units is obtained at the pick load. Accordingly, it is specified which power plants are considered so as to provide reservation power. Figure 6 shows the optimal reservation power of power plants at peak load for different production recovery times.

5. Conclusions

In the present study, a new method is introduced for planning the production system by considering wind, hydro and solar power plants with load management. The outcomes of the proposed multilevel model demonstrate that, as the reliability level decreases, the optimal capacity of wind and hydro power plants will increase and the optimal capacity of other power plants will decrease. It is observed that increasing the average wind speed and average water flow will remarkably increase the optimal capacity of wind and hydropower plants. Moreover, determining the optimal capacity of wind and hydropower plants is of great importance and reduces the total cost and environmental pollution. The proposed method is implemented for IEEE 24 busbar network. In order to solve the multi-purpose objective function, combined PSOGSA optimization algorithm, including the PSO particle swarm optimization algorithm and the GSA gravitational search optimization algorithm, is used for optimization.

REFERENCES

[1] M. Lu, O. Abedinia, M. Bagheri, N. Ghadimi, M. Shafie-khah, and J. P. S. Catalão, “Smart load scheduling strategy utilising optimal charging of electric vehicles in power grids based on an optimisation algorithm,” *IET Smart Grid*, vol. 3, no. 6, pp. 914–923, 2020.

[2] O. Abedinia, M. Lu, and M. Bagheri, “An improved multicriteria optimization method for solving the electric vehicles planning issue in smart grids via green energy sources,” *IEEE Access*, vol. 8, pp. 3465–3481, 2019.

[3] O. Abedinia, M. Lotfi, M. Bagheri, B. Sobhani, M. Shafie-Khah, and J. P. S. Catalão, “Improved EMD-based complex prediction model for wind power forecasting,” *IEEE Trans Sustain Energy*, vol. 11, no. 4, pp. 2790–2802, 2020.

[4] V. Nurmanova, M. Bagheri, O. Abedinia, B. Sobhani, N. Ghadimi, and M. S. Naderi, “A synthetic forecast engine for wind power prediction,” in *2018 7th international conference on renewable energy research and applications (ICRERA)*, 2018, pp. 732–737.

[5] O. Abedinia, A. Ghasemi-Marzbali, V. Nurmanova, and M. Bagheri, “Optimal Strategy for Bidding in Deregulated-Structure of Electricity Market: A Competitive Model,” in *2021 IEEE International Conference on Environment and Electrical Engineering and 2021 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*, 2021, pp. 1–5.

[6] C. E. Paes, D. A. Gandelman, H. T. Firmo, and L. Bahiense, “The power generation expansion planning in Brazil: Considering the impact of greenhouse gas emissions in an Investment Decision Model,” *Renew Energy*, vol. 184, pp. 225–238, 2022.

[7] H. Ebrahimi, A. Yazdaninejadi, and S. Golshannavaz, “Demand response programs in power systems with energy storage system-coordinated wind energy sources: A security-constrained problem,” *J Clean Prod*, vol. 335, p. 130342, 2022.

[8] M. NAJAR and H. FALAGHI, “Reliability Based Stochastic Generation Expansion Planning With Wind and Hydro Units”.

[9] L. M. Putranto, F. D. Wijaya, A. Priyanto, and I. Savitri, “Generation Expansion Planning Based on Local Renewable Energy Resources: A Case Study of the Isolated Ambon-Seram Power System,” *Sustainability*, vol. 14, no. 5, p. 3032, 2022.

[10] A. F. Abdin, A. Caunhye, E. Zio, and M.-A. Cardin, “Optimizing generation expansion planning with operational uncertainty: A multistage adaptive robust approach,” *Appl Energy*, vol. 306, p. 118032, 2022.

[11] Q. Wang, X. Luo, H. Ma, and N. Gong, “Multi-stage stochastic wind-thermal generation expansion planning with probabilistic reliability criteria,” *IET Generation, Transmission & Distribution*, vol. 16, no. 3, pp. 517–534, 2022.

[12] A. Davoodi, A. R. Abbasi, and S. Nejatian, “Multi-objective techno-economic generation expansion planning to increase the penetration of distributed generation resources based on demand response algorithms,” *International Journal of Electrical Power & Energy Systems*, vol. 138, p. 107923, 2022.

[13] M. Toloo, M. Taghizadeh-Yazdi, and A. Mohammadi-Balani, “Multi-objective centralization-decentralization trade-off analysis for multi-source renewable electricity generation expansion planning: A case study of Iran,” *Comput Ind Eng*, vol. 164, p. 107870, 2022.

[14] A. S. Dagoumas and N. E. Koltsaklis, “Review of models for integrating renewable energy in the generation expansion planning,” *Appl Energy*, vol. 242, pp. 1573–1587, 2019.

[15] A. Hasankhani and S. M. Hakimi, “Stochastic energy management of smart microgrid with intermittent renewable energy resources in electricity market,” *Energy*, vol. 219, p. 119668, 2021.

[16] M. Dabbaghjamanesh, A. Kavousi-Fard, S. Mehraeen, J. Zhang, and Z. Y. Dong, “Sensitivity analysis of renewable energy integration on stochastic energy management of automated reconfigurable hybrid AC–DC microgrid

considering DLR security constraint," *IEEE Trans Industr Inform*, vol. 16, no. 1, pp. 120–131, 2019.
[17] P. Firouzmakan, R.-A. Hooshmand, M. Bornapour, and A. Khodabakhshian, "A comprehensive stochastic energy management system of micro-CHP units, renewable energy sources and storage systems in microgrids considering demand response programs," *Renewable and sustainable energy reviews*, vol. 108, pp. 355–368, 2019.
[18] E. Shahrabi, S. M. Hakimi, A. Hasankhani, G. Derakhshan, and B. Abdi, "Developing optimal energy management of energy hub in the presence of stochastic renewable energy resources," *Sustainable Energy, Grids and Networks*, vol. 26, p. 100428, 2021.
[19] R. Karki, "Wind power in power generation planning," in *Canadian Conference on Electrical and Computer Engineering 2004 (IEEE Cat. No. 04CH37513)*, 2004, vol. 3, pp. 1511–1514.
[20] S. Kennedy, "Wind power planning: assessing long-term costs and benefits," *Energy Policy*, vol. 33, no. 13, pp. 1661–1675, 2005.
[21] S. Mirjalili and S. Z. M. Hashim, "A new hybrid PSOGSA algorithm for function optimization," in *2010 international conference on computer and information application*, 2010, pp. 374–377.
[22] P. M. Subcommittee, "IEEE reliability test system," *IEEE Transactions on power apparatus and systems*, no. 6, pp. 2047–2054, 1979.