Master Thesis

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Daily cost optimization in a utility network with renewable energy sources and energy storage

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Abstract

The growing consequentiality of the role of renewable energy sources alongside energy storage devices in the potency and power market in this sector has magnetized the attention of many researchers in this field. The technical potentials indicate the ability to utilize renewable energy resources and energy storage equipment in the network. In order to increase the utilization of these resources in the network, it should be examined from an economic perspective. Therefore, in this master thesis, it has been tried to optimize the effect of using these systems on minimizing the daily cost of electric power generation in the electricity grid. After the technical and economic introduction of the equipment used in the network, the economic and technical model of the network is specified. The goal is to calculate the minimum cost of daily electrical energy production, along with using all the technical and security constraints of the network. The result of the optimization calculations is the amount of power produced by the power plants, the time schedule of operating the storage system during the day and the lowest production cost. The technical and economic model in addition to the optimization algorithm based on the particle swarm optimization is implemented in the MatLab software environment. A standard IEEE network is used to model the data. Simulation results demonstrate the high potential of the storage system to reduce costs and increase the operating efficiency of the network so that the use of a central storage system in the proper bus of the network can reduce the cost of energy production by up to 3%. Also, the use of these new systems at the appropriate capacity can delay network upgrades to 16 years in provided the increasing the demand (equivalent to 2% per annum).

Sammanfattning

Det allt viktigare samspelet mellan förnybara energikällor och energilagringsenheter inom kraftsektorn har attraherat många forskares uppmärksamhet på detta område. Vad gäller den tekniska potentialen finns goda möjligheten att utnyttja förnyelsebara energiresurser och energilagringsutrustning i nätet. För att öka utnyttjandet av dessa resurser i nätet bör en analys ur ett ekonomiskt perspektiv göras. Denna masteruppsats har därför försökt optimera effekten av att använda dessa system för att minimera den dagliga kostnaden för elproduktion i elnätet. Efter den tekniska och ekonomiska introduktionen av den utrustning som används i nätet, specificeras den ekonomiska och tekniska modellen för nätet. Målet är att beräkna minimikostnaden för daglig elproduktion med hänsyn till alla tekniska och säkerhetsmässiga villkor som finns på nätet. Resultatet av optimeringsberäkningarna är mängden producerad energi i kraftverken, tidsplaneringen för driften av lagringssystemet under dagen, och den lägsta produktionskostnaden. Den tekniska och ekonomiska modellen, såväl som optimeringsalgoritmen baserad på particle swarm optimization implementeras i MatLab. Ett standard IEEE-nät används för att modellera data. Simuleringsresultaten visar lagringssystemets höga potential att minska kostnaderna och öka drifteffektiviteten, och att användningen av ett centralt lagringssystem, om det placeras i rätt buss i nätet, kan minska kostnaden för energiproduktion med upp till 3%. Dessutom kan användningen av dessa nya system, med lämplig kapacitet, skjuta fram nätuppgraderingar med upp till 16 år, förutsatt en ökande efterfrågan (motsvarande 2% per år).

Acknowledgment

I am using this opportunity to express my gratitude to everyone who supported me throughout the course of this Renewable energy systems project. I am thankful for their aspiring guidance, invaluably constructive criticism and friendly advice during the project work. I am sincerely grateful to them for sharing their truthful and illuminating views on a number of issues related to the project.

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Table of Contents

List of Figures

Content of Table:

1. Introduction

1.1. Background

Many countries in the world have introduced plans aimed at reducing pollutant emissions by plants and increasing the use of renewable energy sources. Among all the renewable energy sources, wind is recognized as the major options for widespread use in the near future [1]. The generated energy by the wind has advantages such as non-polluting emissions, low initial costs and short run times, but nevertheless due to the fluctuating nature of the wind which can influence the resulting energy, this fact can affect security and sustainability. Injecting a large amount of electrical energy from the wind can create new challenges, reduce the controllability of the network; and even allow the network to withdraw the economic efficiency [2] [3] [4] [5] [6] [7]. The network collapse occurs as a result of reducing the boundary of network stability. In addition, the wind is uncontrollable and the uncontrolled energy injection into the network requires the consideration of compensators in the network, which can affect the economy and the quality of the network.

One of the practical ways to control the uncontrollable electricity production by fluctuating wind, is to use energy storage devices in the network. If a high-capacity storage device (a few tens of megawatts) is profitable, it can convert the produced electricity into a controllable energy like other existing power plants. This cooperation of the storage device and renewable resources can provide a widespread use of these resources. Recently, simultaneous use of storage and energy sources has been proposed as a solution to the economic and technical benefits of the network [8]. For example, in order to reduce the energy fluctuation of an individual unit, the power output of this plant is controlled and uniformly by a chemical-based storage device [9].

By the development of the wind power plant, the high unstable energy is main problem of wind power plant . In normal conditions, power plants is experiencing the challenge of adjusting their production with oscillating consumption. This difficulty will get worse with the addition of uncontrolled producers [10].

1.2. Motivation

In addition to the negative effects of the use of renewable resources on network security and sustainability, there are several factors includes the stimulate the increased use of these resources.

In order to consume the high level of renewable resources, the use of energy storage devices is essential. So, the installation and operation of these devices will require additional investment, which requires the study and evaluation of the exact potential of the economy.

In this master thesis, by introducing the various scenarios, it has been attempted to create a realistic and accurate view of the effects of the use of renewable energy sources and storage systems on the network. This is achieved by analyzing the cost of daily energy production in different scenarios and comparing them in both with or without using energy storage systems.

1.3. Targets

The most important goals of this master thesis are as follows:

- Calculating the cost of generating electrical energy required during a day in an electricity grid, which uses renewable energy sources and energy storage systems, and compares them with the cost of production in the same network under the same conditions but without the use of renewable and storage resources. This issue contains the following subcategories:
  - Determine the best place to install the energy storage system on the network
  - Determining the best process for exploiting network resources, including a system for storing energy in the network with the goal of reducing production costs
- The effect of using the energy storage system on the network exploitation point at different times of the day
- Evaluating the effect of using the energy storage system on latency during network upgrade

1.4. Innovations

The most important things that have been done for the first time in this research are mentioned as follows:

- Introducing a new algorithm for optimizing and dividing loads between production units in order to reduce the cost of energy production over a period of time in the presence of renewable energy sources and energy storage device
- Provide a practical approach to increase the power injection capability from renewable energy sources to the network
- Exact investigation and calculation of network upgrade issues and the use of the storage device in this area

2. Power electricity network overview

2.1. Introduction

Due to increasing concerns about the production of energy from fossil fuels source, attention to the utilizing of renewable energy sources for the world's energy production is experiencing rapid development. In addition, according to increasing demand for electrical energy and specific limits on fossil fuels to produce power, renewable resources had an increasing impact on the increase of attention and the use of.

World Energy Council evaluates that global wind energy production will be 474000 megawatts by 2020 [13]. Different countries around the world have set variety of policies aimed at increasing the use of renewable resources. The most considerable development has been done in the wind power converter design. Today, wind turbines are very sophisticated machines built according to the strict aerodynamic rules, using the latest developments in aerospace, electronics and materials industries to extract energy from a wide range of wind speeds. The wind power features are listed below.

2.2. Power generation from the wind

2.2.1. Wind power curve

Wind power curve is an important item of every wind turbine. This curve shows the relationship between wind velocity and electric power produced by wind turbines [19].

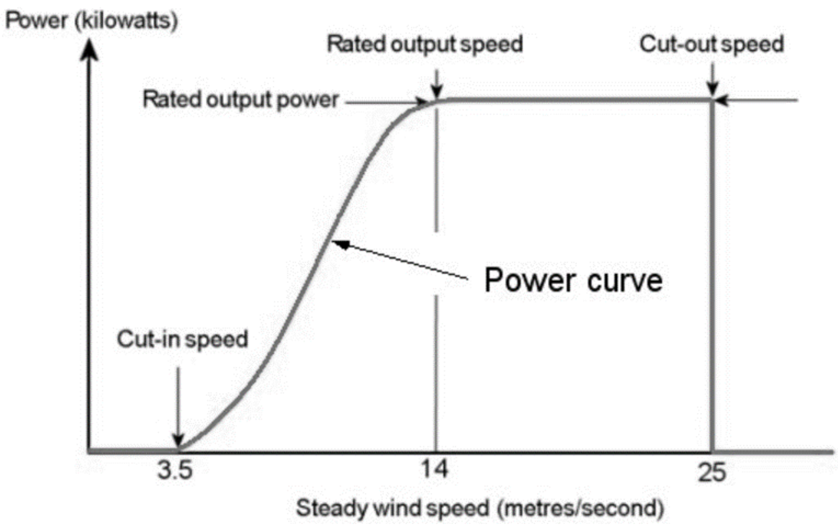


Figure 1: Wind turbine power curve

2.2.1.1. Load Factor

In general, two goals should be considered in the design of wind turbine. The first goal is to reach the highest level of the average turbine output power. The second objective is to meet the necessity of load factor[20]. Generally, it can be assumed that the required load factor should be between 25% and 30%.

2.2.1.2. Seasonal and daily variations of power

It is evident that different seasons and even different hours will have an effect on wind speed and energy. The amount of daily change can be reduced by increasing the height of the turbine installation site As an example, the average wind power in the early hours of the morning is 80% of the annual average wind power in the same region. On the other hand, in the late afternoon, the average wind power increases by 120% of the average annual power [21].

2.2.1.3. Wind Statistics

One of the most commonly used methods to identify variation in wind energy, is to use a time-power curve or a time-wind speed [22]. In this curve, the time takes to generate any amount of power (or any possible velocity of wind) over a given time period can be expected for all possible forces (speeds). This chart can be presented discretely or continuously. An example of this curve is shown in Figure 2 [23]. Weibull distribution is another method to describe wind energy statistically [24].

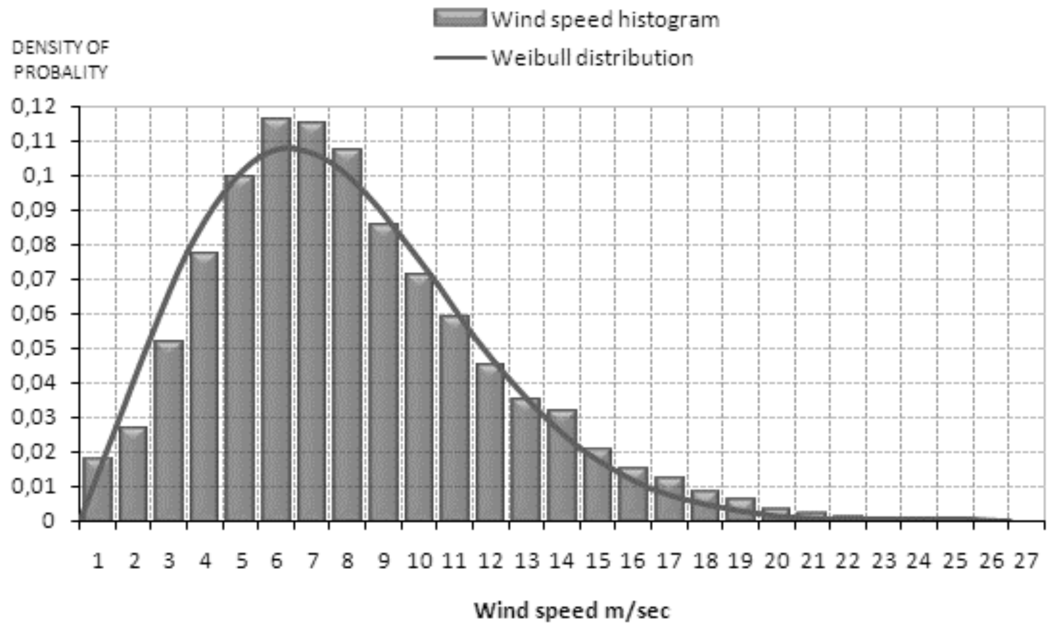


Figure 2: Chart (curve) a kind of time-wind speed

2.3. Energy storage system

The energy storage devices is one of beneficial solution to decrease wind farm problem. Today, pump-water units is the prominent form of energy storage in the utility network. This method, although having sufficient advantages such as scalability and efficiency, suffers from the limitations of a large hydroelectric power plant, which requires extensive water resources and geographical constraints.

2.3.1. Battery as an energy storage system in the network

There are a number of concerns about the use of batteries in the power grid as an energy storage device, which has tried to mention some of the most important issues in this thesis. An attempt has been made to examine all the influential issues from the perspective of the economy, including investment and income, so an accurate view on the investment in this sector can be given.
Different batteries constructed on their physical and chemical materials can have varying electrical characteristics in the network. The factors which should be considered economically will be introduced the following.

2.3.1.1. Efficiency

The word of efficiency in battery is the ratio of produced energy by the storage system the energy consumed to charge the storage. In the other word, this feature indicates the amount of energy and power losses in the storage system, so, it is desirable that this efficiency be higher to prevent energy loss. The batteries are generally high in efficiency and vary between the 70-95% for a full cycle charge and discharge cycle, which is affected by the technology used.

2.3.1.2. Useful lifetime

The lifetime of an electrochemical storage device is the number of charging and discharging cycles of the storage, so that its effective capacity does not go more than specified limits. For calculating the useful lifetime , generally, it is necessary to use 85% of energy. Batteries save energy through chemical reactions. So, the number of full charge and discharge cycles, which reduces the energy storage capacity to 85% of the initial value (the amount designed for the new battery), is considered as the number of battery life cycles and storage system.

2.3.1.3. Cost

The cost to produce each unit of energy from the energy storage system is considered as battery cost. Generally, for calculations, it is important to use costs per unit of energy.

2.3.1.4. Minimum charge possible

At each specific time, the amount of battery charge is referred to as the saved energy in the battery relative to the total energy that can be stored in the battery. As an example, as the nominal capacity for a particular battery is 100 units of energy and 60 units is the current saved energy. In some batteries, such as lead-acid batteries, if this charge is reduced from a certain number, it can lead to irreversible reactions and undesirable effects on the health and useful life of the battery. Therefore, for each battery and energy storage system, a minimum charge level should be considered, which is referred to as the least chargeable feature. These features are exemplified for several preferred battery types in Table 1 [34].

Table 1: Compare common battery features with power usage

Type	Min Charge(%)	Efficiency(%)	Cycles	Cost($/kWh)
Pb-Acid	30	75	1500	135
Ni-Cd	0	75	3000	540
Na-S	0.15	89	2500/4500	500
Li-Ion	20	70	10000	915

Based on the need of this thesis, high power over a long time, the model chosen for this research is sodium-sulfur battery. This battery is based on the positive and negative electrodes which made of sodium and sulfur in the molten state. The aluminum ceramic electrolyte is in solid state [35]. The lifetime of this battery depends on the number of daily cycles and type of use, but the design data illustrates a 15-year life span. The minimum charge for this battery is between 0 and 15 percent. If this minimum charge for battery is zero, then the useful life is 2500 cycles, and if the minimum charge is 15 percent, then the battery life will be 4500 Charging and discharging cycle. In addition, the efficiency of these batteries for a full cycle of charging and discharging is between 89% and 92%, which places them in the category of high-efficiency storage class. This technology puts this technology beyond any other battery application, and its only competitor is the Ambri battery, which is still at the development stage [36]. An example of a 1,008-kVA NaS-based system with a 7200kW-hour power consumption in the United States is the first storage system based on this megawatt battery outside of Japan [37].

3. Combined power grid and free model optimization method

In this chapter, the combined power grid is a power grid, in which, in addition to conventional power plants and devices, a wind power plant and a central energy storage unit are used.

3.1. Network Economic Modeling

The purpose of this thesis is to investigate the impact of the use of renewable resources and energy storage system in the network on the cost of daily energy production. Therefore, providing an economic model that explains the financial and economic characteristics of different components of the network during the exploitation process is necessary in this section.

3.1.1. Power plants

So far, several models have been suggested to verify the cost of production in thermal power plants. The model used in most studies is determined and approached according to the cost curve of a thermal generator shown in Fig. 5. This curve includes four main factors in cost of production, including fuel cost, input / output, heat rate, and plant's incremental costs. [46]

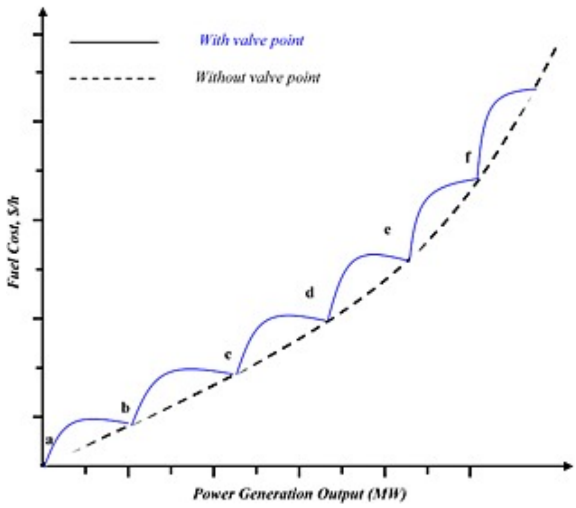


Figure 3: Typical cost curve for thermal generator

The cost curve is represented by a quadratic function. Using quadratic approximation is of prime importance and, with sufficient accuracy, maintains the volume of computation to a reasonably low level. Therefore, the following equation is used to calculate the cost of generating energy in non-renewable units.

$$C_i(P_{Gi}) = a + b\,P_{Gi} + cP_{Gi}^2 \qquad 1$$

Where i represents the number of producers in the network, C_i represents the cost of unit i, P_{Gi} represents the electric power generated in the unit i, the coefficients a, b and c coefficients of the cost of production unit i is for each plant constant And is different from other power plants.

The quadratic charge function is in fact itself an approximation of the fuel consumption function of the power plant, and as the actual behavior approaches a completely nonlinear thermal generator.

3.1.2. Wind farm

The wind farm consists of wind turbines, which are themselves generators. Because these generators do not use fuels and their main source of energy is free from winds, they cannot be used for the cost of the thermal power plants introduced in the previous section, but they can be rewritten by making changes to the quadratic relationship. The same applies to the cost of generating energy from a renewable air unit.

The following method has been used to calculate the cost of generating a unit of energy or power from a wind generator:

- Determine the initial capital required to build a wind farm. This cost is available through wind turbine manufacturers or financial reports from the energy organizations of different countries. (E.g. US Energy Report).
- Determine the useful life of the equipment. For each kind of equipment used in the construction of a wind farm, a useful lifetime is provided, which depends on the technology used to construct it for equipping a different amount for different units. The useful life of the equipment is generally expressed either in hours during operation or per unit of energy.
- Determine operating and maintenance costs. As mentioned in the second chapter, the cost of maintaining fields and wind turbines is much lower than other producers due to the lack of cost of fuel and the need for repairs, and for that the 2% of the initial capital is used for each year of operation opinions have been asked.
- Considering the effect of inflation during exploitation

By specifying all the steps outlined above, the goal is to determine the cost of the production of an electric energy unit. The US Energy Agency annually issues a report that calculates and publishes the cost based on the latest technology and equipment prices, and considering different inflation rates as different scenarios. According to the latest report by the organization, this amount is forecast for wind turbines and wind farms at an annual rate of 2 percent, equivalent to $ 50 per megawatt hour of electrical energy, for the current year. For comparison, this number is set at $ 80 to $ 130 per megawatt for a solar power plant, which represents a much lower cost in producing wind energy compared to the sun.

3.1.3. Energy storage system

A central energy storage system can also be considered as an energy producer and as an energy consumer. During the time the storage system appears as an energy consumer, the energy consumed is stored in the battery, taking into account the technology used, where the NaS battery is assumed to be 90%. Then the stored energy is drained out of the battery and injected into the network. Therefore, for the energy storage system, two terms should be considered for the cost function:

- When charging a storage device, the cost is equal to the cost of purchasing electrical energy from the power grid. This value is in the numerical market of the market determined by the free market or fixed rate and determined by the legislator. In this study, the cost of a unit of energy at any given time is considered to be the total production cost at that time in all units of the power plant divided by the total energy produced.
- At the time of discharging the storage, the cost is considered to be for a production unit, such as a wind power source. In this case, all steps required to calculate the cost of generating a unit of energy by wind should also be calculated for the energy saver. Considering the initial capital, useful life of the equipment, inflation and utilization, this cost is calculated at 40 dollars per megawatt-hour.

3.1.4. Other network devices

Other equipment and equipment on the net are considered without direct payment. For example, transmission lines will not directly charge operating costs, but they will indirectly affect the distribution of energy and network losses by the final number that will affect the total cost of generating and distributing daily energy.

3.2. Optimization methods

From the point of view of control engineering, the issue of this thesis is an efficient and fast algorithm for solving the proposed optimization problem.

In the previous section, a quadratic approximation has been used to determine the cost of generating energy in each network generator. Therefore, the final cost function, which is the sum of the cost of all active generators in the network during the day, is also a second-order function. The goal is to determine the production level of each power plant, renewable energy and energy storage system overnight and in the intervals of one hour, so that the total cost is the lowest. In recent studies, various methods have been proposed to solve this problem, which involves solving linear and nonlinear methods [50] [51] [52].

Using a quick and reliable linear method. In this method, the cost curve of the production of power plants, shown in Figure 3, is approximated by small linear functions and behind it. Therefore, the cost of this speed and reliability in the calculations is to obtain an estimate of the answer to the problem, which is not necessary [53]. On the other hand, the use of nonlinear methods has a high complexity, and the possibility of a convergence problem will be unique [54].

Recently, innovative and ultra-innovative algorithms have been considered, and in similar projects performed in different ways, these algorithms have been remarkably superior. For example, the evolutionary programming in [51], the simulated annealing algorithm in [52], the tabu search algorithm in [53], the genetic algorithm in [55] [56] and the particle swarm optimization [57] have been investigated.

Evolutionary programs can be a very powerful way of solving this problem, but the review shown in [59] shows that these algorithms lose their convergence speed near the optimal answer, and the algorithm works very slowly in reaching the final result. Both SA and TS algorithms can be powerful in solving complex problems, but SA is very slow and timely on the issue involved, and it is not possible to set up controller parameters very easily. TS, due to the difficulty of allocating memory and due to the high number of decision variables in the problem, cannot be adequately addressed. Although genetic algorithms and particle aggregation also have disadvantages in the desired problem, but the high speed of convergence to the final response and the possibility of personalization in order to prevent trapping in local responses are considered as the main constituents of optimization problem solving.

Particle swarm optimization

Particle aggregation algorithm is a comprehensive search technique introduced by two researchers, Kennedy and Eberhart [60]. This algorithm is, in fact, a simulation of social evolutionary knowledge, which aims to investigate the population in order to obtain possible answers to the problem. Compared with other evolutionary algorithms, this algorithm has faster computing and higher accuracy [61]. In short, the particle swarm optimization can be considered as a balanced mechanism that has been able to balance the flexibility and capability of local and comprehensive responses, which has also been able to use many applications in power grid discussions [62]. This algorithm has been experimented with multiple names such as Clark's to help locate local responses and improve the search terms of several personalization and optimizations. The particle swarm optimization is based on observing the behavior of birds in their herd and group [61]. In the original algorithm, each particle, representing a bird, as well as a possible answer to the optimization problem, has a position vector and a velocity vector. For an optimization problem with n decision variables, these vectors are as follows:

$$\begin{cases} x_j(t) = [\, x_{j,1}(t), x_{j,2}(t), \dots, x_{j,n}(t)] \\ v_j(t) = [\, v_{j,1}(t), v_{j,2}(t), \dots, v_{j,n}(t)] \end{cases} \tag{2}$$

The central idea behind the PSO's classic algorithm is to transfer information between the best comprehensive response, the best current response between the population and the current population, which can be expressed as follows:

$$x_j(t+1) = x_j(t) + v_j(t+1) \tag{3}$$

$$v_j(t+1) = \omega . v_j(t) + \varphi . r_1 . \left[p_{pb}(t) - x_j(t)\right] + \eta . r_2 . \left[P_{gb}\,(t) - x_j(t)\right] \tag{4}$$

Where

φ And η are the algorithm parameters

r_1 and r_2 are random values between zero and one

ω coefficient of inertia

P_{pb} best local solution

P_{gb} best global solution
V_j speed vector

A flowchart illustrating some of the calculations in the particle accumulation algorithm is shown in Figure 4 [60].

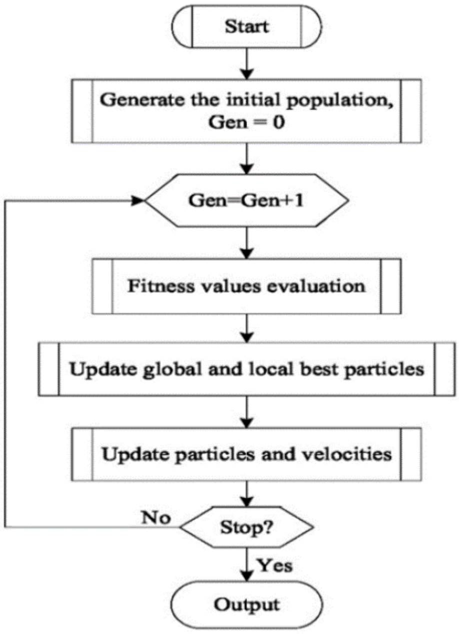


Figure 4: Flowchart of particle swarm optimization

The particle swarm optimization has the proper speed and the need for the length of each variable is less than the other. In summary, the benefits that came with this algorithm here are: simple instructions and rules, easy implementation, high speed computing, and high-power searching for a comprehensive response. The comparison of the performance of the three selected algorithms is shown in Table 2.

Table 2: Comparison of optimization algorithms

Approaches`	Theory	Speed	Accuracy	Variations
GA	Gene evolution	♦♦	♦♦	♦♦♦
IA	Immunology	♦	♦♦♦	♦
PSO	Social evolvement	♦♦♦	♦	♦♦♦

♦ represents the degree or the score of each class.

4. Distribution of optimal load in the network

As stated, the main purpose of this study is to determine the minimum cost required to generate the energy needed for a network day and the effect of using the energy storage system focused on this amount. Optimization with the goal of optimal location for installing a network storage system, as well as identifying the best operating procedures of the day-to-day installed storage system with the goal of the highest cost reduction of production. In order to evaluate the effect of using the storage system, optimal load distribution problem has been optimized in two independent states. In the first section, the traditional network without the use of the energy storage system, the minimum cost for the daily energy demand is calculated, and in the second part, by adding the energy storage system to the network, again, the cost optimization has been done. In the end, by comparing the results obtained for these two parts, we can analyze the results of the use of the energy storage system in the paid electricity grid. It should be noted that in both parts, the energy generated from the wind source is injected into the network as an independent power plant with a personalized cost function.

4.1. Economic Load Dispatch

In a traditional electricity grid, the electrical energy cannot be stored, is generated in generators and delivered to the applicants via the network. In summary, the power grid consists of three parts:

1. Generators that are responsible for the production of electrical energy.
2. Transmission lines transferring energy from place of production to place of consumption. 3. Frequently consuming electrical energy.

The economic load dispatch (optimal) is the process whereby each active generator in the network determines which part of the demanded load is to be generated, and this division is performed in such a way that the final cost of the minimum energy production is possible.
In economic load dispatch, ELD, network losses are not considered, and therefore only the total production is required to be equal to the total demand. ELD therefore allocates load to generators with the lowest cost of production in such a way as to satisfy all network constraints. Therefore, it can be considered an optimization cost minimization cost that is related to the actual production power. The cost of generating real power by each of the network generators, as shown in the previous chapter and rewritten here for the continuity of the relationships, uses the second-order relation as follows:

$$C_i(P_{Gi}) = a + b\,P_{Gi} + cP_{Gi}^2 \tag{4}$$

So in ELD, the cost function is as follows:

$$Total\ costs: C = \sum_{i=1}^{n} C_{gi} \tag{5}$$

The ultimate goal is to minimize the cost of producing electrical energy, therefore;

$$Minimize\ \sum_{i=1}^{n} C_{gi} \tag{6}$$

Optimization has two categories of constraints:
Equality constraints: The total actual power produced must be equal to the total demand for real power, therefore;

$$P_D = \sum_{i=1}^{n} P_{gi} \tag{3}$$

Unequal constraints: The limitation of true power production by each power generating generator, according to which each true power production unit produces a minimum and maximum power output, and the generator must produce within the range specified by these two quantities the actual power.

$$P_{gi\,(\min)} \leq P_{gi} \leq P_{gi\,(\max)} \tag{4}$$

4.2. Discretizing Wind Distribution

The power generated by wind energy is directly a function of the wind velocity vector in the turbine installation site. In order to achieve a comprehensive review that includes all factors, changes in wind speed and generation capacity should be considered in cost calculations. Note that in this project, the time period for power generation planning by active units is considered as an hourly basis. Therefore, given that the wind speed vector is a continuous quantity and may change over an hour, here the wind distribution discretization technique has been used in the installation area. The main idea of this discretion is to calculate the probability of occurrence of each period of wind speed. Finally, a table of probabilities for each power specified by the turbine will be calculated over the time interval.

4.2.1. Wind distribution

The Weibull distribution is known as one of the most accurate and most adapted models for wind speed. Due to its high flexibility, this distribution is widely used globally and its high flexibility has made it possible to predict wind speed in all parts of the world.

$$f(x|\,\lambda, k) = \frac{k}{\lambda}\left(\frac{\lambda}{k}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^{k}} \tag{5}$$

Where k is the shape parameter and λ is called the scale parameter
In order to achieve wind power distribution, a linear estimation has been used with the following equation:

$$Y = \begin{cases} 0 & if\ X \leq V_{ci}\ or\ X > V_{co} \\ \alpha + \beta X & if\ V_{ci} \leq X \leq V_{no} \\ M & if\ V_{no} \leq X \leq V_{co} \end{cases} \tag{6}$$

In this connection, *Y* is the injectable power, *X* is the actual wind speed, M is the maximum power produced by the wind turbine, α and β are linear coefficients, *Vci*, *Vco* and *Vno* respectively show the lowest wind speed for which the turbine can generate electrical power The highest wind speed for which turbines can be operated quickly and the standard wind speed for a turbine. The fact that at high wind speeds, despite the fact that there is energy in the wind, but due to security and physical constraints such as breaking turbine tower or distortion of turbine fins, the turbine rotor gets locked up using physical holders and produces power to zero.

4.2.2. Discretization

The main idea of the discontinuity here is the continuous and random variable (wind velocity) division into several groups, each with distinct variables from that variable. Here the number of these intervals is considered to be five groups.
First, the probability that the wind power is equal to zero is calculated using the following equation:

$$P_1 = Prob\{Y = 0\} = Prob(X \leq V_{ci}) + Prob(X > V_{co}) \quad (7)$$

This relationship states that if the wind speed is less than the minimum required for a turbine or more than the maximum operating speed by a turbine, the output electric power will be zero.
On the other hand, the probability that a turbine generates its own electrical power is calculated from the following equation:

$$P_5 = Prob\{Y = M\} = Prob(V_{no} \leq X \leq V_{co}) \quad (8)$$

For the speeds between *Vci* and *Vco*, the probability density function *Y* is rewritten as follows.

$$\widetilde{f_Y}(y|\lambda, k) = \frac{\frac{1}{\beta} f\left(\frac{y-\alpha}{\beta}|\lambda,k\right)}{1-P_1-P_5} \quad (9)$$

And pay attention to that:

$$\int_0^M \widetilde{f_Y}(y|\lambda, k) = 1 \quad (14)$$

After a few steps of rewriting relationships and simplification, for the remaining three groups, the following relationships are obtained to calculate the probability of occurrence of each mode:

$$p_2 = \frac{-1}{z_2(z_4 - z_2)}$$
$$p_3 = 1 - p_2 - p_1 \quad (10)$$
$$p_4 = \frac{1}{z_4(z_4 - z_2)}$$

Where

$$z_2 = \frac{\lambda_3}{2} - \sqrt{\lambda_4 - \frac{3\,\lambda_3^2}{4}}$$
$$z_3 = 0 \tag{11}$$
$$z_4 = \frac{\lambda_3}{2} + \sqrt{\lambda_4 - \frac{3\,\lambda_3^2}{4}}$$

In these relationships, λ_i represents the center of the i-th range.

4.3. Optimal power flow without energy storage system

The optimization problem is calculated taking into account all the security, physical, and physical constraints of the network. This is similar to the optimal load distribution problem at a given time, with the difference that the number of decision variables, which in fact is the true power generation ratio of each generator, is 24 times greater than the number of load factor variables.

4.3.1. Formulation of the problem

The main function of the optimization problem in this section is named with F, and then the target function is as follows.

$$\min F \tag{12}$$

$$F = \sum_{h=1}^{24} G_h \tag{13}$$

$$G_h = \sum_{i=1}^{np} C_{ih} \tag{14}$$

And in this equation

$$C_{ih} = a_i \times P_{ih}^2 + b_i \times P_{ih} + c_i \tag{15}$$

P_{ih} = productivity Produced by i-th at h-th hour
G_h = total production cost at h-th hour
C_{ih} = the cost of generating power at i-th generator at h-th hour
n_p = number of generators in the grid

4.3.2. Problem constraints

Equal constraints:

- Equality of the actual power generated and consumed in the network at any time interval. Generated power is equal to the total power generated by all network generators, while the power consumption is equal to the total power consumed by the loads as well as the power consumed in the transmission network, so for all the hours of the day, we have:

$$\sum_{i=1}^{np} P_{ih} = \sum_{j=1}^{nb} D_{jh} + \sum_{k=1}^{nl} PLoss_{kh} \tag{21}$$

Where

n_p = Number of network generators
n_b= Number of buses
n_l= Number of transmission lines in the network
D_{jh} = consumed power in j-th bus at h-th hour
$PLoss_{kh}$= real losses in k-th transmission line at h-th hour

- Equilibrium of imaginary power generated and consumed in the network at any time interval

$$\sum_{i=1}^{np} Q_{ih} + \sum_{j=1}^{nb} q_{jh} = \sum_{j=1}^{nb} Qd_{jh} + \sum_{k=1}^{nl} Qloss_{kh} \tag{16}$$

Where;

Q_{ih}= the imaginary power produced in i-th generator at h-th hour
q_{jh}= The imaginary power injected into j-th bus at h-th hour
Qd_{jh}= consumed imaginary power in j-th bus at time h-th hour
$Qloss_{kh}$= consumed or produced imaginary power in k-th line at time h-th hour

Unequal constraints:

- 1. The voltage of each bus must be within the permissible range for all hours.

$$V_{min} \leq V_{jh} \leq V_{max} \tag{17}$$

V_{max} and V_{min} respectively represent the maximum and minimum limits for network voltage, respectively.

V_{jh}= voltage value in j-th bus at h-th hour

- In the power grid, in the transmission lines between some of the shafts, an autotransformer is used to correct the voltage level and control the power transmission in the grid. For each of these transformers, there is a secondary voltage level control relative to the initial one, which at all times should be within the permissible range defined in the network.

$$T_{min} \leq T_{ih} \leq T_{max} \tag{18}$$

- The true and imaginary power generated by each generator must be within the permissible range for that generator. The minimum and maximum power outputs produced by each generator (power plant), along with its cost function generator coefficients, are available in tables. So, for each power plant, and at all times around the day:

$$P_{imin} \leq P_{ih} \leq P_{imax} \tag{19}$$

$$Q_{imin} \leq Q_{ih} \leq Q_{imax} \tag{20}$$

- The transmission power of each transmission line between the network wires shall be at all times less than the maximum power specified for that transmission line. So for all the hours and all the lines:

$$P_{l_{kh}} \leq P_{l_{k.max}} \tag{21}$$

In this regard, $P_{l_{kh}}$ represents the transmission power of the k line at time h and $P_{l_{k.max}}$ equal to the maximum power transmitted by the line k.

4.3.3. Calculation algorithm

Performing load power flow calculations in the network using a Newton-Raphson numerical repeat method with a precision of 1 000 volts. Broadcasting in the network has always been one of the power grid issues that needs to be done massively. Performing these calculations alone is at an acceptable time, but the problem arises when the optimizer algorithm needs to be loaded for hundreds of times for each replication, and according to its results, the value of the cost function is computed. Therefore, it is necessary to avoid a large amount of computations by performing preliminary steps. In this part of the energy storage is not used, so you can consider the amount of generators generated at different times independently. Considering this assumption, the minimum cost associated with the total cost of full hours can be set at a minimum total cost of all hours separately. Equations 17 and 18 can be rewritten as follows:

$$\min F \tag{22}$$

$$\min\{F\} = \min\{\sum_{h=1}^{24} G_h\} = \sum_{h=1}^{24} \min\{G_h\} \tag{23}$$

Using this assumption, we can calculate the volume of calculations using the algorithm shown in figure 5 in a reasonable amount of time.

4.3.3.1. Explain the flowchart computing

- Network information including the characteristics of the waves and their type, the characteristics of the transmission lines, which include the true and end-of-life characteristics, the characteristics of the transformers, the characteristics of the loads and their location to the network, as well as the characteristics of the generators and their location in the program. Energy demand information is also available for the first hour of the day.
- The initial population of potential responses is generated. Initial population and range of decision variables are given by default.
- Initial velocity vectors of particles are generated randomly and calculated for random initial values, the best local and comprehensive response is calculated.
- Using the well-defined Newton-Raphson method, for the power values assigned, the network load distribution equations are solved, and the true and imaginary power generation of all generators, the voltage and angle of the power in all wires, as well as the inputs and outputs all buses are determined after calculating the load distribution.
- The transmission capacity of all network transmission lines is calculated.
- The calculated values are compared with the limits set, and if the conditions are not met, the amount of fines to be added to the total cost is determined. These limitations include generating output power, transmission throughput, and the size and angle of the voltage across all network points.
- Considering the calculated values for production in the generators and the fines considered, the value of the cost function and its suitability are calculated.
- Calculated values for the cost function are compared with the current values of the best local and comprehensive answers, and the best local and comprehensive answers are given for replication (if necessary and need to be repeated).
- The calculated values are compared with the conditions considered for the response, and if it is determined that acceptable responses are calculated, they are transferred to step 11, otherwise, step 10
- Program counter is added to the unit and according to the vectors of the location and velocity of the particles, the location and velocity vector of the repetition of the dimension are calculated and returned to step 4.
- Check whether the best answer is calculated for all hours of the night. If yes, go to step 13 and otherwise move to step 12.
- Network information stays constant, but electrical energy demand data is replaced for the new clock with previous values and the program returns to step 2.

- The best answer is calculated for all hours of the day. The program will produce proportional reports

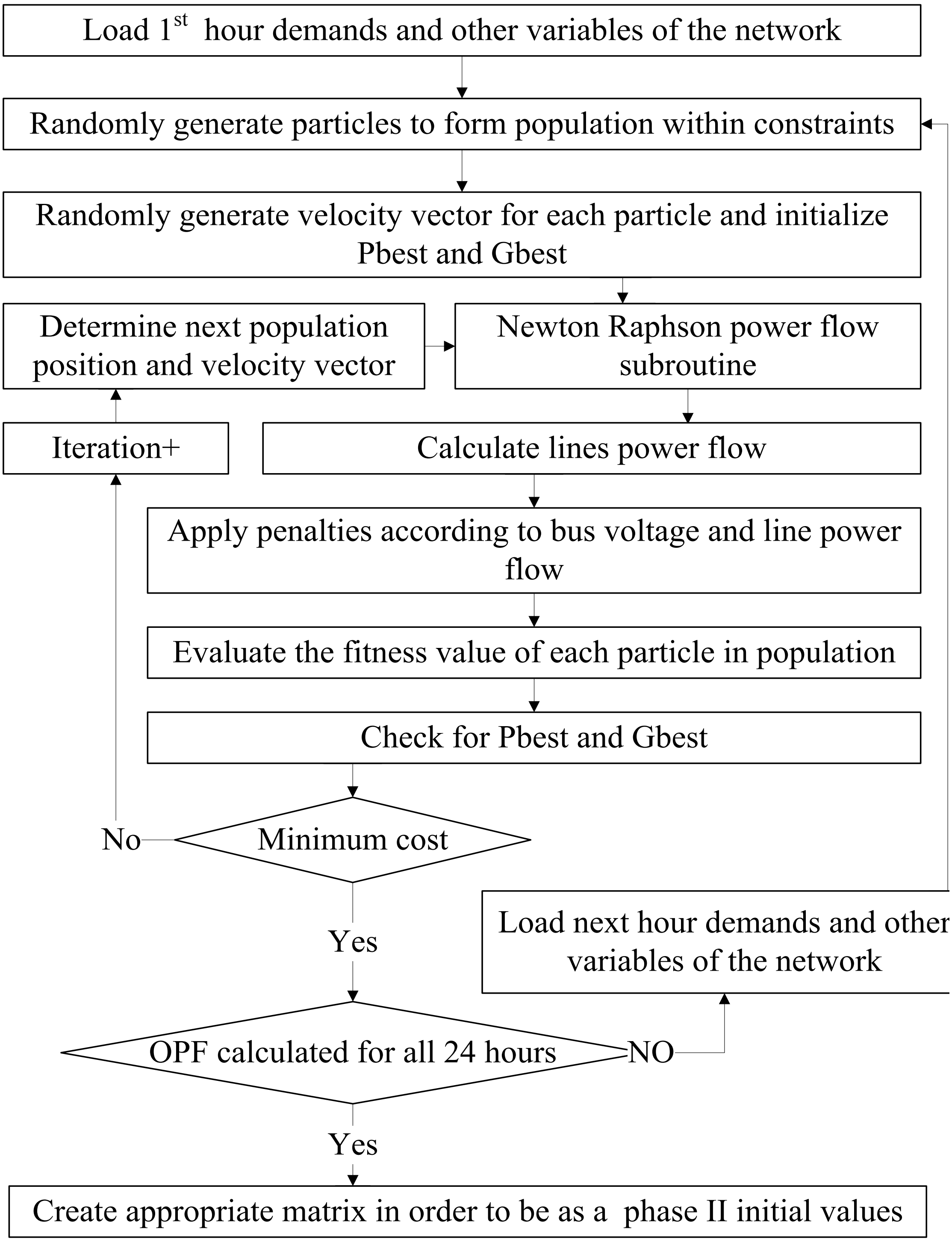


Figure 5: The proposed algorithm computes the minimum cost of production in the network, in the non-energy-consuming mode

4.4. Optimal power flow with energy storage system

The existence of the energy storage system makes a lot of changes to the optimization problem. The main reason for this is the ability to use the cache both as a generator and as a load, which makes it impossible to assume its connection to the network (bus) during a constant day. Changing the storage mode from the consumer (in charging mode) to the generator (in discharging mode) causes a change in the bus connector type from PQ to PV and vice versa. Another limitation that the use of a network storage system should be considered in solving the optimization problem is the need to balance the energy in charge and discharge mode. The charge of the storage system at the end of the day should be equal to the amount of charge at the beginning of the day.

4.4.1. Formulation of the problem

The main function of the optimization problem in this section is named with F 'and then the target function is as follows.

$$\min F' \tag{24}$$

$$F' = \sum_{h=1}^{24} G_h \tag{25}$$

$$G_h = ESSC_h + \sum_{i=1}^{np} C_{ih} \tag{26}$$

$$C_{ih} = a_i \times P_{ih}^2 + b_i \times P_{ih} + c_i \tag{27}$$

And $ESSC_h$ is the cost of operating an energy storage system at h. H. This is because the system can be rewritten as follows when it is used in productive or consumer mode:

$$ESSC_h = ce.PE_h \tag{28}$$

In this regard, ce is the cost function of the energy storage system, which shows how much each unit of power generated by the storage system is and PE_h represents the capacity of the storage system at its h.

When used as a consumer energy storage system (the storage system is in charge mode), the cost of the charge is equal to the cost of power and energy consumed, which is automatically paid at the time of computing the production of each of the generators.

4.4.2. Problem constraints

The problem, like without using a storage system, has two categories: the equal constraints of unequal constraints, each of which is presented below.

4.4.2.1. Equal constraints

- Equality of the real power generated and consumed in the network at any time interval.

$$\sum_{i=1}^{np} P_{ih} + PE_h = \sum_{j=1}^{nb} D_{jh} + \sum_{k=1}^{nl} PLoss_{kh} \quad (35)$$

In this case, if the energy storage system is being discharged, PE_h has a positive sign and a negative charge state.

- Equilibrium of imaginary power produced and consumed in the network at any time interval.

$$\sum_{i=1}^{np} Q_{ih} + \sum_{j=1}^{nb} q_{jh} = \sum_{j=1}^{nb} Qd_{jh} + \sum_{k=1}^{nl} Qloss_{kh} \quad (36)$$

- Equivalent power generated and consumed in the storage system during the day and night, taking into account its efficiency.

$$\sum_{h=1}^{24} PE_h \times ESSE = 0 \quad (29)$$

In this regard, ESSE is considered to be equal to one (unit) in the case of PE_h non-positive and 90% is considered to be PE_h, indicating the efficiency of the charge and discharge cycle of the energy storage system.

4.4.2.2. Unequal constraints

- The voltage of each bus must be within the permissible range for all hours. So;

$$V_{min} \leq V_{jh} \leq V_{max} \quad (30)$$

- The restriction to the transformers is the same as without using the storage system.

$$T_{min} \leq T_{ih} \leq T_{max} \quad (31)$$

- The true and imaginary power generated by each generator must be within the permissible range for that generator. This restriction will also include the energy storage system. That is, the storage system is allowed at a production limit or power consumption at a maximum limit.

$$P_{imin} \leq P_{ih} \leq P_{imax} \quad (32)$$

$$Q_{imin} \leq Q_{ih} \leq Q_{imax} \quad 33)$$

When charging the storage:

$$PE_{discharge.max} \leq PE_h \quad (34)$$

When the storage is discharging:

$$PE_h \leq PE_{charge.max} \quad (35)$$

- The transmission power of each transmission line between the network wires shall be at all times less than the maximum power specified for that transmission line. So for all the hours and all the lines

$$P_{l_{kh}} \leq P_{l_{k.max}} \quad (36)$$

4.4.3. Calculation algorithm

In solving the problem of minimizing the cost of producing daily energy without the use of an energy storage system, with the assumption np of the active production unit, the problem has a decision variable of (np.24), which makes it possible to solve the 24 independent problems and each of the np variables. With the addition of the storage system to the network, in addition to calculating the production of each generator overnight, the amount of production or consumption of the storage system is also computed daily. Therefore, this minimization problem will have (1 + np).24 variables, which cannot be separated into smaller issues due to the lack of independence of different hours from each other.

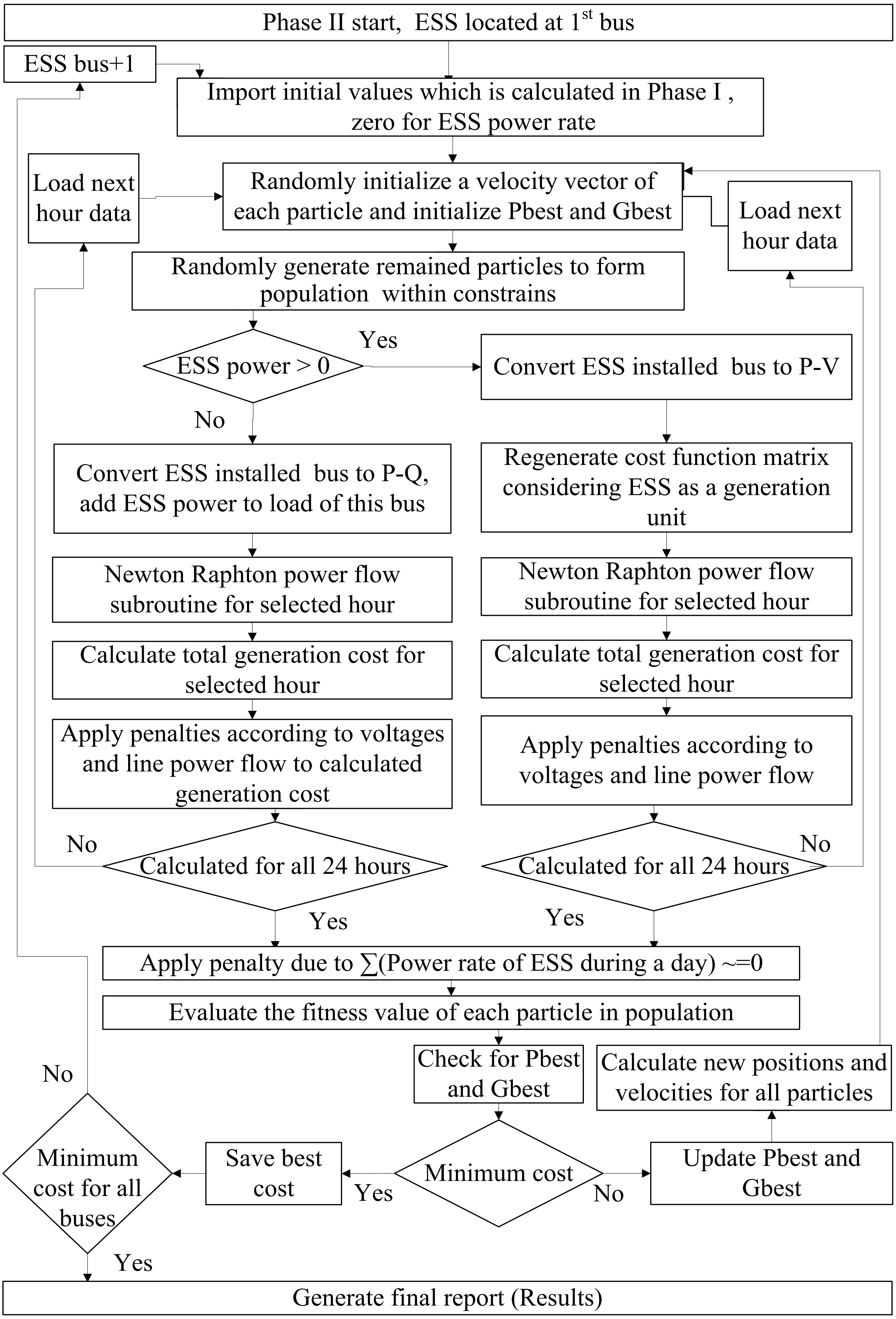


Figure 6: Proposed algorithm for computing the minimum cost of production in the network, in the mode using the energy storage

4.4.3.1. Explain the flowchart

- The energy storage system is assumed to be the first connected network bus.
- The result of the calculation in the non-storage mode (as calculated in the previous section) is entered into the program and assuming operation of the storage system in all hours is zero. This information is considered as the first particle of the initial population.
- Initial velocity vectors are randomly assigned to the specified interval. Given the current values, the value of the objective function and the optimal value is calculated.
- The information for other members of the primary population is set randomly and within the permissible range.
- For each hour, if the storage system is in charge mode (consumer), go to step a, and if it is in discharging mode (manufacturer), then step b will be transferred.
- a. The bus in which the storage system is installed is converted to a specified load cell (PQ). It should also be checked whether the table of coefficients of the cost functions of the power plants includes the coefficients of the cost function of the storage system, these coefficients are eliminated from the table and the number of generators of the network in that hour is reduced. It should be noted that if a generator is connected in this bus, the type of bus does not change and PV remains.
- b. The bus where the storage system is connected to the PV bus becomes. Also in the second part of this step, the table shows the cost function of the power plants updated, and the cost of using the storage system as a generator will be added.
- This stage is considered separately and independent in the computing algorithm for two modes of storage function, but because of the similarity of these steps, here are both commonly expressed. The network load distribution is solved using the Newton-Raphson numerical repeat method and the network quantities are determined in all waves.
- Based on the cost functions and the respective coefficients table, the production cost per hour is calculated for all members of the population.
- Establishing network constraints and constraints, including the voltage of the waves, the transmission power in all transmission lines, and the true and fictitious power of all generators, are checked and, if they are not set up in proportion to the error, a fine is added to the cost of that hour.
- The operation of the energy storage system is checked at different times and in the event of imbalance between the power production and the power consumed, taking into account the overall efficiency of the energy storage system, a fine is considered.
- For each member of the population, the value of the total cost function is calculated by summing the cost of all hours as well as the penalty for imbalance in the performance of the storage system. The merit of each member is considered to be considered as the best answer.
- 13. The best local and global answer is identified.
- 14. Based on the criteria of the end of the calculation and the fulfillment of the specified conditions in order to achieve the desired response, it is

checked whether the best answer (lowest cost for one day) is found for the specified wavelength in which the storage system is installed.

- The calculated value is stored as the lowest production cost for the storage system installed in the specified bus.
- The lowest response for installing the storage system in all network wires is considered as the final answer.

5. Simulation and discussion the sample study

Implementation on a case study and the results are compared in two modes. The first mode is the minimum amount of daily energy required for a grid without the use of a power storage system but with the simultaneous use of thermal power plants along with the production of the wind source, and the second condition of the generators and the wind generator is considered the same as the first one, but along with the generators of one The central energy storage system is also used. In order to investigate the effect of using the energy storage system against various characteristics, power plant cost functions and network changes such as load increase, various scenarios have been introduced and reviewed.

5.1. Network study sample

In order to evaluate the performance of the proposed algorithm in a real network, the IEEE standard 30-buses network has been used. In this network, six generators are connected to the network in the bus 1, 2, 5, 8, 11 and 13 to generate energy demand. Also in this network, 41 transmission lines have the task of transmitting power from generators to the loads, the specifications of which are shown in Table 4.

Table 3: Characteristics of network transmission lines

Line number	From bus	To bus				Autotransformer	Maximum power transferable
1	1	2	0.0192	0.0575	0.0264	1	130
2	1	3	0.0452	0.18522	0.0204	1	130
3	2	4	0.057	0.1737	0.0184	1	65
4	3	4	0.0132	0.0379	0.0042	1	130
5	2	5	0.0472	0.1983	0.0209	1	130
6	2	6	0.0581	0.1763	0.0187	1	65
7	4	6	0.0119	0.0414	0.0045	1	90
8	5	7	0.046	0.116	0.0102	1	70
9	6	7	0.0267	0.082	0.0085	1	130
10	6	8	0.012	0.042	0.0045	1	32
11	6	9	0	0.0208	0	0.978	65
12	6	10	0	0.556	0	0.969	32
13	9	11	0	0.208	0	1	65
14	9	10	0	o.11	0	1	65
15	4	12	0	0.256	0	0.932	65
16	12	13	0	0.14	0	1	65
17	12	14	0.1231	0.2559	0	1	32
18	12	15	0.0662	0.1304	0	1	32
19	12	16	0.0945	0.1987	0	1	32
20	14	15	0.221	0.1997	0	1	16
21	16	17	0.0824	0.1923	0	1	16
22	15	18	0.1073	0.2185	0	1	16
23	18	19	0.0639	0.1292	0	1	16
24	19	20	0.034	0.068	0	1	32

25	10	20	0.0936	0.0209	0	1	32
26	10	17	0.0324	0.0845	0	1	32
27	10	21	0.0348	0.0749	0	1	32
28	10	22	0.0727	0.1499	0	1	32
29	21	22	0.0116	0.0236	0	1	32
30	15	23	0.1	0.202	0	1	16
31	22	24	0.115	0.179	0	1	16
32	23	24	0.132	0.27	0	1	16
33	24	25	0.1885	0.3292	0	1	16
34	25	26	0.2544	0.38	0	1	16
35	25	27	0.1093	0.2087	0	1	16
36	28	27	0	0.396	0	0.968	65
37	27	29	0.2198	0.4153	0	1	16
38	27	30	0.3202	0.6027	0	1	16
39	29	30	0.2399	0.4533	0	1	16
40	8	28	0.0636	0.2	0.0214	1	32
41	6	28	0.0169	0.0599	0.065	1	32

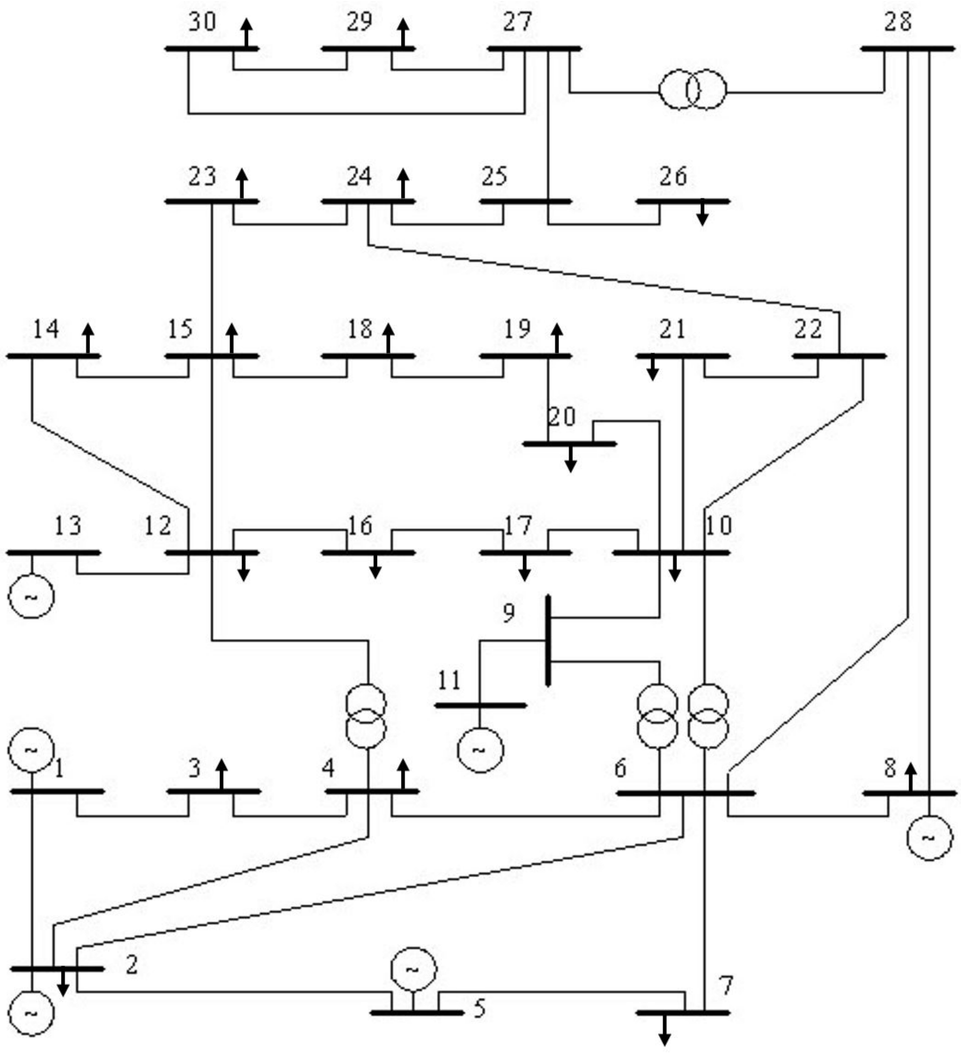


Figure 7: The standard 30 buses IEEE networking network used for simulation [64]

In order to conduct the study, the amount of demand in different hours and in each bus from the network should be specified. The maximum demanded power is 283.4 megawatts per day, which is at 5am.

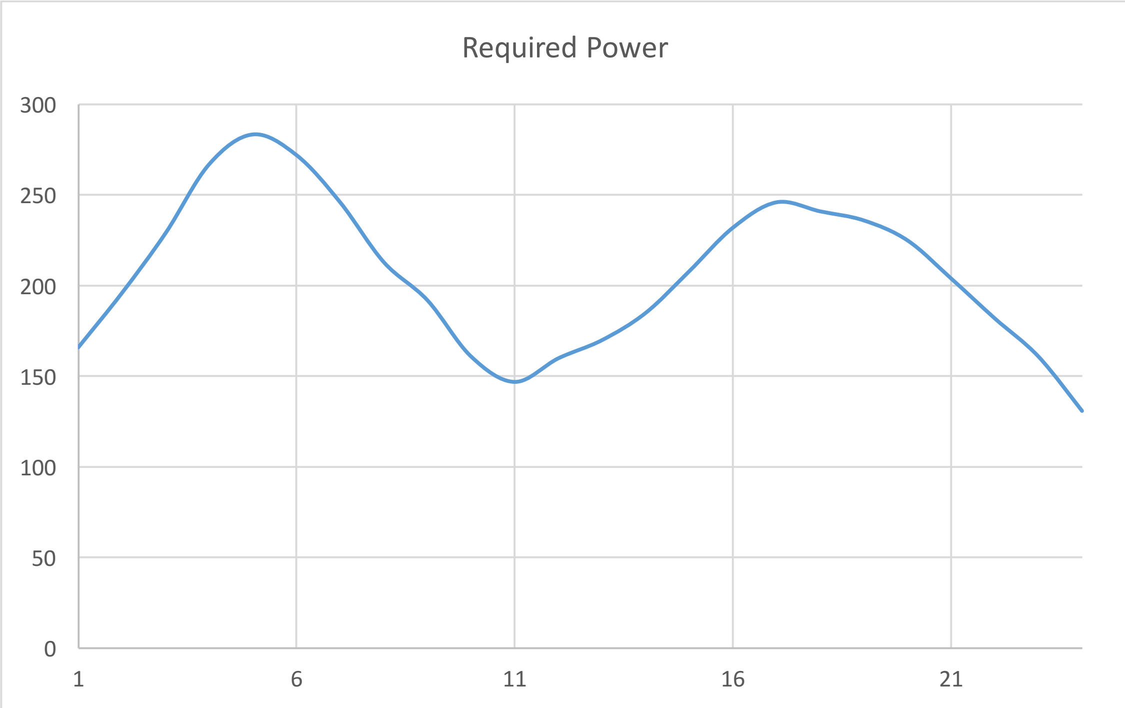


Figure 8: Required power at different hours

Table 4:Total demand power a day in the studied network

Time (hour)	Total Power Requirement MW
1	166
2	196
3	229
4	267
5	283/4
6	272
7	246
8	213
9	192
10	161
11	147
12	160
13	170
14	185
15	208
16	232
17	246
18	241
19	236
20	225
21	204
22	182

23	161
24	131

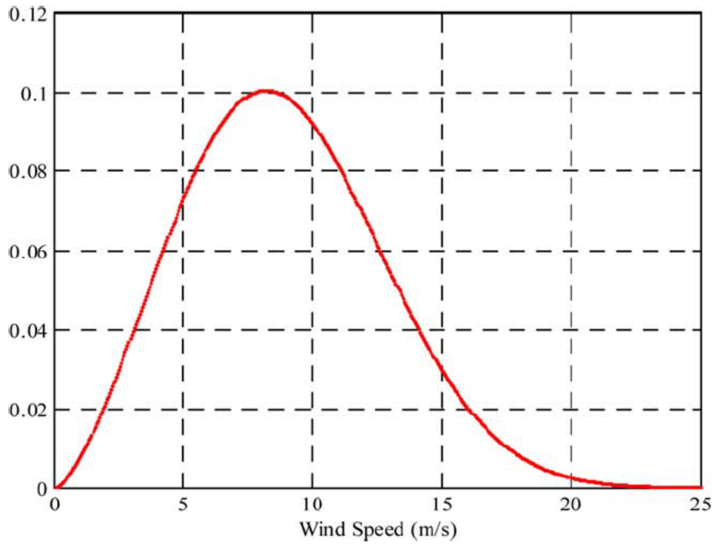
Table 5:Required real and imaginary power at 5 a.m.

Bus number	Required real power at 5 a.m.	Required imaginary power
1	0	0
2	21.7	12.7
3	2.4	1.2
4	7.6	1.6
5	94.2	19
6	0	0
7	22.8	10.9
8	30	30
9	0	0
10	5.8	2
11	0	0
12	11.2	7.5
13	0	0
14	6.2	1.6
15	8.2	2.5
16	3.5	1.8
17	9	5.8
18	3.2	0.9
19	9.5	3.4
20	2.2	0.7
21	17.5	11.2
22	0	0
23	3.2	1.6
24	8.7	6.7
25	0	0
26	3.5	2.3
27	0	0
28	0	0
29	2.4	0.9
30	10.6	1.9

5.2. Case study of weather conditions

In order to achieve realistic wind data, wind speed data from the past 10 years of Madison has been used [65]. The information in this area has been used to determine the distribution of Weibull, as shown in Equation 9.

Table 6: The fitting diagram of the wind velocity probability at various speeds related to Madison



The wind distribution characteristics for the generator used are summarized in Table 7.

Table 7: Wind distribution characteristics

k	λ	α	β
2.5034	10.0434	-39.55	11.3

Based on the relationships noted in the wind-discretization section, this continuous distribution function of the wind distribution has been discontinued at five points. The result of these calculations is shown graphically in figure 9.

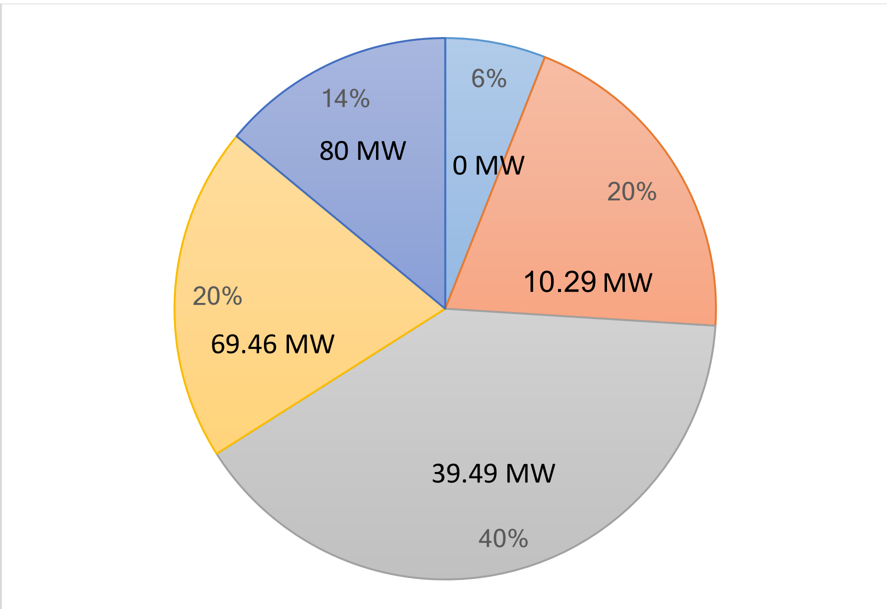


Figure 9: Distributed potential distribution of wind power production at five points

5.3. Validation

The numbers used for validation are at 5am in the IEEE 30 IEEE Standard Grid and derived from [66]. The value of the cost function coefficients for the generators of this network, which are used in both tests and in the reference, are shown in Table 8. Fig.

Table 8: The cost function coefficients used in validating the algorithm

Gen. No.	Bus	a	b	c	Min Power (MW)	Max Power (MW)
1	1	0.00375	2	0	50	200
2	2	0.0175	1.75	0	20	80
3	5	0.0625	1	0	15	50
4	8	0.0083	3.25	0	10	35
5	11	0.025	3	0	10	30
6	13	0.025	3	0	12	40

According to reference calculations, the minimum cost at 5 am for the surveyed network is $ 802.88.

5.3.1. Validation without using a storage system

The results are shown in Table 9 for all hours of the day. The final value obtained for this section is 802.36 $, which not only indicates the accuracy of the reference value, but also indicates the relative improvement of the optimal calculated response. It should be noted that although in the implementation plan, there is the ability to make calculations for a specific clock, but in order to display the computational results in general, the process is performed for all hours of the day and the results are shown. Figure 10 also shows the convergence rate of the implemented algorithm at 5 am and with initial membership of 20.

Table 9: The values calculated by the algorithm in the section without using the energy storage system

Time (Hour)	Gen.1 (MWhr)	Gen.2 (MWhr)	Gen.3 (MWhr)	Gen.4 (MWhr)	Gen.5 (MWhr)	Gen.6 (MWhr)	Loss (MWhr)	Cost ($/hr)
1	93.3	28.6	15	10	10	12	2.93	418.17
2	117.4	34.4	16.6	10	10	12	4.43	506.74
3	143.9	40.8	18.7	10	10	12	6.39	611.93
4	168.4	46.8	20.8	17.1	10.6	12	8.63	743.18
5	176.7	48.8	21.5	21.8	12.1	12	9.51	802.36
6	170.9	47.4	21	18.5	11	12	8.9	761.07
7	157	44	19.8	10.7	10	12	7.52	669.49
8	131	37.7	17.7	10	10	12	5.38	559.86
9	114.2	33.6	16.4	10	10	12	4.22	494.57

10	89.1	27.6	15	10	10	12	2.71	404.12
11	77.3	24.9	15	10	10	12	2.17	365.84
12	88.2	27.4	15	10	10	12	2.67	401.34
13	96.7	29.4	15	10	10	12	3.11	429.55
14	108.6	32.3	15.9	10	10	12	3.79	473.32
15	127.1	36.7	17.3	10	10	12	5.09	544
16	146.3	41.4	18.9	10	10	12	6.58	621.92
17	157	44	19.8	10.7	10	12	7.52	669.49
18	153.6	43.1	19.5	10	10	12	7.2	652.32
19	149.6	42.1	19.2	10	10	12	6.86	635.35
20	140.7	40	18.4	10	10	12	6.13	598.72
21	123.8	35.9	17.1	10	10	12	4.86	531.46
22	106.2	31,7	15.7	10	10	12	3.65	464.43
23	89.1	27.6	15	10	10	12	2.71	404.12
24	63.9	21.7	15	10	10	12	1.61	323.86
Total	2990	868	419.3	268.8	243.8	288	124.6	13087.2

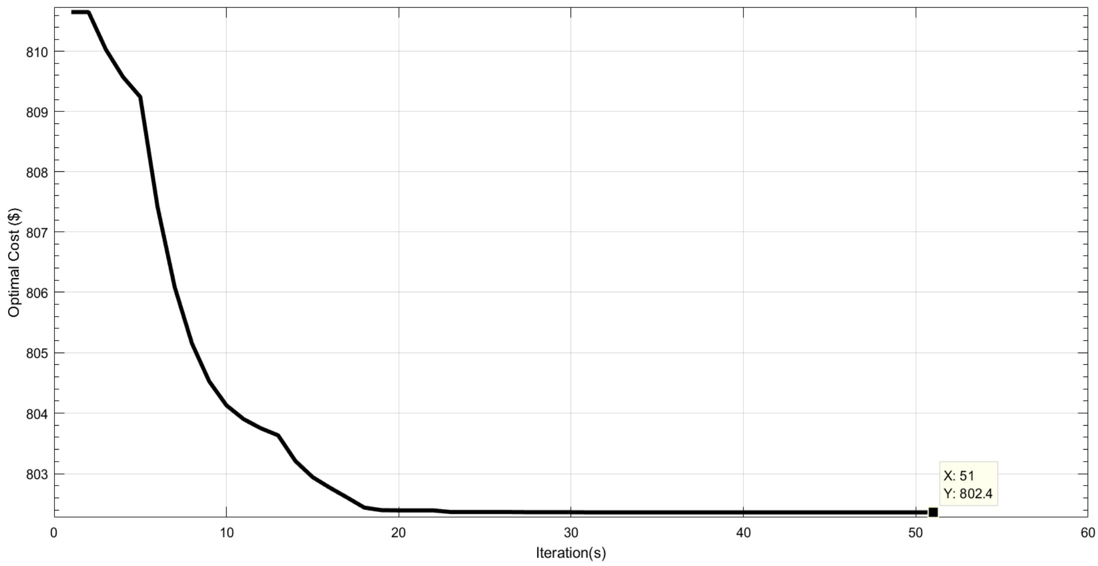


Figure 10: The convergence of the algorithm designed to solve the validation problem is about 5 am

5.3.2. Validation with using energy storage

In this section, the final algorithm has been designed. For this purpose, the capacity of the storage system is considered to be very small at 1 watts, and due to the lack of efficiency and cost effectiveness in this very small capacity, with the aim of accelerating the calculation, the efficiency and cost of this system is considered ideally. The calculation results are shown in Table 10. The results shown in this table indicate a 0.05% error at 5 and a 0.05% error in the total number of hours a day, compared with the first one. Considering a very large number of decision variables, in the second case, 144 variables Compared to the 6 variables, it represents the very accurate accuracy of the calculations. It is worth mentioning that in the absence of an energy storage system, the time required to perform all calculations is 10 minutes, while in state using the energy storage system, this time has increased by more than 24 hours. This increase is due to the increasing number of decision variables.

Table 10: The values calculated by the algorithm in the section using the energy storage system

Time (Hour)	Gen.1 (MWhr)	Gen.2 (MWhr)	Gen.3 (MWhr)	Gen.4 (MWhr)	Gen.5 (MWhr)	Gen.6 (MWhr)	**ESS** (MWhr)	Loss (MWhr)	Cost ($/hr)
1	93.5	28.5	15.0	10.0	10.0	12.0	0.0	2.94	418.38
2	117.6	34.3	16.63	10	10	12	0	4.63	507.04
3	143.7	40.9	18.8	10	10	12	0	6.41	612.0255
4	168.35	46.9	20.6	17.2	10.7	12	0	8.73	743.649
5	176.65	48.9	21.35	21.88	12.13	12	0	9.51	802.4237
6	170.95	47.35	21.1	18.45	11.04	12	0	8.9	761.136
7	157.1	44.07	19.73	10.65	10.05	12	0	7.52	669.77
8	131.12	37.71	17.67	10	10.1	12	0	5.38	560.56
9	114.25	33.65	16.3	10	10	12	0	4.22	494.58
10	89.12	27.61	14.8	10	10	12.01	0	2.71	404.42
11	77.25	24.96	15	10	10	12.01	0	2.17	365.97
12	88.23	27.34	15	10	10	12.06	0	2.67	401.52
13	96.71	29.34	15	10	10	12.03	0	3.112	429.69
14	108.53	32.39	15.91	10	10	12	0	3.8	473.57
15	127.11	36.69	17.305	10	10	12	0	5.091	544.09
16	146.25	41.46	18.91	10	10	12	0	6.59	622.03
17	157.04	43.98	19.82	10.5	10	12	0	7.52	669.73
18	153.62	43.14	19.41	10	10	12	0	7.201	653.98
19	149.71	41.92	19.21	10	10	12	0	6.859	635.86
20	140.65	40.06	18.41	10	10	12	0	6.131	598.94
21	123.84	35.91	17.01	10	10	12	0	4.863	531.97
22	106.29	31.62	15.71	10	10	12	0	3.652	465.01
23	89.04	27.63	15.03	10	10	12	0	2.7	404.42
24	63.92	21.68	15	10	10	12	0	1.61	323.93
Total	3014.5	868.01	418.705	268.68	244.02	288.11	0	124.9	13093.694

Figure 11 shows an image of the software environment implemented to perform the optimization process at the beginning of its execution. In this image, the software is receiving the system information of the storage system, including the minimum and maximum allowable power for the system, the efficiency of the operation with the percentage of units, the bus number in which the storage system is installed, and the cost of using the user's storage system. The information shown is input data for the algorithm performance evaluation and validation section.

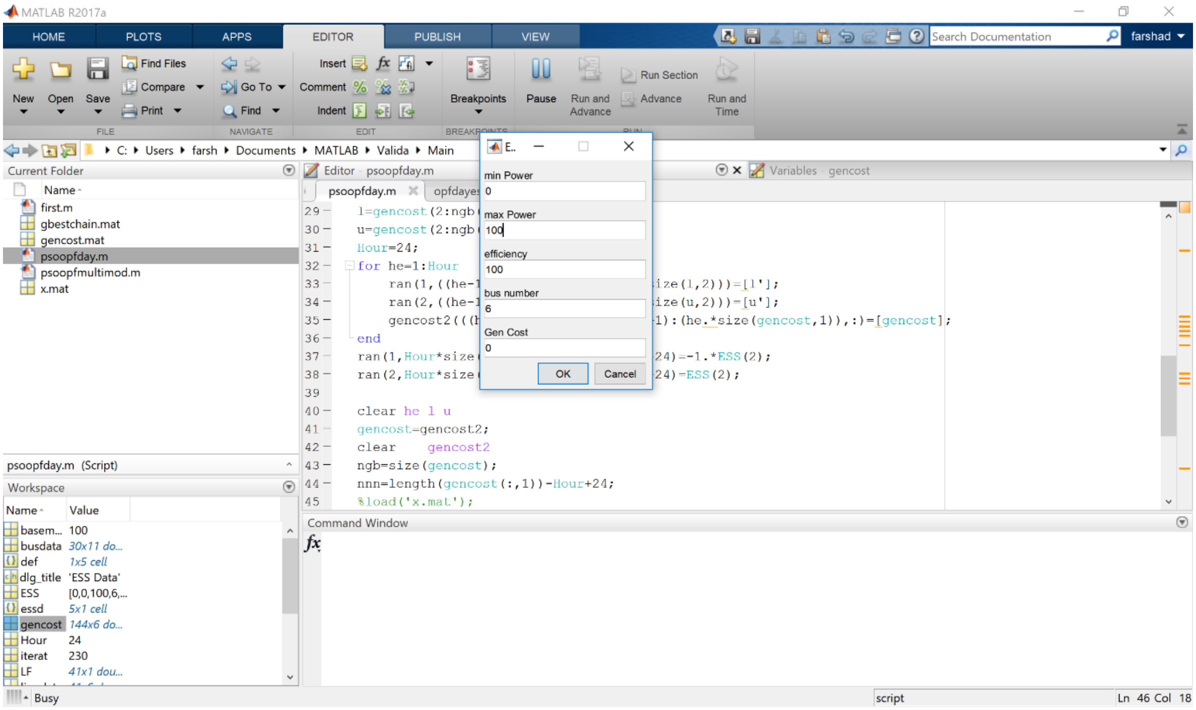


Figure 11: An image of the software environment at the moment of simulation startup and how to get information from the user

5.4. Explanation of different scenarios

5.4.1. Scenario 1: Equal coefficient cost functions

This scenario illustrates the impact of using renewable energy sources and energy storage systems on daily energy costs when the cost function of all generators is the same and equal. In this case, the maximum and minimum output power generation is considered equal. The coefficients used along with the power generation constraints for all generators in this scenario are shown in Table 11.

Table 11: Cost Function Coefficients for All Generators in Scenario 1

a	b	c	Min Power (MW)	Max Power (MW)
0.01	1	0	10	80

5.4.1.1. Minimum cost of production without using a power storage system

Given the equality of all the characteristics of the active generators in the network, it is expected that, in the ideal state, without loss and network constraints, the load at any given moment will be equally divided between all generators. The reason for this is the existence of a second power in relation to the cost function. The results for this section are shown in Figure 12.

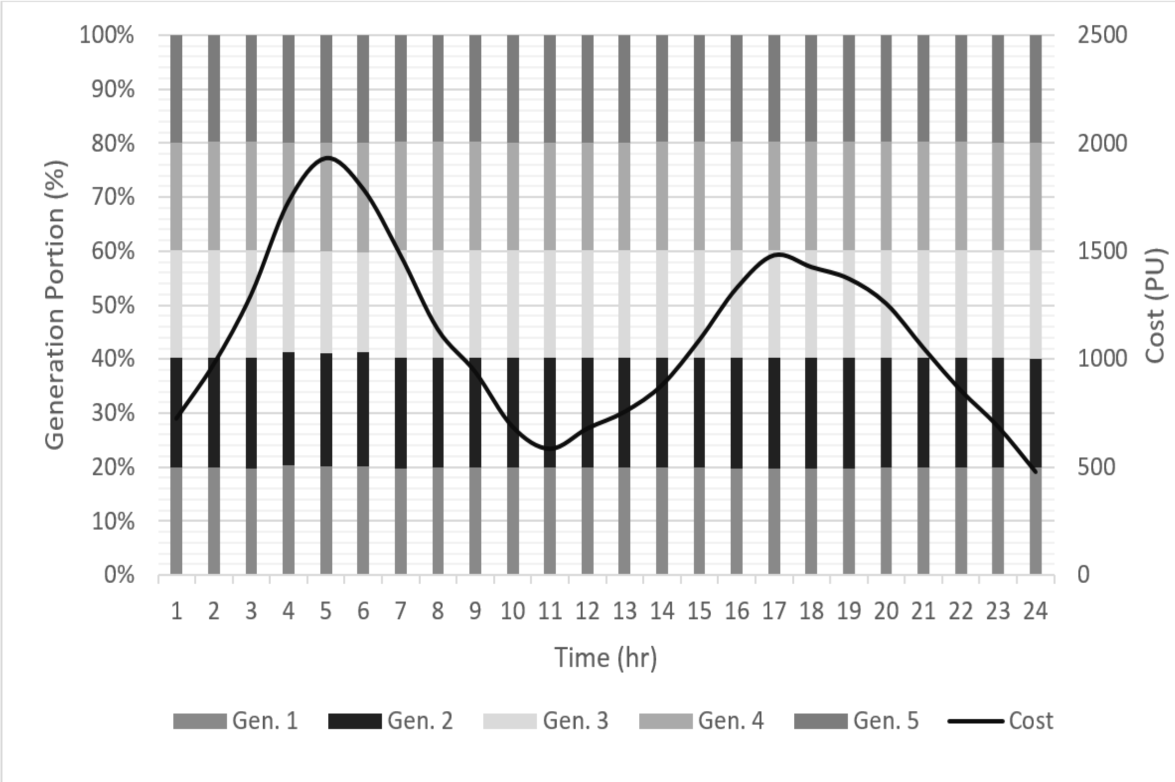


Figure 12: Results for the first part of scenario 1

Considering the amount of energy required in each of these hours, it can be calculated that at 5 o'clock, to generate each unit of energy of 6.81 ounces per unit, and the same quantity at 24 o'clock is 3.66 ounces. This difference is related to coefficient an in relation to the cost function of power plants. The total daily production cost of a network power in this case is equal to 266.52 per unit.

5.4.1.2. Minimum production cost using the energy storage system

This section shows the effect of using the energy storage system on the cost. In order to achieve and display the maximum effect of using the storage system on production costs, the system's storage efficiency is not 100% and costs are not included. The result obtained is shown in Figure 13.

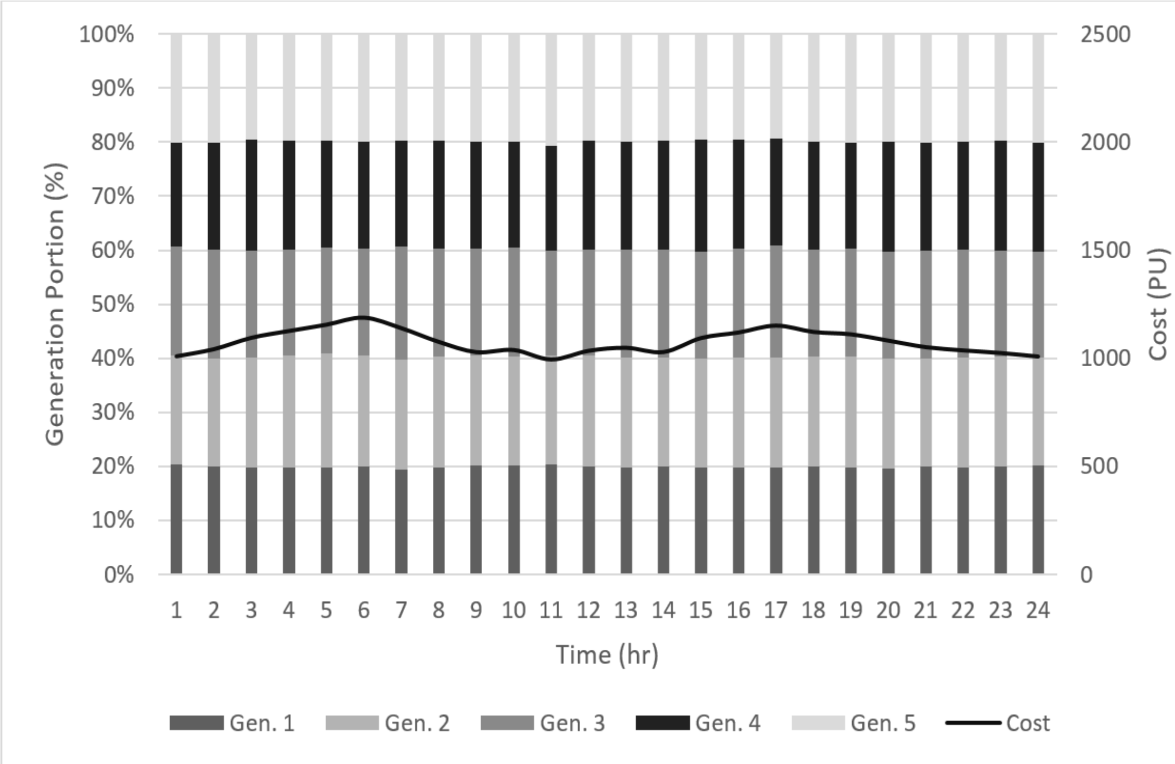


Figure 13: Results for the second part of scenario 1

In this case, the minimum cost per hour is equal to 994.88 units per hour and the maximum value is 1190.3 units and is at 6 pm. Also, the lowest cost per unit of energy is 4.08 for the 5th hour and the maximum for it is 7.7 units per megawatt-hour, and it is about 24 hours. Eventually, the total charge of 24 hours in this case is equal to 25829.62 units.

5.4.2. Scenario 2: Different Coefficient Cost Functions

In the network, generally, different power plants have different cost functions for power generation, so in this scenario, the effect of using the storage system on the cost of generating energy in a grid that has power plants with different cost functions is tried. This study has been done in two parts. In the first part, the coefficient of each production unit is 0.1 times the coefficient b of the unit, and in the second part, the coefficient a, is 0.01 times the coefficient b. It should be noted that in both parts, the coefficient b of the production unit located in the first shaft is considered as the basis for the price system in the unit. This value, as previously mentioned, is $ 100 per megawatt-hour. The computing algorithm and other network parameters are similar to Scenario 1.

Part I: The cost function coefficients of the various production units used in this section are presented in Table 12.

Table 12: The characteristics of the manufacturing units used in the first part of scenario 2

Generator number	bus	a	b	c	min	Max
1	1	0.1	1	0	10	80
2	5	0.07	0.7	0	10	80
3	8	0.115	1.15	0	10	80
4	11	0.085	0.85	0	10	80

5	13	0.13	1.3	0	10	80

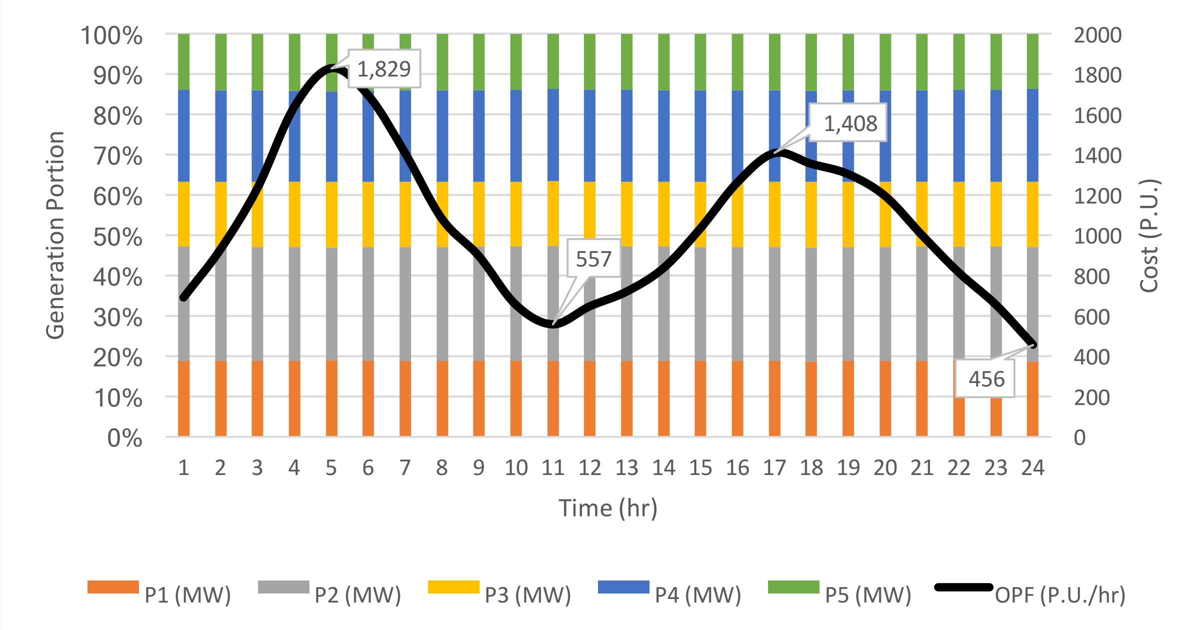


Figure 14: Results for the first sub-section of the first part of scenario 2

Comparing the results obtained in this section with the same section in Scenario 1 shows that, as in Scenario 1, here too, with increasing production (consumption), the cost of producing each unit of energy increases, as well as the share of each producer in supplying the load during different hours it remains almost constant. Unlike scenario 1, in this case, the share of producers is not equal to each other, and producer number 2 with an average of 28.3% of the total production has the highest share and producer number 5 with 14% of the lowest share in production. The total daily charge for a non-storage system is 25,294 units, and if you use a storage system, this will be reduced to 24,587 units, which represents a 2.8 percent reduction in daily charges.

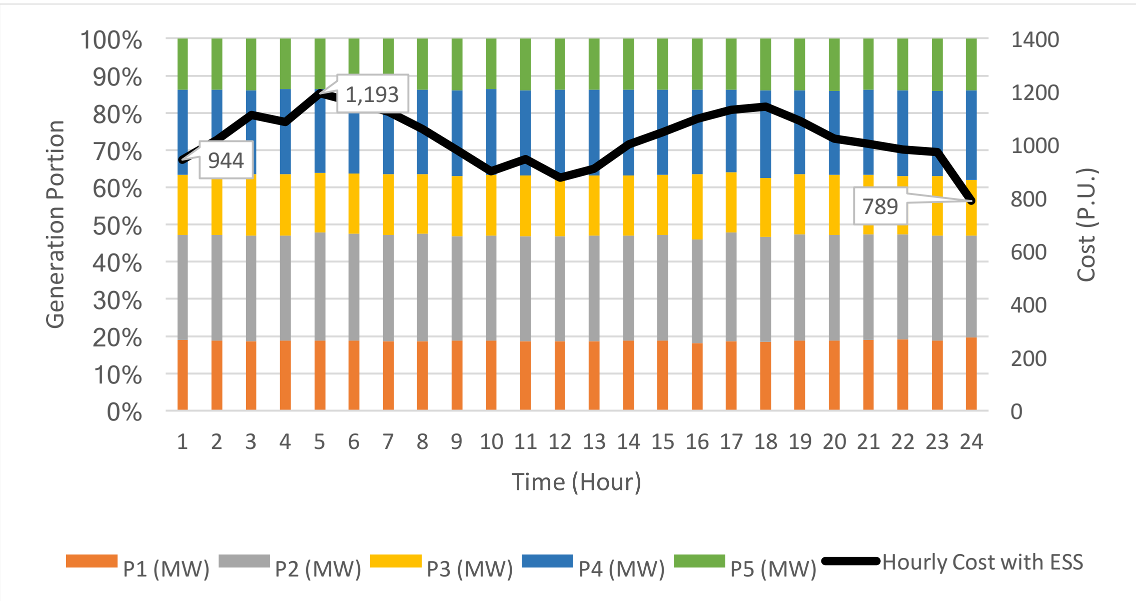


Figure 15: The results obtained under the second part of the first part of scenario 2

Using the energy storage system causes the production status of the power plants and their contribution to the load along with the hourly cost as shown in Figure 15. The chart shows a decrease in price changes at different times so that without using the storage system, the difference between the maximum and minimum costs is 1,373 units and in the case of using the storage system, this difference has decreased to 404 units.

Part II: In order to evaluate the effect of coefficient a in the study, in this section, the algorithm is similar to the first part, with the difference that the coefficient a in this section instead of 0.1 is equal to 0.01 coefficient b of each power plant has been implemented.

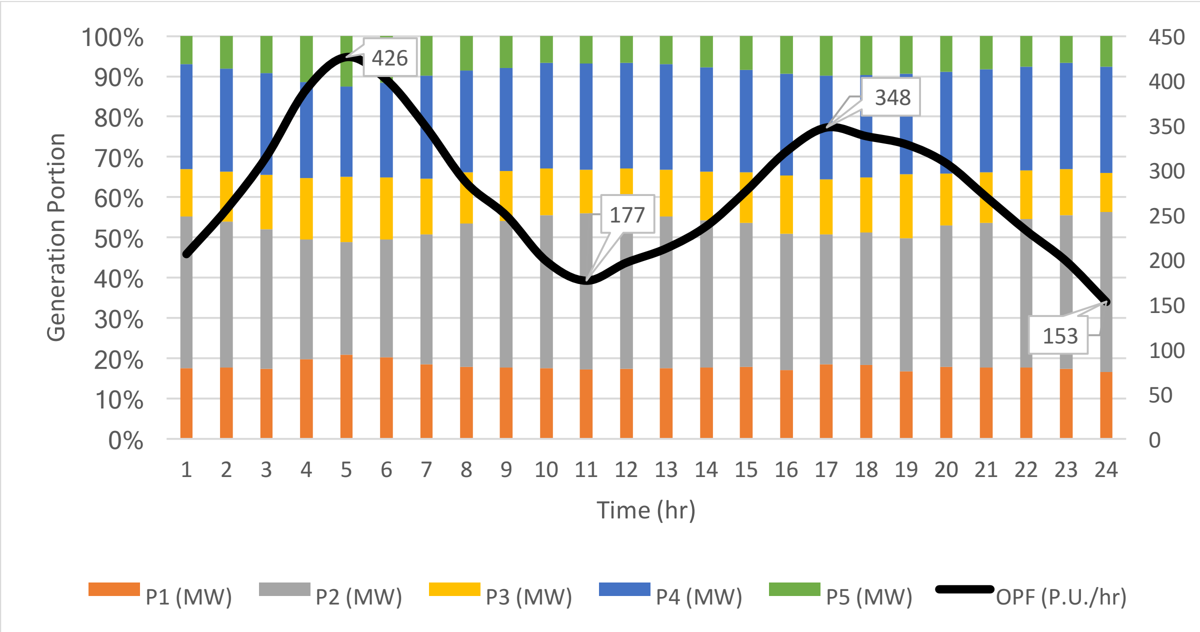


Figure 16: The results obtained in the first part of the second part of scenario 2

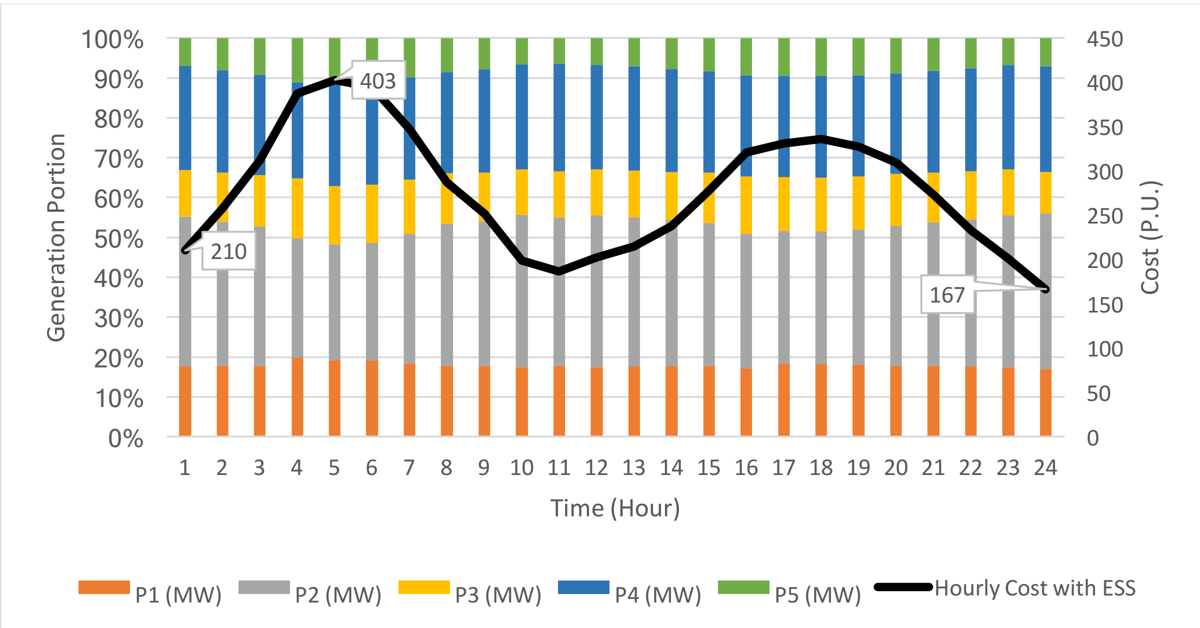


Figure 17: The results obtained in the second part of the second part of scenario 2

According to the results, it is shown that the share of each producer at different times in both cases is not equal to using the energy storage system and using the storage system. Using the storage system, the change in the share of each power plant in the state using the storage system has not been created in relation to the non-use of the energy storage system, and as before, these changes are negligible. Regarding the total cost of charging in this section, in the non-use of the energy storage system, 6,680 units were used and 6,665 units were used when using the energy storage system, which represents a decrease of 0.22%.

5.4.3. Scenario 3: Effect of using energy storage system and power transmission in transmission lines

In scenario 2, it was found that network parameters such as transmission capacity and factor a in the cost function of power plants make the energy storage system not a high potential for reducing the cost of generating energy needed throughout the day. In Scenario 3, the effect of the capacity of the transmission lines on the cost of energy production in the state of using the storage system and the non-use of the storage system is investigated.

To this end, considering that the capacity of the transmission lines in the IEEE standard network of 30 buses is enough to provide loads at all times, this amount is considered as the maximum capacity of available lines, and then in different intervals the capacity of all lines with coefficient Specifics are reduced and this reduction continues to apply to at least one of the three following conditions:

1.At least one hour from the day of study, transfer power from at least one line is greater than the intended capacity for that line.
2.At least one hour a day, the power generated by at least one of the power plants is greater than or less than the minimum possible value for that power plant. This may reduce the capacity of the transmission line between the producer and the consumer in the distance, and demand should not be produced by the production unit that may not have the capacity to produce that capacity.
3.At least one hour from the day of study, the voltage of at least one of the network buses should be greater than the maximum permitted voltage or less than the minimum voltage of the voltage for that bus.

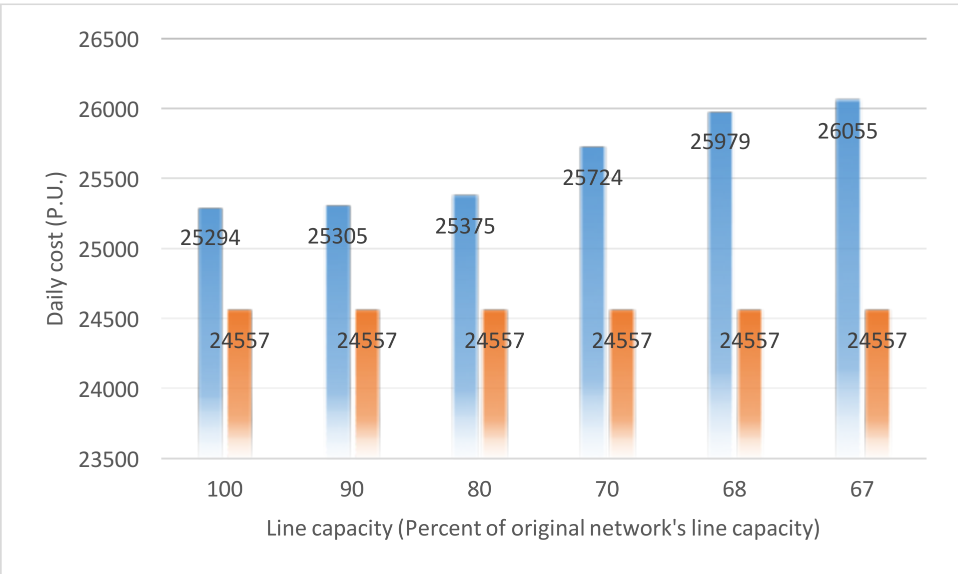


Figure 18: The effect of the capacity of the transmission lines on the minimum daily production cost

As shown in Figure 18, the minimum daily energy cost in an energy storage system will be increased by decreasing the capacity of the transmission lines, while if the energy storage system is used, the minimum cost is approximately equal to Will be fixed.

5.4.4. Scenario 4: The Effect of Using Wind Power Plant

In this section, the aim is to evaluate the effect of using wind energy produced on the daily energy production cost of the grid. As mentioned in the Economic Modeling of Wind Farm, given that this electric power generator is not required to pay fuel during operation, the production cost curve of this generator is linear and does not have an effective coefficient of the second power. On the other hand, the linear coefficient is generally and based on the calculations of the economic modeling sector, it is equal to half the corresponding value in conventional fossil fuel producers. Therefore, it is expected that this generator will always be used at maximum output power in order to reduce the production cost in the optimization algorithm unless network constraints limit this amount of power generation.

Another point is that due to the fact that the wind blowing and therefore the production of wind generators cannot be accurately predicted, here, given the winds in the past times and the discretization technique introduced in the previous chapter, the results are discretely Will be expressed. In other words, for each of the five possible modes of power generation with certain probabilities for each one, the calculation is performed and the result is also presented as probable. For example, if the probability of not producing power (output power zero) per hour is equal to 10%, the maximum output power is zero in the optimization algorithm and at the end the result is also 10% probability.

In this scenario, the cost coefficients of the second scenario are used and the wind power plant is installed in the bus No. 2.

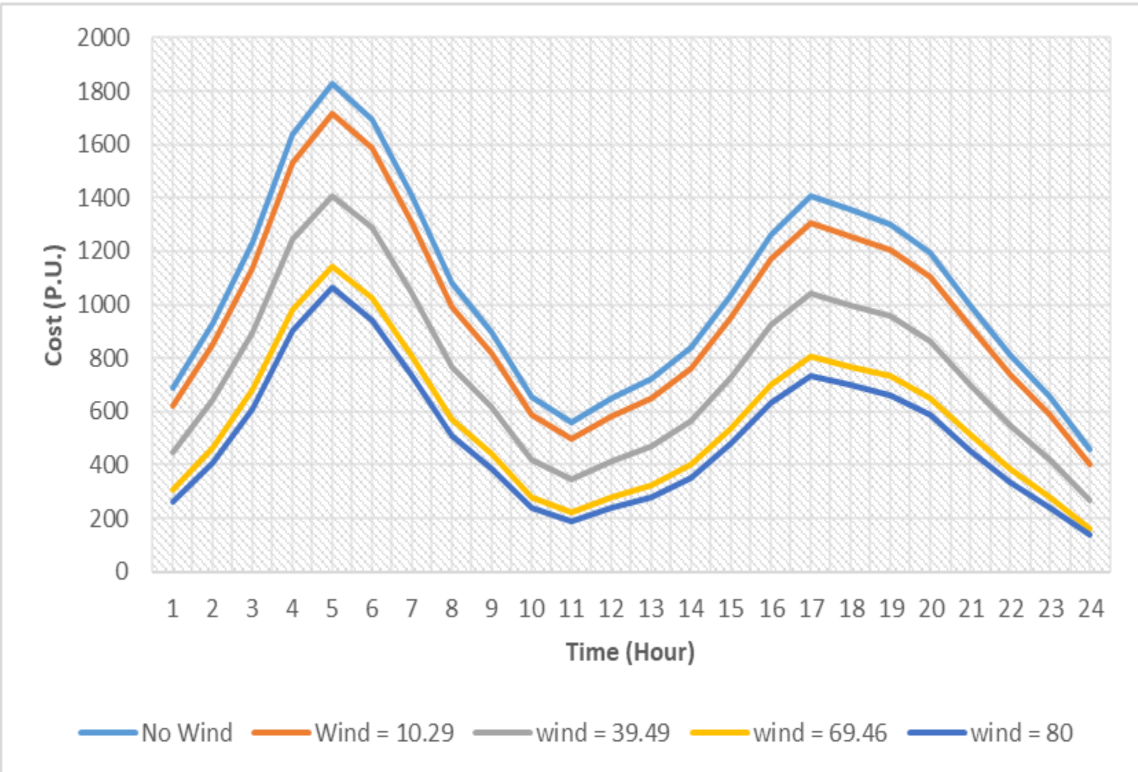


Figure 19: Changes in the cost of producing hourly energy when using a wind generator in a grid

The point to be expected is that, given the linear power cost function of the wind power plant and the small amount of this coefficient, and if the network constraints do not prevent the power generation from wind power, this generator should always produce the maximum possible power. Figure 20 shows the power produced by this generator in the case of a maximum power output of 80 megawatts. As predicted, the production capacity is constant and constant throughout the day and is equal to the maximum allowed for the wind generator.

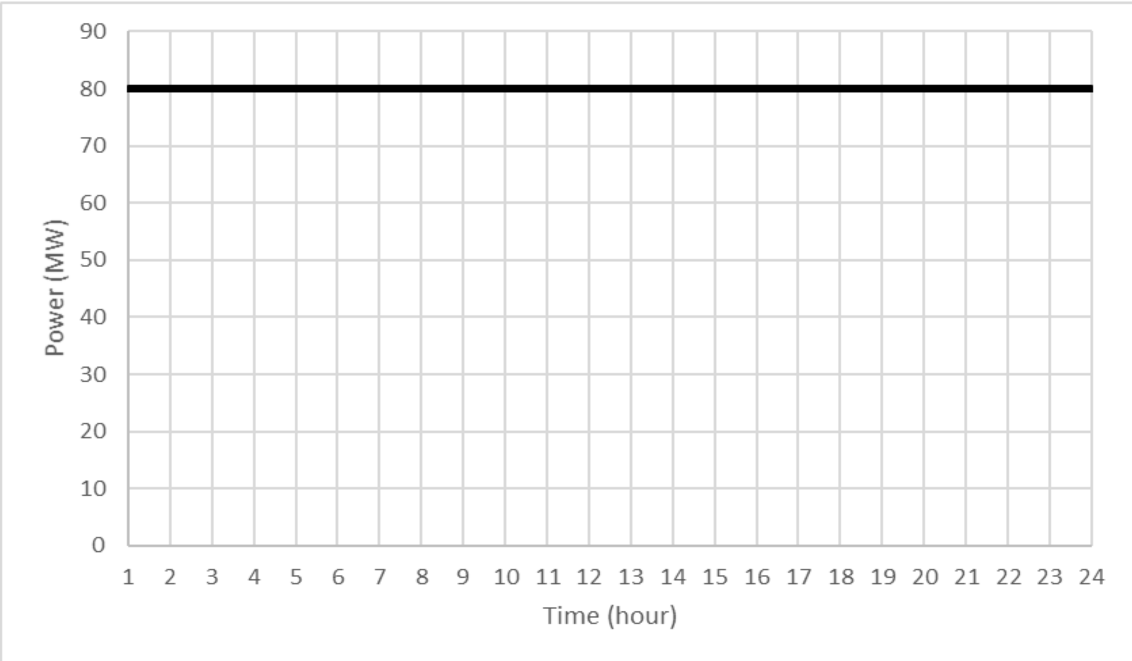


Figure 20: The amount of power generated by the wind generator in a day

Table 13: The cost of generating energy in different hours - using a wind generator in the grid

Time	**Cost**				
Hour	No Wind	Wind = 10.29	wind = 39.49	wind = 69.46	wind = 80
1	690،29582	622،1525622	448،3791602	304،187829	261,68545
2	929،6705	849،7762752	641،9529449	463،5414751	409،06228
3	1233،1373	1140،446386	896،6547047	680،2640953	612،50364
4	16375849	1530،044899	1242،182216	982،2542115	900،34299
5	1829،3871	1715،332142	1408،998766	1144،52304	1067،2873
6	1694،8837	1585،399176	1291،۹۰۷۲۲۶	1027،830518	942،70053
7	1407،7726	1308،408572	1044،169744	808،3138128	733،74116
8	1080،6459	994،1619411	767،2870289	570،1401441	508،78532
9	895،79704	817،4527545	614،1095675	440،2638618	387،38263
10	653،93892	587،7371329	419،532619	281،0395439	240،53155
11	557،32463	496،5406164	343،704882	221،9497064	186،73083

12	646,78458	580,9698347	413,9008017	276,5268883	236,43066
13	720,08401	650,392458	472,158025	323,4070541	279,30881
14	837,36043	762,3961865	566,8909062	401,032988	350,9474
15	1035,0615	950,5161655	729,2465269	537,7884999	478,4343
16	1262,8544	1168,999077	921,8576794	702,0333869	633,07125
17	1407,7905	11308,408571	1044,169744	808,3138128	733,74116
18	1354,163	1258,216426	999,5978785	769,469015	696,90062
19	1303,0306	1207,679537	956,0140271	731,6105777	661,04588
20	1194,0675	1102,92886	863,6027273	651,7894681	585,63094
21	999,30227	916,3075286	699,5209852	511,9750687	454,85905
22	813,20081	739,3881826	547,2411024	384,8056308	335,91788
23	653,93892	587,7371452	419,5326189	281,0395439	240,53155
24	456,1814	401,6522647	266,6685843	163,2199103	137,65325

As the final conclusion of this section, according to the numbers given in Table 13, the use of a wind generator can:

- With a 6 percent probability, it does not make any changes in the cost of generating energy daily.
- With a 20% probability, 2012 will cut unit costs of daily energy production, which is equal to 7.95% of the original cost.
- With 40%, it reduces 7276 units of daily energy production, which is equal to 28.76% of the original cost.
- With 20%, 11828 units reduce daily energy production, which equals 46.76% of the original cost.
- With 14%, it will reduce 13220 units of daily energy production, which equals 52.76% of the original cost.

6. Conclusion

In the framework of various scenarios with the aim of covering the maximum potential of new energy resources, an optimization algorithm is designed and implemented with the aim of allocating these resources in the network and the regime of their use with the aim of minimizing the cost of producing energy in a given period (here a day or night). In summary, the following results can be derived from a case study on a true standard network (IEEE 30 buses network):

1. In case the power plants of a network have similar cost functions, the use of the energy storage system can reduce up to 3% of the cost of generating energy. Examples of this kind of network can be called small networks with small generators or island networks.
2. In the case of network facilities with different cost functions, the reduction of energy costs from renewable sources and energy storage system depends on the quadratic coefficient in the cost function of the power plants. More precisely, the higher the linear coefficient in the cost function to the quadratic coefficient, the potential of new devices for reducing production costs is reduced. For example, if this ratio is equal to 10, the use of the storage system can reduce the cost of production by 2.8%, and if this reaches to 100, the production cost reduction will be limited to 0.22. An example of this network can be seen in the vast network of countries where a wide range of power plants is used.
3. 3. If there is no upgrade in the network facilities including generators and the transmission network, with the increase in load over the coming years, the cost of generating unit units will also increase. In the surveyed network, existing facilities have the ability to provide up to 33% more load than the current 16 years old. The cost of generating energy required in its current state (current time) is 25294 units, while the maximum energy available (16 years ahead) will be 26055 units. It should be noted that these figures represent the current financial value and the real value in the next 16 years depends on the inflation rate.
   The use of the energy storage system, by making it possible to operate uniformly and optimally from network resources, which involves the uniform production level in power plants and the maximum use of transmission lines, can prevent higher cost of production in the coming years. The use of the storage system not only reduces the cost of generating energy at the current time to 24557 units, but also maintains this number for the next 16 years. So at the current time, a 2.9 percent reduction in production costs and in the next 16 years, 75.5 percent of the cost of production without the need to upgrade the network can be created using a central storage system in the network.
4. 4. The use of a wind power plant with regard to the calculated cost function, which is linear (and not the second degree), can always reduce the cost of generating energy. Given that the wind speed and, hence, the production potential of it have been introduced as a possible function, it can be briefly summarized as follows: (The network used for the same network is used as a result of number 3 with similar cost functions.)
   - Using a wind power plant in the network, with a 6% probability, will not change the cost of generating daily energy.
   - The use of a wind power plant in the network, with a 20% probability, reduces the cost of energy production by 95.7%.
   - The use of a wind power plant in the network, with a 40% probability, reduces the cost of energy production by 76.88%.
   - Using a wind power plant in the network, with a 20% probability, reduces the cost of energy production by 76.76%
   - Using a wind power plant in the network, with a probability of 14%, will reduce 13220 units of daily energy production, which is equivalent to 52.76% of the use of wind power in the network.

It should be noted that with regard to the use of a wind power plant in the network, the maximum allowed power production by it, with regard to network security and technical constraints, is considered to be 30% of the total demand at peak demand time.

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