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Presenting An Economic Planning Model to Determine the Optimal Capacity of a Flexible Wind Power Plant

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Abstract: Calculating the optimal size of renewable power plants, including wind power plants, along with storage in a power system is an important issue due to the increasing demand for renewable energy sources. One method for calculating the optimal size is to use the dynamic economic distribution formulation. The goal of this formulation is to find the optimal combination of different energy sources at any given time, based on factors such as production cost, energy demand, investment cost, and other economic-technical factors. However, in all economic distribution problems, it is often assumed that the variables are completely certain. While many variables are subject to uncertainty. Feasible optimization can model these uncertain variables. Feasibility optimization is a method that allows planners to consider uncertainty in their models. Instead of assuming that all variables are known for certain, feasibility optimization considers a range of values for each variable and calculates the degree of necessity and possibility for a given outcome in each scenario. This situation allows planners to plan better even in conditions where there is a high degree of uncertainty. In this thesis, by considering the uncertainty in interest rates, electrical load and wind energy, 7 degrees of necessity and possibility are created and the optimal planning of energy production resources will be discussed by considering different costs with the aim of maximizing the profit of the wind power plant. In order to validate the proposed method, this method is implemented on a standard IEEE 33-bus network and the simulation results show its performance improvement and realism.

Keywords: Dynamic economic distribution, wind power plant, feasibility optimization, degree of necessity and feasibility.

.1Introduction

In the past, power plants were usually built on a large scale, but with the advancement of the science of restructuring and operating power systems, researchers concluded that building power plants on a small scale and close to the consumer has many technical and economic advantages and improves the performance of power systems. Considering the incentives and advantages mentioned, the tendency of investors and operators of power systems is towards the construction and use of generating units based on renewable energies. The increase in the penetration rate of renewable power plants in networks has caused a change in the traditional operating pattern of these networks and the importance of issues such as coordination in the operation of these generating units. In other words, the uncoordinated operation of these units may jeopardize the reliability of the system, the decline in the operating indicators and the quality of power.

On the other hand, the growth and development of smart metering and control devices gives the network operator the opportunity to offer various load management programs to end users and convert them from passive to active mode. The use of load management programs can reduce energy supply costs and maintain network reliability and security at the desired level. The increasing growth of electrical energy consumption and the limitation of fossil energy resources in recent years have caused power system operators in different countries to always seek new solutions for managing consumption and supplying the energy needed by subscribers. Some of the research presented indicates that in the coming years, the high cost of extracting fossil energy resources will practically not allow the exploitation of these resources. On the other hand, the environmental pollution of these energy sources has limited their use in recent years. These problems have increased the tendency of governments to invest in renewable and clean energy sources. The main problem of renewable energy-based power plants is the high investment cost for their construction.

In smart grids, the grid operator, as an independent entity, must provide the energy needed by subscribers in a safe and reliable manner. The high penetration of uncertain resources has jeopardized the security of system operation. Providing effective planning models for the operation and control of future electrical systems is a necessary and essential matter and must be considered when planning for the construction and development of new resources.

In addition, given the uncertainty in the output power of renewable resource-based products, including wind resources, and the penetration of these resources along with appropriate storage devices in the network, this view has greatly strengthened that the combination of the two can be used as a flexible source and the correct management of the two together greatly improves the successful performance of the flexible wind power plant output in the network. A flexible wind power plant, with proper management and control of the power plant unit, allows the operator to benefit from its many economic benefits in addition to managing the penetration of such resources in the network and overcoming some of the existing challenges.

The term flexibility describes the ability of a power system to cope with variability and uncertainty in both generation and demand, while maintaining a satisfactory level of reliability at reasonable cost over different time horizons. There are different definitions of power system flexibility. For example, flexibility is described as the ability to adjust generation in response to changes in net demand over a given energy period. This parameter can be depicted as an important system characteristic for overcoming uncertainties, both in terms of generation and demand changes, while maintaining system reliability with minimal extraordinary cost. Flexibility can be described as the ability of the system to respond to a series of operational deviations based on risk management criteria.

Flexibility resources will be effective in coping with the effects of large intrusions in power systems. These resources can be divided into different categories. The resources have used fast ramp conventional resources to improve flexibility. The use of demand side resources has been considered. And the effects of energy storage on power system flexibility have been investigated. Grid expansion, market design reinforcement, additional ancillary services and smart grid efforts can be considered as other flexibility tools in the power system. These flexibility options help in better control of VER resources and lead to improved electricity cost in the presence of VERS. It should be noted that the best possible option depends on the technical and economic needs of the system. However, energy storage systems should generally be considered as part of energy flexibility, even if energy storage is always the more expensive option. It is important to consider energy storage fully alongside energy flexibility options due to its high reliability.

Wind changes occur on different time scales Seconds Minutes Hours Days Months Seasons and Years In the context of generation scheduling and planning, the goal of managing the daily net load cycle is that the changes can be adequately monitored on an hourly time scale. Very rapid changes are smoothed out due to the inertia of the large rotating blades of variable speed wind turbines. When considering a large area with geographically dispersed wind farms, the second and minute variations are reduced by the smoothing effect of the wind generation variability. In addition, the variations on longer time scales (days, months, seasons and years) are reflected by the total effect of hourly variations. Therefore, hourly wind data cover important information that describes the WG variability in a large system. For this purpose, hourly flexibility is evaluated in this work. Weekly and seasonal flexibility are considered by conducting studies covering a full year.

Large-scale integration of variable renewable energy poses significant technical challenges, largely due to its variable and difficult-to-predict nature. Traditionally, the generation portfolio was designed to provide sufficient flexibility to cope with variability and demand forecast errors and unplanned generation outages in a cost-effective and reliable manner. As the generation capacity from variable renewable sources (such as wind power) increases, the system must also be able to cope with the variations and uncertainties associated with these sources. The need and cost of providing additional flexibility to meet large intermittent generation demands has been recognized from a central planning perspective. However, today this issue also needs to be considered from the perspective of electricity market participants. Some of these participants are flexibility providers with potential providers. They will only provide this flexibility when it is economically profitable. Therefore, the electricity market must provide sufficient revenue to create flexibility in the short and long term. Previous studies have provided a comprehensive list of issues related to the flexibility requirements in a wind-rich system. However, important questions such as how to invest in enough flexible units to meet these requirements, whether flexible sources can be rewarded in a market environment, and how to assess the level of flexibility of a system still await answers. First, we define the term flexibility in the context of the transition to low-carbon electricity systems, and then in the next section we briefly explain the UCC algorithm that It combines long-term investment costs and short-term operations to determine the optimal construction of flexible generation units. The algorithm is able to define a generation portfolio with sufficient flexibility to cope with high wind power penetration while maintaining generation adequacy and system reliability. Over the past years, the power system has been in the transition phase to systems with a high level of penetration of renewable energy sources (RERS). Since RERS produce variable and uncertain electricity depending on weather conditions, new threats to the operation of the power system arise. In this situation, the remaining system must be able to handle the fluctuations present at all times. Even though the electricity production from these new sources changes rapidly and can only be estimated with uncertainty. While contemporary culture has long been adapted to the concept of sustainable electricity consumption and serviceability, this leads to the definition of a new system need for flexibility. In the context of the power system, there are different explanations for the term flexibility. The main aspect is that flexibility is described as the ability of the system to track load changes. Increasing flexibility can play a role It has an important role in the stable and reliable operation of future energy systems with high penetration of renewable energy sources.

In [1], coordinated planning of wind farms, storage facilities, and energy transmission networks with high penetration of renewable energies has been carried out.

In [2], a cost-benefit analysis has been carried out to determine the optimal storage capacity in the power system and the mixed integer linear programming method has been used to solve it.

In [3], several spatial and temporal simplification methods and the mixed integer linear programming formula for the GTEP problem have been presented to optimize the planning of generation and transmission expansion in power systems with respect to fluctuations in renewable energy generation.

In [4], a solution has been presented to improve the performance of the power system, such as the uncertainties in wind power and the proposed model adjusts the participation and distribution of units while ensuring flexible storage capacity adaptively after the realization of wind generation, and also creates a set of adjustable and flexible uncertainties by balancing operational costs and operational risks. In [5], low-carbon generation development planning considering flexibility requirements and wind energy harvesting: This paper uses a CUC cluster unit participation formula to investigate the impact of flexibility on power systems with a high share of wind energy. In this paper, 10-minute ramp-up and ramp-down constraints are introduced for operational reserves, flexible ramp reserves, and precautionary reserves, and a linear programming model is used to formulate

In [6], coordinated reactive power planning has been carried out to increase the voltage stability of a wind power system by considering resilience indicators. It should be noted that in some cases, researchers have used resilience along with flexibility.

In [7], the economic value and optimal size of an energy storage system in a grid-connected wind farm are evaluated using economic models for South Korea, taking into account government incentives. It shows that the way the ESS is managed has a significant impact on the results. The Markov model MDF processing has also been used in this study.

In [8], energy storage allocation in distribution networks with wind integration: In order to compensate for short-term fluctuations in wind energy, the deployment of ES energy storage units in different types has been introduced as a suitable solution and MILP has been used to solve it.

.2The method under study

Determining the optimal size of wind power plants with energy storage system in a power network is an essential issue due to the increasing electrical loads in order to use new energy sources.

Uncertainty modeling: The problem caused by uncertain parameters in the power network has encouraged operators to use various uncertainty modeling methods to prepare for its consequences and make the best decision . [9]

Dynamic Economic Distribution as a Nonlinear Integer Problem:

After reviewing and presenting the formulation of dynamic economic distribution, this section discusses and presents the final model in the nonlinear integer form used in this thesis. The final model consists of the constraints shown in Figure 1. Next, we discuss and explain the objective function and constraints of the problem.

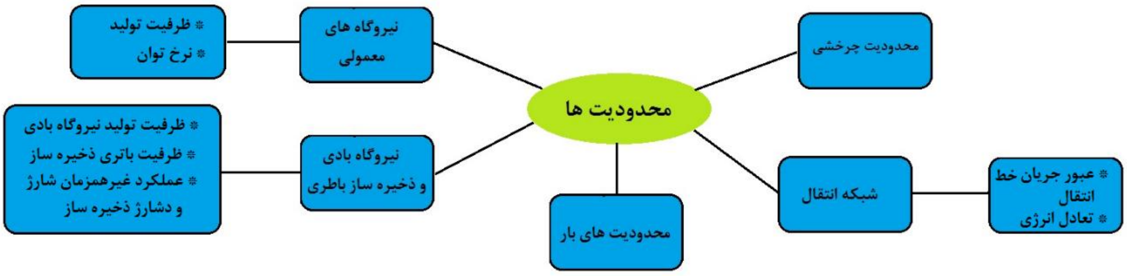

Figure 1: Constraints in the problem of finding the optimal capacity of power plants and storage in dynamic power distribution

DED dynamic economic distribution is actually an optimization problem whose goal is to determine the amount of production for the production units in such a way that the total operating cost is minimized in a given time period, while observing a set of constraints.

Proposed problem-solving model:

In this section, an attempt has been made to present a method for solving the multi-objective programming model with decision variables and fuzzy resources that, while eliminating the shortcomings of previous models, also has simplicity in calculations. This model can be used for all types of cases for right-hand numbers and variables, from definite numbers to symmetric, asymmetric, positive and negative triangular fuzzy numbers.

In this section, to solve Problem 10, we follow the following steps:

Step 1: Each function considers the objective alone and together with the functional constraints of the original problem, and thus, we define a linear programming problem based on the possibility theory with an objective function:

Step 2: According to the definition of fuzzy operators, each fuzzy programming problem of Step 1 can be transformed into Problem:(1)

$$
\begin{aligned}
&max\left(min\right)\left(Z_{Pm},Z_{Pw},\dots,Z_{pw'}\right)=\left(\sum_{j=1}^{n}c_j x_{jm},\sum_{j=1}^{n}c_j w_j,\sum_{j=1}^{n}c_j w'_j\right)\\
&\forall P=1,\dots,p\\
&\left(\sum_{j=1}^{n}a_{ij}x_{jm},\sum_{j=1}^{n}a_{ij}w_j,\sum_{j=1}^{n}a_{ij}w_j\right)\begin{pmatrix}\le\\=\\\ge\end{pmatrix}\left(b_{im},b_{iw},b_{iw'}\right) \qquad (1)\\
&\forall i=1,\dots,M\\
&\tilde{x}=\left(x_{jm},w_j,w'_j\right) is\, non-negative \qquad j=1,\dots,n
\end{aligned}
$$

Step 3: According to the definition of fuzzy number ranking, the problem is transformed into the deterministic model (1). In fact, given the assumption that if and , for the objective function to maximize, since the result of the expression is a fuzzy number of type , in order to maximize this fuzzy number as much as possible, we maximize the value and minimize the value. In the case of minimizing functions, we act in the opposite way; that is, in order to minimize the fuzzy number as much as possible, we minimize the value and maximize the value. We act in the same way in the case of constraints; therefore, we will have:

$$
\begin{aligned}
& max(min)(Z_{Pm}) = \sum_{j=1}^{n} c_j x_{jm} \\
& \min(\max)(Z_{Pw} + Z_{pw'}) = \sum_{j=1}^{n} c_j w_j + c_j w'_j \qquad \forall P = 1,...,p \\
& s.t. \sum_{j=1}^{n} a_{ij} x_{jm} \begin{pmatrix} \leq \\ = \\ \geq \end{pmatrix} b_{im} \qquad \forall i = 1,...,M \\
& \sum_{j=1}^{n} a_{ij} (w_j + w'_j) \begin{pmatrix} \geq \\ = \\ \leq \end{pmatrix} b_{iw} + b_{iw'} \qquad \forall i = 1,...,M \\
& x_{jm} - w_j \geq 0 \qquad j = 1,...,n
\end{aligned} \tag{2}
$$

Step 4: We calculate the optimal solution of the single-objective objective function using the problem $\left(\tilde{x}_p^*\right)$ and then calculate the value for $Z_P^* = \left(Z_{Pm}^*, Z_{Pw}^*, Z_{Pw'}^*\right). \forall P = 1,..., p$ را برای

Step 5: We define a new single-objective problem with the deterministic constraints defined in Step 3 as follows:

$$
\begin{aligned}
& \min \sum_{p=1}^{P} w_P \left[(Z_{Pm}, Z_{Pw}, Z_{Pw'}) - \left(Z_{Pm}^*, Z_{Pw}^*, Z_{Pw'}^*\right) \right] \\
& s.t. \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} x_{jm} \begin{pmatrix} \leq \\ = \\ \geq \end{pmatrix} b_{im} \\
& \sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij} (w_j + w'_j) \begin{pmatrix} \geq \\ = \\ \leq \end{pmatrix} b_{iw} + b_{iw'} \\
& x_{jm} - w_j \geq 0
\end{aligned} \tag{3}
$$

So that represents the weight of the objective function m, which is determined by the decision maker.

Step 6: We find the optimal solution of the Step 6 model, which is an efficient solution to the initial fuzzy multi-objective problem.

Objective function:

The objective function is considered as equation (4). The ultimate goal of this modeling is to determine in the sovereign market what capacity the investor should build a solar power plant with a thermal storage to maximize his profit, considering that he pays the cost of fuel and maintenance of conventional generators and the cost of rotating storage.

$$
\begin{aligned}
\max imize \quad PR
& = \sum_{h=1}^{H} \sum_{d}^{D} \left(P_h ld_{d,h}\right) - \sum_{h=1}^{H} \sum_{f=1}^{F} \left(\alpha_{f,h} gen_{f,h}\right) - \sum_{h=1}^{H} \left(RC_h . SR_h\right) \\
& - \sum_{h=1}^{H} \sum_{f=1}^{F} \left(OM_{f,h} Gen_{f,h}\right) - \sum_{c=1}^{C} \frac{TC_c^{(CAP)}}{y_{LC}} (1+i) \\
& - \sum_{w=1}^{W} \sum_{h=1}^{H} \left(OM_{w,h} gen_{w,h}\right) - \sum_{h=1}^{H} \sum_{d}^{D} \gamma \left(P_h \left(D_{d,h} - ld_{d,h}\right)\right)
\end{aligned} \tag{4}
$$

In this modeling, the parameters, and are considered as uncertain parameters due to their nature. In the following, the problem with uncertainty will be examined from the perspective of feasibility theory.

Simulation of IEEE 33-bus network in the problem:

In this section, the proposed algorithm is applied to the IEEE standard 33-bus network. Figure (2) shows the single-line diagram of this network. This network is radial and has 32 lines.

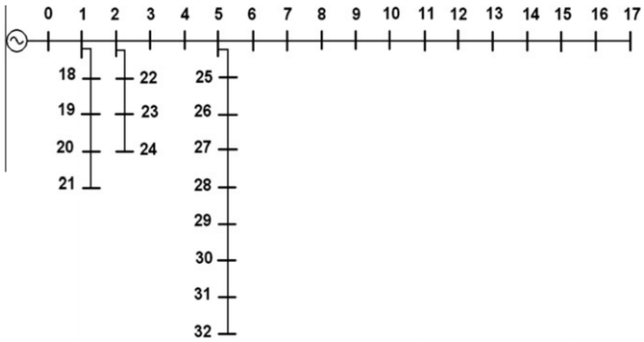

Figure (2): Single-line diagram of IEEE standard 33-bus network

.4Simulation results

In the previous section, a MINLP problem model was introduced in the presence of a wind farm along with an energy storage system. This section examines the aforementioned problem for a standard 39-bus power grid in the New England region of the United States. Based on real data from the United States database, the existing uncertainties will also be formulated and finally, using the feasibility theory, optimal solutions to the problem in the presence of uncertainty will be presented.

.5Simulation results

Twenty-four scenarios that show the time of occurrence of the power outage determined in the first and second cases have been simulated and the total energy outage values are shown in Figures (3) and (4), respectively. From both figures, it is clear that the amount of load outage strongly depends on the start time of the outage. This parameter determines the amount of load consumption and the available power of the renewable energy storage resources (RES) during the disturbance. For example, when the disturbance occurs between 19:00 and 24:00 and lasts for 10 hours, the load demand is moderate and the available wind generation is sufficient. Hence, the amount of energy outage for such a disturbance is low.

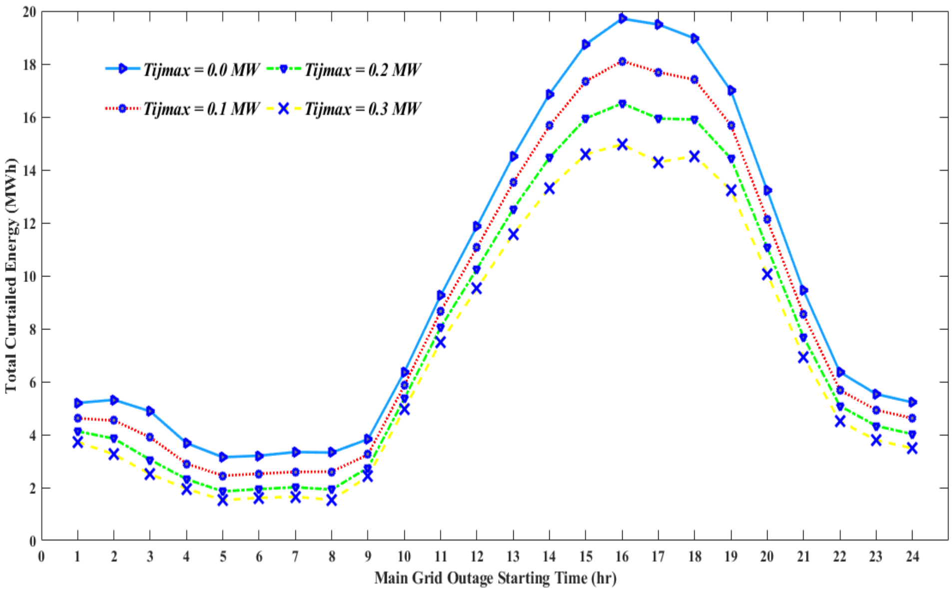

Figure (3): Total energy confined as a function of the blackout onset time in the first case

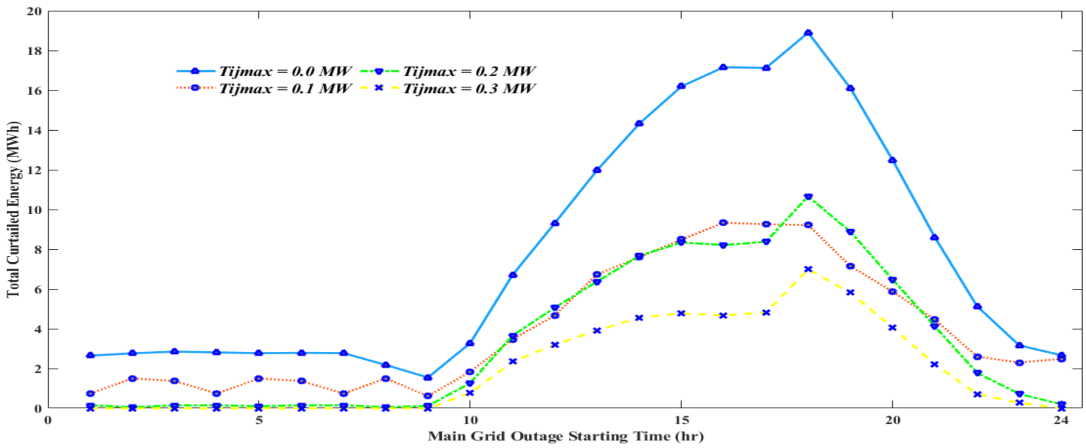

Figure (4): Total energy confined as a function of the blackout onset time in the second case

As can be seen in Figure (4), the proposed management system can significantly increase the overall system performance against main grid outages. For example, when $T_{ij}^{\max}$ $0.1MW$ is set to , the load shedding values for cases starting in the middle of the day can reduce the load shedding by 45%, not when there is no power exchange between the microgrids and the grid. These scenarios are shown in Figures $T_{ij}^{\max}=0$ and model the situation in which the microgrid uses only its own power generation units to supply the loads. When the maximum allowed transmitted power is increased, it leads to further improvements. However, when it exceeds $0.3MW$ $T_{ij}^{\max}$, this increase is insignificant and the results for and coincide, especially at the beginning of the day. The load shedding rate in the second case is significantly higher than in the first case. The power exchange between $0.2MW$ the microgrids and the grid can lead to improved system management. However, this $0.3MW$ و improvement is not as large as in the first case. This can be caused by the loss of the wind turbine in microgrid In addition, the loss of conventional generators reduces the efficiency of the management system. It should be noted that due to the high capacity of conventional generators, they play an important role in reducing power outages in the system, as they can help other parts of the grid that are experiencing power shortages

Figures (5) to (6) show the energy reduction value for each microgrid in cases I and II for $T_{ij\max}=0.2MW$ and $T_{ij\max}=0.3MW$. As can be seen in Figure (5), the maximum power exchange value between the microgrids and the grid is 0.3 MW and there are sufficient renewable energy sources, there is no load reduction before 10. However, when the maximum allowable power exchange decreases, the load reduction decreases as shown in Figure (6). Under these conditions, the reduced load of microgrid 3 is clearly less than that of the other two microgrids. In case II, the line disconnection between microgrid 3 and the grid and the loss of conventional generators increase the reduced load of all microgrids, but this increase is more severe for microgrid 3, as shown in Figures (7) and (8). This emphasizes the connection between microgrid 3 and the grid.

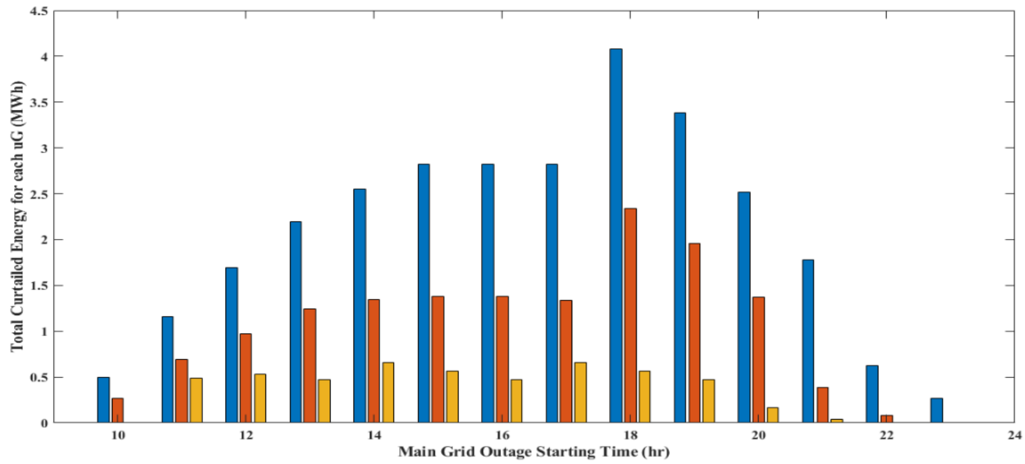

Figure (5): Load limiting in different microgrids as a function of the onset time of different disturbances (first case) considering $T_{ij\max} = 0.3\,MW$

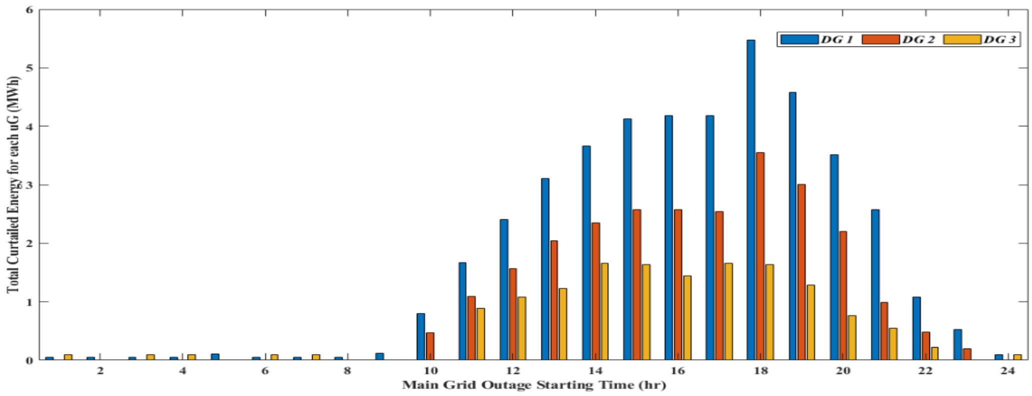

Figure (6): Load shedding in different microgrids as a function of the onset time of different disturbances (first case) considering $T_{ij\max} = 0.2\,MW$

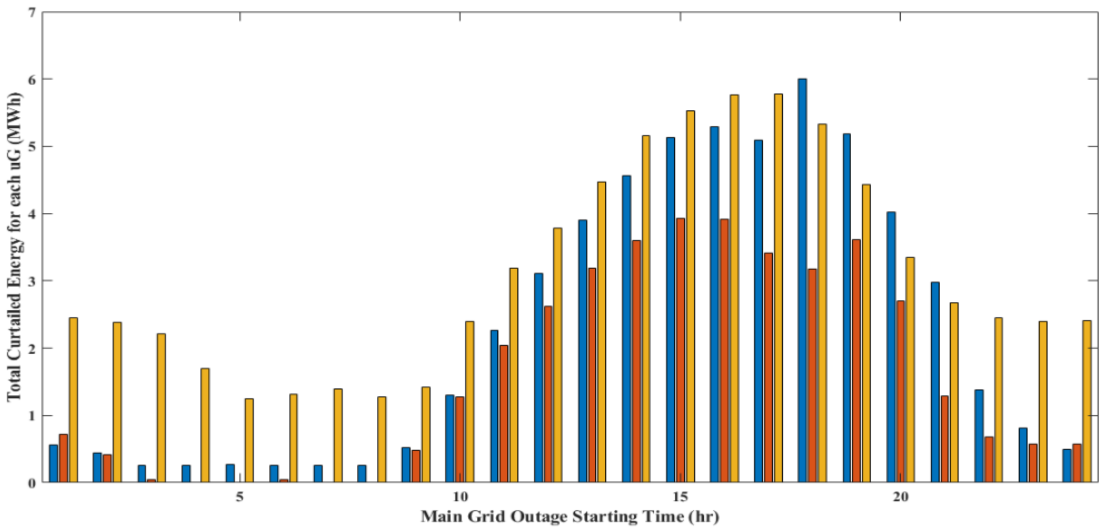

Figure (7): Load limiting in different microgrids as a function of the onset time of different disturbances (second case) considering $T_{ij\max} = 0.3\,MW$

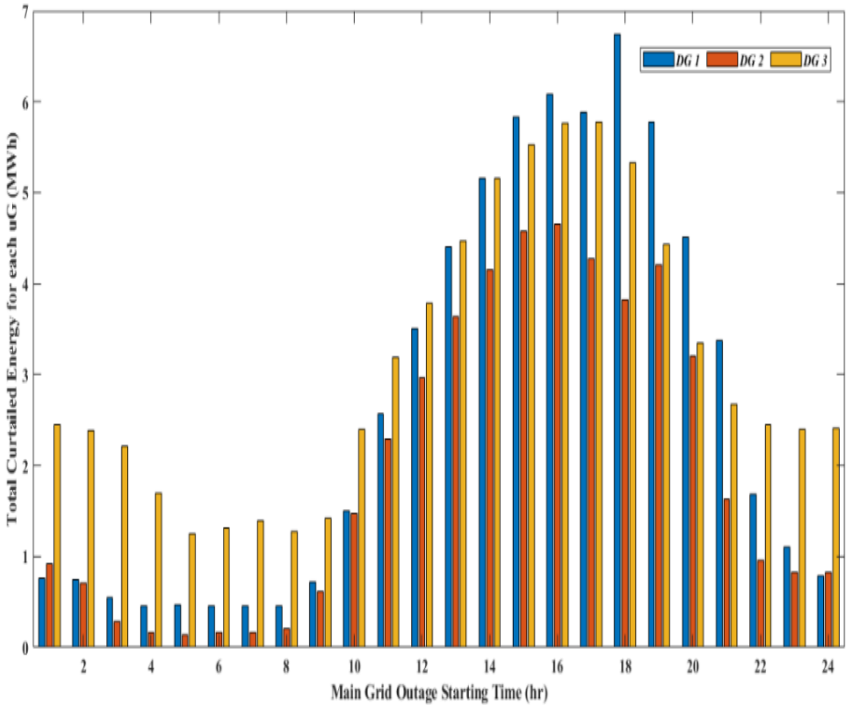

Figure (8): Load limiting in different microgrids as a function of the onset time of different disturbances (second case) considering $T_{ij\max} = 0.2\,MW$

The simulation results are summarized in Table (1). The simulation was performed on a personal computer equipped with a 2.3 GHz processor, DDR RAM, Windows 10 operating system, and MATLAB R2023a and GAMS software.

Table (1): Simulation results

Objective function	Average value $LS_{i,h}(MW)$	Average value $gen_{w,h}(MW)$	Necessity ρ	Possibility ρ
7.3×10^9	6.45	135	0	0/25
7.1×10^9	7.34	143	0	0/5
6.9×10^9	6.68	138	0	0/75
6.6×10^9	6.23	125	0	1
6.5×10^9	6.05	113	0/25	1
6.3×10^9	5.94	109	0/5	1
6.1×10^9	5.74	92	0/75	1

.6Conclusion and Suggestions

The most important goal of this research is to create a planning model for energy production systems by considering technical and economic indicators. In this planning, uncertainties were examined using two new indicators called possibility and necessity. In fact, using these two indicators in modeling uncertainty is one of the innovations of this research. In addition to this innovation, modeling a wind power plant with a storage device that can participate in the electricity market in combination with other sources of electrical energy production is a new phenomenon in this field that has recently attracted the attention of those who are active in the field of power system planning.

In Table 2, net profit, net income from electricity sales, electricity purchase costs, repair and maintenance costs, and investment costs are given for each degree of possibility and necessity. On the other hand, as the degree of possibility and necessity increases, the total profit of the network, which is obtained from meeting demand, also decreases. Because increasing necessity will lead to a decrease in consumer demand. Also, despite the investment cost per megawatt remaining constant, the value of the allocated investment cost per megawatt increases at the end of the first year due to the increase in interest rates. However, due to the higher rate of capacity reduction per increasing degree of necessity, the value of the total investment cost decreases at the end of the year according to Table 2.

Table (2). Economic costs per degree of necessity and various possibilities

Possibility ρ	Necessity ρ	Wind power plant investment cost	Wind farm maintenance costs	Cost of purchasing electricity from the grid	Revenue from selling electricity to the grid	Net profit	Investment percentage
0/25	0	75	22	25	245	145	%125
0/5	0	69	18	23	233	124	%110
0/75	0	63	15	17	217	103	%103
1	0	57	10	16	202	93	%95
1	0/25	52	8	13	184	85	%87
1	0/5	46	6	10	171	73	%73
1	0/75	43	5	7	165	65	%68

Suggestions:

The following suggestions are made for future studies:

•Analyzing the performance of the proposed method with a qualitative objective function approach from the perspective of feasibility theory

•Considering the size of energy storage devices

•Two-level optimization and improving other parameters such as network losses, voltage profile and pollutant emission rate

•Optimal placement of energy sources in the network

•Adding new concepts such as electric vehicles and smart parking lots

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