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PROPOSING AN ECONOMIC PLANNING MODEL TO DETERMINE OPTIMAL CAPACITY OF A FLEXIBLE WIND POWER PLANT

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***ABSTRACT*:**

It is difficult but essential to decide on the cost planning and borrowing method to implement large-scale projects under uncertain time conditions. Considering the unique design of each power plant and the climatic conditions affecting its design and establishment, conducting any research for the design and implementation of special projects such as wind power plants (WPPs) requires the utiliza-tion of uncertain models for planning in order to provide appropriate financial resources and manage the use of WPPs. Tradtional design of power systems is in such a way that offer a flexible context where demand is fulfilled by mass generation. Besides, flexibility required for maintaining load-generation balance is increased by the incorporation of uncertain and variable renewable generation sources, like wind. This manuscript is an attempt to determine the sizing of the WPP capacity along with the amount of storage capacity that can provide the possibility profit for the investor, consider-ing the uncertainties and challenges available in this regard. Thus, it is essential to specify in the planning horizon the amount of load needed by the grid, the wind level of the geographical area, the wind farm's output power and the interest rate, all of which have major uncertainties. This is possible by presenting a mixed integer model and considering the behavior and characteristics of the storage WPP and the challenges of grid flexibility. To develop this hybrid model, possibilistic programming will be used for optimization.

Keywords*: Flexible wind power plant, Possibility, Necessity.*

INTRODUCTION

The surging growth of electric energy consumption (EEC) and limitation of fossil energy sources in recent years have compelled power system operators in different countries to keep seek-ing new solutions for managing consumption and supplying the energy needed by subscribers. Some studies have shown that the high cost of extracting fossil energy resources will practically tackle the exploitation of these resources in the coming years. On the other hand, the environmental pollution of these energy resources has curtailed their use in recent years. These problems have compelled governments to invest in renewable and clean energy resources. The major problem of renewable energy power plants is the high investment cost for their construction.

The operator in smart grids, as an independent entity, must provide the energy needed by subscribers in a safe and reliable manner. The extensive integration of unpredictable energy sources threatens the reliability of operations of power systems. Providing effective planning models for the operation and control of future electrical systems is so essential that it needs to be considered when planning for the construction and development of new resources.

In addition, given the uncertainty in the output power of renewable energy sources, including wind, and penetration of these resources along with appropriate storage devices in the grid have strengthened the view that their combination can be used as a flexible source and their proper management can improve the performance of the flexible WPP in the grid. Through the proper management and control of the power plant unit, a flexible WPP allows the operator to profit from its extensive economic benefits in addition to managing the penetration of such resources in the grid and overcoming some of the existing challenges.

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Reference [1] proposed several spatial and temporal simplification methods based on the mixed integer linear programming (MILP) formulation for the generation and transmission expansion planning (GTEP) problem in order to optimize the GTEP in power systems considering volatility in renewable energy generation.

A solution was proposed in Reference [2] to improve the performance of the power system, such as the uncertainties in wind power. The proposed model optimizes the unit commitment and dispatch solutions for the base case and guarantees adaptive adjustment of flexible reserve capacity following realization of wind generation. It produces a flexible and adotable uncertainty set through making a balance between the operational risk and costs. Reference [3] dealt with the optimal sizing and economic value assessment of an energy storage system (ESS) in a grid-connected wind farm using economic models for South Korea, considering government incentives. It demonstrated that the ESS management method greatly affects the outcome. The Markov decision process (MDP) model was also utilized in this study.

Reference [4] presented a generation capacity planning model to integrate grid-connected solar photovolta-ic (PV) generation systems and utility-scale wind farms through multi-stage stochastic programming. For modeling with nine stages for a year, a multi-stage scenario tree was constructed.

Reference [5] proposed the information gap decision theory (IGDT) to address long-term wind energy planning that considers voltage stability. The central aspect of the model is to consider the long-term wind energy uncertainty through the IGDT. Monte Carlo simulation was applied for managing uncertainty. The proposed model confirms its applicability for optimal wind energy planning and helps farm investors making optimal wind energy investment decisions on a large scale.

Reference [6] focused on the investment optimization of grid-scale energy storage to support varying wind power utilization levels. It used multiple storage technologies for wind farm planning. It also considered load and wind uncertainty in solving the problem and utilized nonlinear integer programming with Benders de-composition (BD) method to simplify the implementation of the algorithm and ultimately improved the computational efficiency to solve these chance-constrained problems.

Reference [7] formulated two main planning problems in power systems, namely reactive power and transmission expansion as a MILP, which consider the bilevel configuration for reflecting market clearing in varying load-wind conditions. This approach aimed at minimizing costs of installing transmission network, reactive power sources, and the annual operational costs of conventional generators associated with the cur-tailed wind energy and ensuring reliable performance of system. Lower-level problems in the bilevel configu-ration dealt with market clearing, modeled through linearized optimal power flow equations. For obtaining MILP formulation, the lower-level components were reformulated using primal-dual approach. This approach helps power system planners develop cost-effective investment strategies by making a balance between wind power curtailment and the deployment of reactive power resources and transmission infrastructure.

Reference [8] dealt with the flexible design problem of RESs in optimization software GOSSIP that offers a structure for formulation and efficient solution complicated large two-stage stochastic programs. Two-stage stochastic programming, as an optimization method, considers uncertainty by separating the decision varia-bles into two stages. It uses the MILP and the decomposition method embedded in the software. It has been demonstrated that the flexible design approach, that utilizes the two-stage stochastic programming frame-work, results in profitability of the project through enhancing flexibility via battery energy storage and regulat-ing the deployment capacity of renewable resources.

Reference [9] dealt with the optimal sizing and siting of wind farms. It formulated the metrics that capture wind speed characteristics (wind power density, arithmetic mean of wind speed) for specifying the possibility of establishing wind power plant. Additionally, a linear optimization approach was presented for determining the deployed capacity and geographical location of wind farms so that the predicted generation of annual wind power is maximized and the restrictions imposed by the transmission system operator and electrical power grid in Turkey are met.

According to Reference [10], there is a linear relationship between the increase in the net present value for investment and wind farm capacity and the transformer size. It can be concluded that electricity cost and wind resources are primary parameters for feasibility of wind farms.

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Reference [11] provided an optimal capacity outline of ESS for wind farm by the use of the Improved Sto-chastic Particle Swarm Optimization (ISPSO). For obtaining the HESS optimal capacity framework, the pre-sent study presented an optimization plan for enhancing of HESS performance/cost ratio and fulfilling the condition of smoothing wind power fluctuations. The major constraints in the optimization model included the maximum fluctuations in wind farm and power output average, with introducing simulated annealing ap-proach into Stochastic Particle Swarm Optimization (SPSO) for improving its convergence, resulting in an ISPSO.

Reference [12] analyzed the generation effect on returned investment cost and investment risk in transmis-sion network. The recovered values of investment and risk costs in transmission lines were obtained and compared in different wind power penetration levels. This is an approach for finding investment attractive lines with uncertainties, where transmission network expansion planning (TNEP) is expressed as a multi-objective optimization problem with maximization of the network reliability and recovered investment cost and minimization of the investment cost as its objectives. Using the point estimation method (PEM), wind speed changes at wind farms in the optimization problem is addressed. The trade-off regions between the TNEP objective functions were determined using the NSGA II algorithm. The final optimal plan was decided upon using fuzzy satisfying approach. Reference [13] analyzed the cohort intelligence optimization (CIO) method in order to tune proportional integral derivative (PID) controller for load supervision of single region nuclear power plant. Different cost functions were also studied for finding the CIO-based supremacy. The CIO-PID controller approach pro-vides enhanced solutions to the extent of an objective function, function evaluation, calculation time, and dy-namic system response-based ITAE objective function. Lastly, the presented PID controller offers enhanced dynamic response for 1, 2, 5, and 10% robustness validation. Moreover, a sensitivity analysis involving ± 25 to ± 50% variations in nominal parameters was conducted to evaluate the feasibility of the presented ap-proach.

Reference [14] used a multi-stage model to present a coordinated wind-thermal-energy storage presenting strategy in energy and spinning reserve markets. A three-stage stochastic multi-objective framework based on mixed-integer programming was developed for a wind-thermal-energy storage generation firm operating in the energy and spinning reserve markets. It utilized two separate strategies, including a emission trad-ing pattern and preference-based method for obtaining the most preferred option among Pareto optimal solutions. As shown by the results, in the offering strategy framework, spinning reserve market provided greater profitability for the energy storage system compared to energy market.

Reference [15] proposed a method to avoid short-term market exposure of electricity producers in the Brazilian electricity system. To achieve this goal, the researchers employed a simulation method that allowed to model cash flows considering uncertainty in variables corresponding to electricity generation, project financial assumptions, and producer exposure to the short-term market. To this aim, they presented a novel method for investment analysis, which allows identifying the major uncertainty parameters and risks related to these projects in the Brazilian electricity market. Moreover, they employed the Value at Risk approach for conduct-ing the risk management analysis.

Reference [16] proposed an integrated regulation strategy (IRS) for WT/BESS that contains a cooperative output adjustment scheme for WT and a dual-hysteresis charging/discharging process for BESS. According to results, ISBPP effectively helps decision makers gain optimal SES planning schemes with introducing elec-tric vehicles (EVs). Besides, results showed that transitioning from a fossil-based energy system to a sustaina-ble model requires governmental policies and financial incentives that promote development of renewable energy sources. These results are helpful for decision makers in crafting an effective sustainability strategy by comprehensive investigation of trade-offs between system costs, environmental pollution mitigation, and level of EV adoption.
As mentioned above, one of the problems of renewable generation penetration in the grid is the uncer-tainty of the output power of these sources. The two renewable generation sources, wind and sunlight, which have high penetration in the power grid, especially in recent years, have their output power dependent on weather conditions. Sudden and unpredictable changes in weather conditions, including the intensity of solar radiation and wind speed, influence the output power of renewable generation. Therefore, the amount of power generated by these sources in real time is different from the predicted and planned values, which is a big challenge for the microgrid operator. This uncertainty and prediction error creates an imbalance between generation and consumption and makes the operation of the microgrid difficult. In this case, the operator attempts to remove the imbalance and preserve the security of the grid by consideration of reserve power in the system.

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By solving the optimization problem for multiple scenarios, MIP methods allow for a comprehensive analysis of the uncertainty in the system and provide a more robust solution to the optimization problem. The solution considers a full range of possible outcomes rather than the expected value, thereby providing a more realistic representation of the system under uncertainty.

Possibilistic optimization is a method for solving optimization problems under uncertainty that considers both the likelihood and the possibility degree of scenarios. Unlike stochastic programming and chance-constrained programming, which use probability distributions to model uncertainty, possibilistic optimization uses the possibility theory for this purpose. This theory provides a more general framework for modeling uncertainty than the probability theory and can be used to model situations where probabilities have not been defined properly or where it is difficult to estimate the probabilities.

This manuscript proposes a novel method for the economic distribution of generation units considering uncertainty using possibility distribution with the objective of maximizing the profit of electrical energy sales. The second section deals with formulation of the economic distribution problem considering uncertainty. The proposed method is implemented in an IEEE standard grid and next section presents the results are prsented in detail. Lastly, a general conclusion is presented.

PROBLEM FORMULATION

The problem's final model is presented in this section. The final model consists of constraints relating to conventional generators, load, transmission grid, spinning reserve, and WPP. The constraints and objective function of the problem are analyzed and explained.

The constraints of conventional generators include the generation capacity and power rate constraints. The generation capacity and power rate constraints are formulated as Equations (1) and (2), respectively.

$$\text{A.}\quad \alpha_{f,h} Gen_f^{(MIN)} \le gen_{f,h} \le \alpha_{f,h} Gen_f^{(MAX)} \qquad (1)$$

$$\text{B.}\quad -\alpha_{f,h} Gen_f^{R} \le gen_{f,h} - gen_{f,h-1} \le \alpha_{f,h} Gen_f^{R} \qquad (2)$$

2.1 WPPs and ESSs

The maximum wind energy generation level, as mentioned, is dependent on the amount of wind blowing at that hour, which is uncertain. Besides, ESSs have constraints on the power generation and consumption as well as on energy storage. These constraints are presented in Equations (3) – (5).

$$\text{C.}\quad gen_{w,h} \le \alpha_{w,h} Gen_w^{(MAX)} \qquad (3)$$

$$\text{D.}\quad 0 \le ch_{w,h} \le \alpha ch_{w,h} ch_{w,h}^{\max} \qquad (4)$$

$$\text{E.}\quad 0 \le dch_{w,h} \le \alpha dch_{w,h} dch_{w,h}^{\max} \qquad (5)$$

$$\text{F.}\quad \alpha ch_{w,h} + \alpha dch_{w,h} = 1$$

$$E_{w,h+1} = E_{w,h} + \left(\alpha ch_{w,h} ch_{w,h} \eta_{ch} \Delta t - \alpha dch_{w,h}\, dch_{w,h} \eta_{dch} \Delta t / \eta_{dch}\right) \qquad (6)$$

2.2 Spinning reserve constraints

Reserve constraint is an operational requirement of a power system in which a certain amount of power generation capacity must always be available to balance the grid against sudden changes in demand or supply. The spinning reserve constraint ensures that adequate capacity is maintained in storage to respond to unfore-seen events. Storage systems can help with this constraint, while WPPs cannot because their power capacity is not always available. The spinning reserve constraint is modeled as Equation (7).

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$$G.\ \left\langle \sum_{f}\left(Gen_{f}^{(MAX)}-\alpha_{f,h}gen_{f,h}\right)+\sum_{w}\left(\alpha dch_{w}\eta_{dch}dch_{w}-\alpha ch_{w}\eta_{ch}ch_{w}\right)\geq SR \qquad \forall h \right\rangle \quad (7)$$

2.3 Load and transmission grid constraints

The goal of a price-based dynamic economic distribution problem is to maximize profit (via power sales), so the variable must be curtailed to the amount of demand and maximize its value with respect to the objective function. This constraint is modeled as Equation (8). One of the transmission grid constraints is related to the electricity flow through a transmission line, modeled by Equations (9) and (10).

$$H.\ \ 0\leq ld_{d,h}\leq D_{d,h} \quad (8)$$

$$I.\ \ -K_{l}^{(MAX)}\leq flow_{l,h}\leq K_{l}^{(MAX)} \quad (9)$$

$$J.\ \begin{aligned}&\sum_{n}\sum_{s}\lambda_{s}dch_{s,h}-\sum_{n}\sum_{s}\lambda_{s}ch_{s,h}+\sum_{n}\sum_{f}\lambda_{f}gen_{f,h}\\&-\sum_{n}\sum_{d}\lambda_{d}ld_{d,h}+\sum_{n}\sum_{c}\lambda_{c}gen_{c,h}=flow_{l,h} \qquad \forall l,h\end{aligned} \quad (10)$$

2.4 Electric energy balance constraint

It is very important to maintain a balance between electricity demand and generation, because any signifi-cant deviation from this balance can lead to instability (voltage fluctuations, frequency deviations, etc.) in the power system and potentially cause power outages or even damage to equipment. The electric energy balance constraint in the presence of a WPP with a storage system is formulated as Equation (11).

$$K.\ \sum_{f}\alpha_{f,h}gen_{f,h}+\sum_{s}\left(\eta_{dch}P_{dch}-\eta_{ch}P_{ch}\right)=\sum_{d}ld_{d,h} \qquad \forall d,h \quad (11)$$

2.5 Objective function

The objective function is formulized as Equation (12). This modeling aims at specifying the capacity with which the investor should build a solar power plant with a thermal storage device in a sovereign market for maximization of his yield so that he can pay the cost of fuel, repair and maintenance of conventional genera-tors as well as that of spinning reserve.

$$L.\ \begin{aligned}&\max imize \quad PR\\&=\sum_{h=1}^{H}\sum_{d}^{D}\left(P_{h}ld_{d,h}\right)-\sum_{h=1}^{H}\sum_{f=1}^{F}\left(\alpha_{f,h}gen_{f,h}\right)-\sum_{h=1}^{H}\left(RC_{h}.SR_{h}\right)\\&-\sum_{h=1}^{H}\sum_{f=1}^{F}\left(OM_{f,h}Gen_{f,h}\right)-\sum_{c=1}^{C}\frac{TC_{c}^{(CAP)}}{y_{LC}}\left(1+i\right)\\&-\sum_{w=1}^{W}\sum_{h=1}^{H}\left(OM_{w,h}gen_{w,h}\right)-\sum_{h=1}^{H}\sum_{d}^{D}\gamma\left(P_{h}\left(D_{d,h}-ld_{d,h}\right)\right)\end{aligned} \quad (12)$$

This manuscript analyzes the MINLP model with objective function (12) and constraints (1)-(11). In this modeling, the parameters, and are considered uncertain parameters due to their nature. In the following, the uncertain problem will be examined based on the possibility theory.

2.6 Reformulating the problem into a possibilistic programming model

Given the uncertainties in the interest rate and the electrical demand of the wind energy , it is necessary to reformulate the terms in the constraint and the objective function that include these parameters using the possibility and necessity indices. Equations (8) and (12) are transformed into Equations (13) – (15) for the necessity index and into Equations (16) – (18) for the possibility index.

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$$M.\quad Nes\left(ld_{d,h} \le D_{d,h}\right) \ge p \tag{13}$$

$$N.\quad Nes\left(gen_{w,h} \le \alpha_{w,h} Gen_{w}^{(MAX)}\right) \ge p \tag{14}$$

$$\max imize \quad PR = u$$

$$O.\quad Nes\left(\begin{array}{l} \sum_{h=1}^{H}\sum_{d}^{D}\left(P_h ld_{d,h}\right) - \sum_{h=1}^{H}\sum_{f=1}^{F}\left(\alpha_{f,h} gen_{f,h}\right) - \sum_{h=1}^{H}\left(RC_h . SR_h\right) \\ -\sum_{h=1}^{H}\sum_{f=1}^{F}\left(OM_{f,h} Gen_{f,h}\right) - \sum_{c=1}^{C}\frac{TC_c^{(CAP)}}{y_{LC}}(1+i) \\ -\sum_{w=1}^{W}\sum_{h=1}^{H}\left(OM_{w,h} gen_{w,h}\right) - \sum_{h=1}^{H}\sum_{d}^{D}\gamma\left(P_h\left(D_{d,h} - ld_{d,h}\right)\right) \end{array}\right) \tag{15}$$

$$P.\quad Pos\left(ld_{d,h} \le D_{d,h}\right) \ge p \tag{16}$$

$$Q.\quad Pos\left(gen_{w,h} \le \alpha_{w,h} Gen_{w}^{(MAX)}\right) \ge p \tag{17}$$

$$\max imize \quad PR = u$$

$$R.\quad Pos\left(\begin{array}{l} \sum_{h=1}^{H}\sum_{d}^{D}\left(P_h ld_{d,h}\right) - \sum_{h=1}^{H}\sum_{f=1}^{F}\left(\alpha_{f,h} gen_{f,h}\right) - \sum_{h=1}^{H}\left(RC_h . SR_h\right) \\ -\sum_{h=1}^{H}\sum_{f=1}^{F}\left(OM_{f,h} Gen_{f,h}\right) - \sum_{c=1}^{C}\frac{TC_c^{(CAP)}}{y_{LC}}(1+i) \\ -\sum_{w=1}^{W}\sum_{h=1}^{H}\left(OM_{w,h} gen_{w,h}\right) - \sum_{h=1}^{H}\sum_{d}^{D}\gamma\left(P_h\left(D_{d,h} - ld_{d,h}\right)\right) \end{array}\right) \tag{18}$$

SIMULATION RESULTS

A MINLP problem in the presence of a wind farm with an ESS was presented in the previous section. This section examines the problem for a standard 39-bus power grid in the New England region of the Unit-ed States. Based on real data from the U.S database, the uncertainties will be formulated and finally the opti-mal solutions to the problem in the presence of uncertainty will be presented using the possibility theory.

3.1 Uncertain parameters

Demand data

Electricity demand is the total amount of electricity required by consumers at any given time and it can be divided into commercial, industrial, and residential loads. Commercial load means the electricity demand of businesses and other commercial establishments such as stores, offices, and hospitals, while industrial load implies the electricity demand of factories and other manufacturing facilities. However, residential load denotes the electricity demand of households and apartments. These different types of loads have distinct EEC pat-terns an understanding of which is essential for planning and operating the power system. For example, commercial loads typically peak during the day, while residential ones typically peak in the evening. However, industrial loads may have varying demand patterns depending on generation schedules.

According to a report on the U.S energy consumption rate [18], total EEC is composed of 26% industrial load, 39% residential load, and 35% commercial load, the electricity consumption profile (ECP) of each is examined below. All power profiles used in the following sections were obtained based on real data from several New Eng-land cities available in the Homer software.

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Industrial Load
Fig. 1 shows the ECP for industrial load for New England power grid in various cities in one year and the first week.

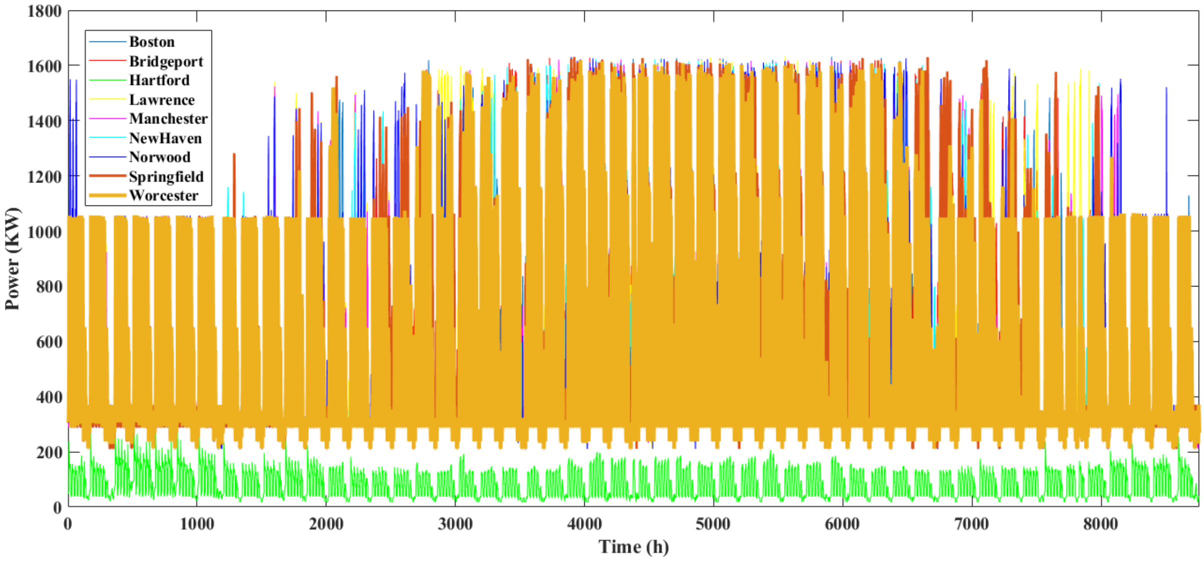

Fig. 1 ECP for industrial load in New England cities

Commercial Load
Fig. 2 shows the ECP for the commercial load for the New England power grid in various cities for one year and the first week. The commercial profile consists of a large hospital with an area of approximately 5000 m2. The goal was to find the consumption profile in the commercial part of this grid.

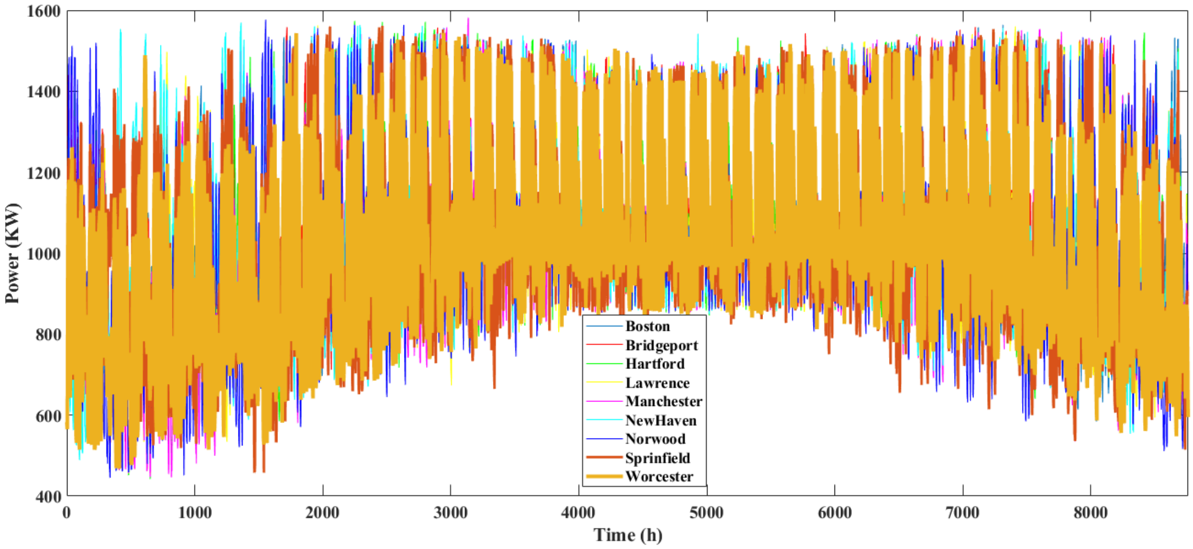

Fig. 2 ECP for commercial load in various cities of New England

Residential Load
Fig. 3 shows the ECP for the residential load for the New England power grid in one year and the first week. The average consumption load of 8 houses from each city was used to calculate the residential load. It was also assumed that the load per hour has a Gaussian distribution with the mean values given in Fig. 3 and a 10% variance of these values.

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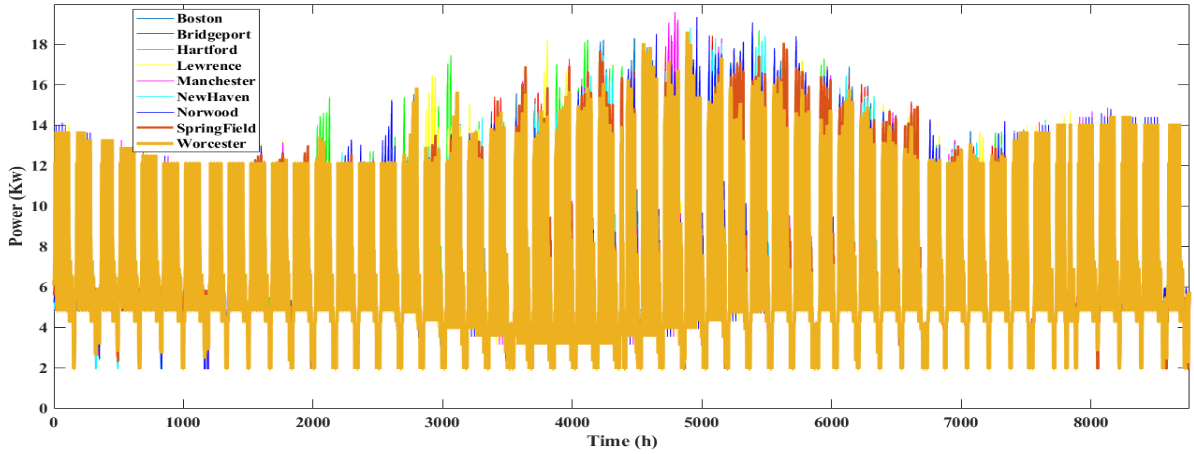

Fig. 3 ECP for residential load

As a result, , which consist of industrial, commercial and residential loads, has uncertainty with a Gaussian distribution (since residential loads have uncertainty with a Gaussian distribution).

Interest rate

Since the problem modeled in the previous section can be solved with the aim of maximizing profit for an arbitrary number of years and the investment cost per year is calculated using the interest rate, it is essential to consider the interest rate each year during the life cycle of the wind farm and the storage system. According to the interest rate data available on the World Bank website [19], the interest rate data for the last 60 years in the USA is as shown in Fig. 4. It can be examined as statistical data based on which the best Gaussian distribu-tion can be estimated.

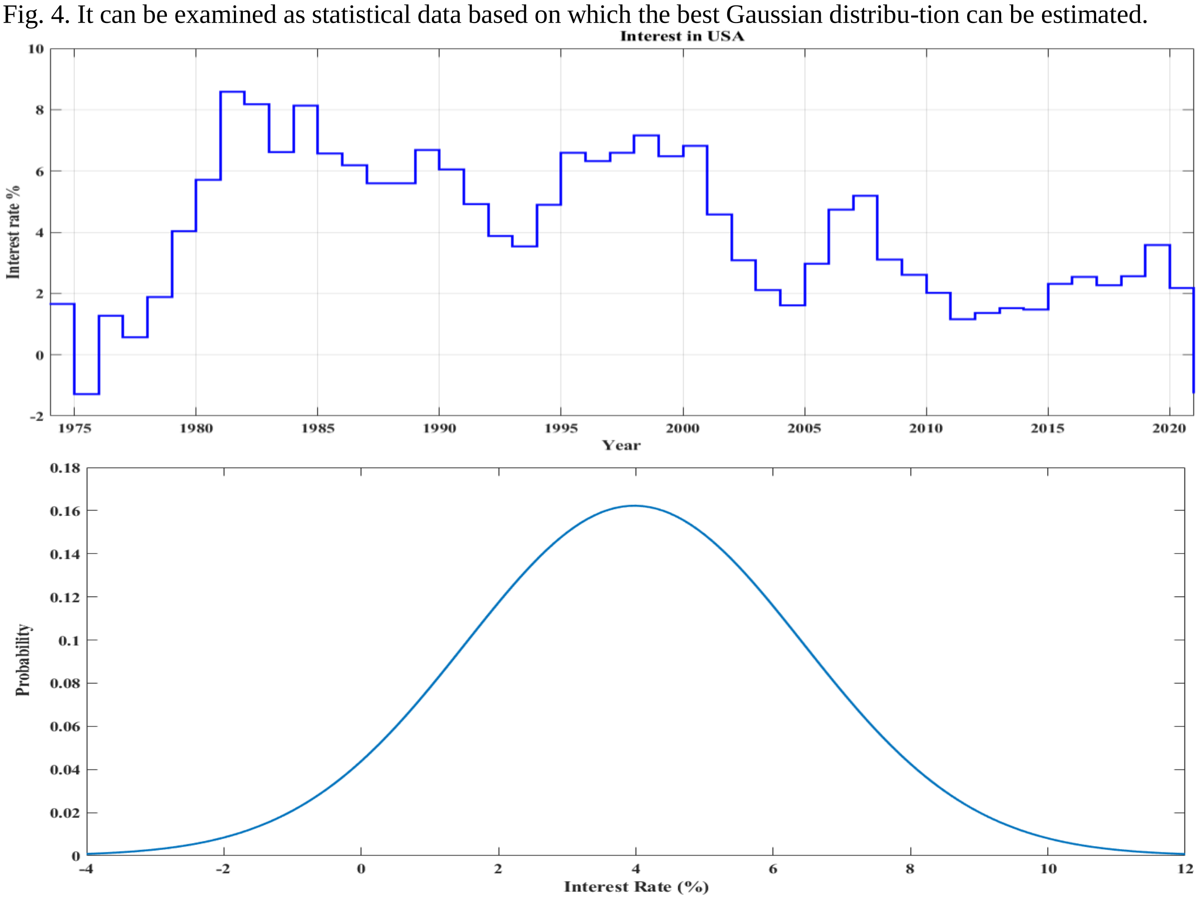

Fig. 4 Interest rate in a given time period and its possibility distribution

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3.2 Certain parameters

Electricity price

Since the problem is modeled as economic distribution, the price of electricity in New England is needed. The time of use (TOU) price has been considered for weekdays and weekends and quantified using price data on the Bureau of Labor Statistics website [99] for each hour, as shown in Fig. 5.

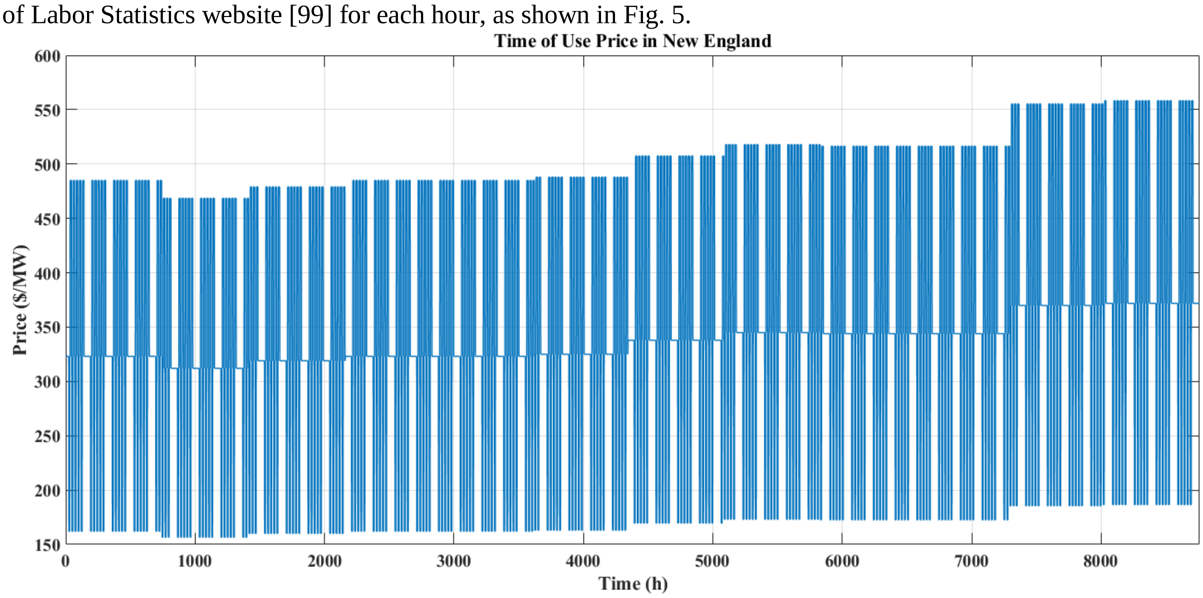

Fig. 5 TOU price considered for each megawatt

Other Parameters

The other parameters involved in the problem are presented in Tab. 1.

Tab. 1 Parameters considered for simulating the problem

A. $\forall f, cs, h, y = 1$					
G. F	F. 10	E. γ	D. 5	C. OM_f	B. 15
M. C	L. 1	K. OM_C	J. 22	I. RC_f	H. 40
S. S	R. 1	Q. OM_S	P. 22	O.	N.
Y. D	X. 21	W. SR	V. 500	U.	T.
EE. H	DD. 8760	CC. η_{ch}	BB. 0.8	AA.	Z.
KK. L	JJ. 46	II. η_{dch}	HH. 0.6	GG.	FF.
QQ. y_{LC}	PP. 25	OO. η_{Loss}	NN. 0.01	MM.	LL.
WW. Y	VV. 1	UU. $TC_c^{(CAP)}$	TT. 2847600	SS.	RR.

Evaluation of the problem solutions

The results of the simulation are given in Tab. 2. This simulation was performed using a PC with an In-tel(R) Core(TM) i5-4200 processor with a frequency of 2.3 GHz, 4 GB of DDR4 RAM, and a 250 GB SSD storage device, 100 GB of which was considered as virtual RAM. The PC had a Windows 10 operating sys-tem and the simulation was performed using MATLAB R2023a and GAMS. The solver settings used in the simulation included the default mixed integer optimization algorithm. These PC capabilities are reported to ensure the transparency and reproducibility of the simulation results.

Tab. 2 Simulation results

J. Possibility K. ρ	H. Necessity I. ρ	F. Interest rate G. i	D. Consumption load $D_{r,h}$ E. Energy generated by wind $gen_{w,h}$	C. Objective Function PR	B. Average size $gen_{w,h}$	A. Solving time (per second)
R. 0.25	Q. 0	P. 0	O. $\mu_{D_{r,h}} + \sigma_{D_{r,h}}\sqrt{-2\ln(0.25)}$ $\mu_{gen_{w,h}} + \sigma_{gen_{w,h}}\sqrt{-2\ln(0.25)}$	N. 8.5×10^{9}	M. 555	L. 1010
Y. 0.5	X. 0	W. 0.92%	V. $\mu_{D_{r,h}} + \sigma_{D_{r,h}}\sqrt{-2\ln(0.5)}$ $\mu_{gen_{w,h}} + \sigma_{gen_{w,h}}\sqrt{-2\ln(0.5)}$	U. 8.2×10^{9}	T. 540	S. 1020
FF. 0.75	EE. 0	DD. 1.9%	CC. $\mu_{D_{r,h}} + \sigma_{D_{r,h}}\sqrt{-2\ln(0.75)}$ $\mu_{gen_{w,h}} + \sigma_{gen_{w,h}}\sqrt{-2\ln(0.75)}$	BB. 8.0×10^{9}	AA. 534	Z. 989
MM. 1	LL. 0	KK. 3.6%	JJ. $\mu_{D_{r,h}} + \sigma_{D_{r,h}}\sqrt{-2\ln(1)}$ $\mu_{gen_{w,h}} + \sigma_{gen_{w,h}}\sqrt{-2\ln(1)}$	II. 7.8×10^{9}	HH. 527	GG. 1004
TT. 1	SS. 0.25	RR. 5.4%	QQ. $\mu_{D_{r,h}} + \sigma_{D_{r,h}}\sqrt{-2\ln(1)}$ $\mu_{gen_{w,h}} + \sigma_{gen_{w,h}}\sqrt{-2\ln(1)}$	PP. 7.7×10^{9}	OO. 515	NN. 1208
AAA. 1	ZZ. 0.5	YY. 6.4%	XX. $\mu_{D_{r,h}} + \sigma_{D_{r,h}}\sqrt{-2\ln(1)}$ $\mu_{gen_{w,h}} + \sigma_{gen_{w,h}}\sqrt{-2\ln(1)}$	WW. 7.6×10^{9}	VV. 503	UU. 1175
HHH. 1	GGG. 0.75	FFF. 7.5%	EEE. $\mu_{D_{r,h}} + \sigma_{D_{r,h}}\sqrt{-2\ln(1)}$ $\mu_{gen_{w,h}} + \sigma_{gen_{w,h}}\sqrt{-2\ln(1)}$	DDD. 7.5×10^{9}	CCC. 497	BBB. 1280

RESULT

This manuscript mainly focuses on the analysis of an energy power grid planning model with the objective of meeting economic and technical needs. This planning is performed using a novel approach in terms of uncertainty based on two indices in this regard, namely the possibility and necessity indices. Compared to similar studies in this research area, the development of a novel approach can be considered its major innovation. Besides, modeling a WPP with a storage module which functions in the electricity market both as an independent actor and in conjunction with the WPP is a novel concept in this area of study that has recently drawn the interest of researchers across the world. From an economic perspective, an attempt was also made to provide the investor with a broad range of different investment plans by considering the uncertainty in the interest rate and using the possibility and necessity indices in this rate. It results in increased number of different options with different degrees of risk.

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