The Journal of CPRI,
Vol. 12, No. 1, March 2016 pp. 119-126

Interval optimization technique for the coordination of hydro units with wind power generation

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In the deregulated electricity market, the power generators profit depends on its unit scheduling, bidding strategies and on the market price. The coordination of wind energy with other renewable resources serve an effective way for the generating companies to increase its payoff. Accordingly, the wind power with hydro power system coordination incur the enhancement of power dispatch and thereby reducing imbalance prices. This paper proposes an interval optimization technique to solve the price based unit commitment problem. It also suggests to solve the bidding strategy with the accurate intervals. Variations in wind hydro power, the volatilities in day ahead energy price, intra hour energy price are considered as periodic numbers. Comparing to the conventional technique it is easier to determine and optimizes the entire profit intervals. Henceforth, has an inherent advantage on computational complexity and associates under worst case scenarios.

Keywords: *Price based unit commitment, interval optimization, day ahead and intra hour energy price.*

1.0 INTRODUCTION

The wind power is inconsistent and is difficult to forecast, whereby leading the Generating Companies (GENCO's) to arise with the inequality pricing. The computation of the wind power error prediction costs by multiplying expected energy generation deviations in each hour by hourly supplemental energy reserve prices [1]. The lack of ability of power dispatch makes the GENCO's to serve as price takers and resist upon price instability. To prevail over this weakness, the generating companies coordinated the storage units with wind power [2]. Luan Shiyan *et. al,* forecasted with the development of artificial technique and other forecasting methods, various new models for wind speed and power prediction are mushrooming. The performance of this model could be improved by increasing the model order, but it could decrease the stability of the system. A filtering method was used to filter out the undesired parts of frequency components of wind speed. Compared with the actual wind speed data, it was proved to be an efficient method to predict wind speed. Often they were used as input of time-series models as ARMA, ANN, etc., and help them to obtain better results. The persistence models are considered as the simplest time-series models. They can surpass many other models in very short-term prediction. In spite of the unstable forecasting efficiency, they have been widely used in practice [3].

On considering it arises with the unit scheduling problem. The optimal solution to resort the price based unit commitment problem is undertaken. Reference [4] indicates a joint short-term operation of a wind farm and of an isolated

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pumped-storage plant by using the stochastic approach and has proven to be an effective way to model the real decision making process that wind park operators face in a spot-market framework under uncertainty. The wind and pumped storage energy coordination will lead to more wind energy curtailments as the coordination imposes additional binding operation constraints. Reference [5] and [6] approaches the stochastic programming model has wind power utilization constraints and a combined wind-hydro offer is profitable, imbalances decrease, the system can reduce premiums and subsidies. The total profit from sale of electricity can be increased by exploiting arbitrage opportunities available due to the inter-temporal variation of electricity prices in the day ahead market.

The stochastic optimization requires the exact probability distribution of random variables which are difficult to obtain the expected profits. The robust optimization is a tractable alternative to stochastic programming, whereby selecting the budgets of uncertainty appropriately to match the expected number of times that the uncertain parameters [7]. However, all these conventional techniques only approaches with the expected profits and associated with the exact distribution of variables. It is also that the occurrence of infinite losses in most likely ranges. When severe case like wind power shortages arise then the GENCO's experience an unavoidable condition.

To rise above these problems [8] interval-based results are compared with a deterministic robust non interval matrix inversion-based solution of a model of the benchmark 68-node New England / New York interconnected power system. [9] represents a novel unit commitment formulation based on interval number optimization to improve the security as well as economy of power system operation. Reference [10] compares the applications of scenario-based and interval optimization approaches to stochastic security-constrained unit commitment considering the uncertainty of wind power generation. Reference [11] defines a subjective way to compare and order any two interval numbers on the real line in terms of value. On ordering interval numbers, the inequality constraints involving interval coefficients are reduced in their satisfactory crisp equivalent forms and a satisfactory solution of the problem [12].

The wind power and storage plants are also equated under neural network involving the Chebyshev's inequality approach and hybrid intelligent algorithm [13] and [14]. But still these technique lay a negative feedback on coordination systems. Reference [15] also present with various simulation model, based on a multi-variant ARMA(1,1) time-series model, has been developed in Matlab™. It linked with various errors resulting from practical limitations of input data have been quantified. Holger Heitsch *et al.* [16] established the Portfolio and risk management problems of power utilities may be modelled by multistage stochastic programs. the research concluded that the scenario tree construction algorithms successively reduce the number of nodes of a fan of individual scenarios by modifying the tree structure and by bundling similar scenarios. All the research works gives the bibliography of wind power forecasting and the coordinated systems. On the following, further steps are indeed necessary to develop a planned configuration.

Based on the preceding problems, this paper aims to solve the price based unit commitment on coordinating the hydro units with wind power generation. Here the differences in wind and hydro power are represented in interval numbers, thereby using the interval optimization technique. Further, the day ahead and intra hour energy prices are taken into account for solving the PBUC problem. The uncertainty parameters are also considered in interval numbers rather than probability distribution. This approach has the major advantage depending on the profit intervals and not on expected profits. It optimizes the complete profit periods instead of usual profits. This reduces the computational burden involving less number of constraints. On comparing the interval numbers for solving the PBUC problem the preference ordering is adopted. The degree of pessimism is taken as per the decision maker on analyzing the real generation and the day ahead energy sales.

This paper structures the formulation and constraints in order to solve the PBUC problem that arise on coordinating the hydro units with wind power systems in Section 2.0. Section 3.0 illustrates the technique approached to overcome the drawbacks and the related modelling. Section 4.0 represents the simulation results and discussions. Finally, Section 5.0 summarizes with the conclusion.

2.0 PROBLEM FORMULATION

The major objective of hydro - wind coordination focuses to solve the price based unit commitment problem. It aims to maximize the profit of the GENCO. The GENCO submit their hourly bids, while the consumers submit hourly demand offers. Based on this, a strategy is provided on the aspect of delivering superior power to the consumers as well as to increase the GENCO's payoff.

2.1 Objective Function

The objective for hydro with wind coordination depends upon profit of the GENCO, the following equation is indicated to obtain the maximum profit for the GENCO's.

$$\text{Max Power} = \sum_{t=1}^{NT} \left(\mathrm{PT_t} \cdot \mathrm{DAPr_t} + \sum_{k=1}^{NK} \mathrm{imb_{t,k}}\right) \quad ....(1)$$

Hence the profit is given by revenue minus cost, the (1) is related to two compositions such as profit from the day ahead energy market and the profit settling the intra hour market.

2.2 Hydro - Wind Constraints

The hydro and wind units as a complete coordinated energy sales in day ahead market is given in (2). The periodic numbers of wind power in the maximum and minimum possible values are assumed to be $[\mathrm{PW}_t^L, \mathrm{PW}_t^R]$ and represented in (3). These left and right limits denote the amount of wind power availability and that to be sold in the day ahead market.

$$\mathrm{PT_t} = \mathrm{PW_t} + \mathrm{PH_t} \quad ....(2)$$

$$\mathrm{PW}_t^L \leq \mathrm{PW_t} \leq \mathrm{PW}_t^R \quad ....(3)$$

$$I_t^g . \mathrm{PH_{min}} \leq \mathrm{PH_t} \leq I_t^g . \mathrm{PH_{max}} \quad ....(4)$$

Constraint (4) illustrates the state of the hydro unit complementing the minimum and maximum limits. For simplicity the water head is maintained constant to have an accurate periods.

2.3 Spinning Reserve Constraints

To avoid the risk of imbalance the hydro units are made to reserve a certain capacity since to have equal participation in day ahead energy market. The spinning reserve constraints (5) and (6) are also represented in interval numbers on the basis of upward and downward requirement. The coordination from upward spinning reserve is given as $\mathrm{PW_t} - \mathrm{PW}_t^L$, whereas the downward spinning reserve is $\mathrm{PW}_t^R - \mathrm{PW_t}$.

$$0 \leq \mathrm{SR}_t^{up} \leq \mathrm{PW_t} - \mathrm{PW}_t^L \quad ....(5)$$

$$0 \leq \mathrm{SR}_t^{dw} \leq \mathrm{PW}_t^R - \mathrm{PW_t} \quad ....(6)$$

2.4 Constraints on Energy Sales

The objective function has the derivative $\mathrm{imb_{t,k}}$ to obtain the profit interval in intra hour market. This (7) contains the imbalance profits from the intra hour market.

$$\mathrm{imb_{t,k}} = (\Delta \mathrm{P_{t,k}} . \mathrm{IHPr_{t,k}} - |\Delta \mathrm{P_{t,k}}| . \mathrm{BPr})/NK \quad ....(7)$$

$$\Delta \mathrm{P_{t,k}} = (\mathrm{PW}_t^L - \mathrm{PW_t} + \mathrm{SR}_t^{up}, \mathrm{PW}_t^R - \mathrm{PW_t} + \mathrm{SR}_t^{dw}) \quad ....(8)$$

$$\mathrm{imb}_{t,k}^L = (\mathrm{PW}_t^L - \mathrm{PW_t} + \mathrm{SR}_t^{up}).(\mathrm{IHP}_{t,k}^R + \mathrm{BPr}) \quad ....(9)$$

$$\mathrm{imb}_{t,k}^{R} = (\mathrm{PW}_{t}^{R} - \mathrm{PW}_{t} + \mathrm{SR}_{t}^{dw}).(\mathrm{IHP}_{t,k}^{R} - \mathrm{BPr}) \quad ....(10)$$

These imbalance profits are dependent on the deviation value $\Delta P_{t,k}$. Constraint (8) is able to predict the amount of energy is either to be sold nor to purchase. It is also that the ISO has the equal part in setting up the pricing limits called to be the energy balancing price. The ISO sets prices in order to curtail from wind power losses. Constraints (9) and (10) with the imbalance in prices with minimum and maximum values are associated with the objective function.

3.0 INTERVAL OPTIMIZATION APPROACH

3.1 Modelling of Interval Numbers

The interval number or the periodic number defines the array that a random variable may be taken in left and right limits. The limits are represented in (11) such a way that the left limit a^L denotes the minimum possible value and the right limit a^R denotes the maximum possible value. These interval numbers in alternate equation (12) and (13) can also be represented as A = m(A), w(A) , where m(A) and w(A) are the mid-point and width of the periodic number A.

$$\mathrm{A} = [a^L, a^R] = \{a{:}a^L \leq a \leq a^R\} \quad ....(11)$$

$$\mathrm{m(A)} = \frac{1}{2}(a^R + a^L) \quad ....(12)$$

$$\mathrm{w(A)} = \frac{1}{2}(a^R - a^L) \quad ....(13)$$

The mid-point shows the location and width indicates the uncertainty of the periodic numbers. For simplicity, the width of the intervals are assumed to be zero and a real number is considered. This gives the apparent analysis of the interval numbers where the representation of hydro wind coordination can be illustrated and shows the better results, simplifying the complicated variables.This can be in analyzing with the binary operation of periodic intervals which can be transformed to end point formulas. R.E. Moore *et. al* analyzed with the introduction of interval numbers, solving with variable interval numbers on either of the maximum or minimum values. Such structures denote the enhancement of this technique to be used in various applications. It also improve the overall aspects in modifying the optimistic results.

3.2 Optimistic Preference Ordering of Interval Numbers

According to interval optimization, the objective to attain the profit is obtained by interval numbers. In such case of obtaining the profit, the optimistic ordering of the profit intervals are preferred by the decision maker. The profit intervals should determine the location and uncertainty of the system. In general the decision maker has the risk in associating with pessimistic ordering. To analyze with the maximization of profit, the DM expresses with more uncertainty is inferior than less uncertainty having in choice that more money is healthier than less money (14). Obviously the decision maker chooses with the interval number of larger mid-point and lower uncertainty. It is also noted that the profit depends on the power produced and the day ahead energy sales.

$$\text{Profit Interval} = \sum_{t=1}^{NT}(\mathrm{PT}_t.(\mathrm{DAPr}_t) + \sum_{k=1}^{NK} \mathrm{imb}_{t,k} + (\xi_p - 1).\ \mathrm{PT}_t \cdot \mathrm{DAPr}_t + (\xi_p - 1)\,\mathrm{imb}_{t,k}) \quad ....(14)$$

The flowchart describes the interval optimization on using the objective function subjected to its constraints. Thus the coordination of hydro and wind units provide the profit intervals thereby reducing uncertainty and enhancing the system performance. This proposed method results in reducing the computational complexity as well as minimizing with profit intervals. The attained profit intervals satisfy the objective function and its constraints and therefore makes it available for the generating companies to increase their profits. Thus the hydro and wind power coordination has a greater impact on considering among the other renewable energy resources.

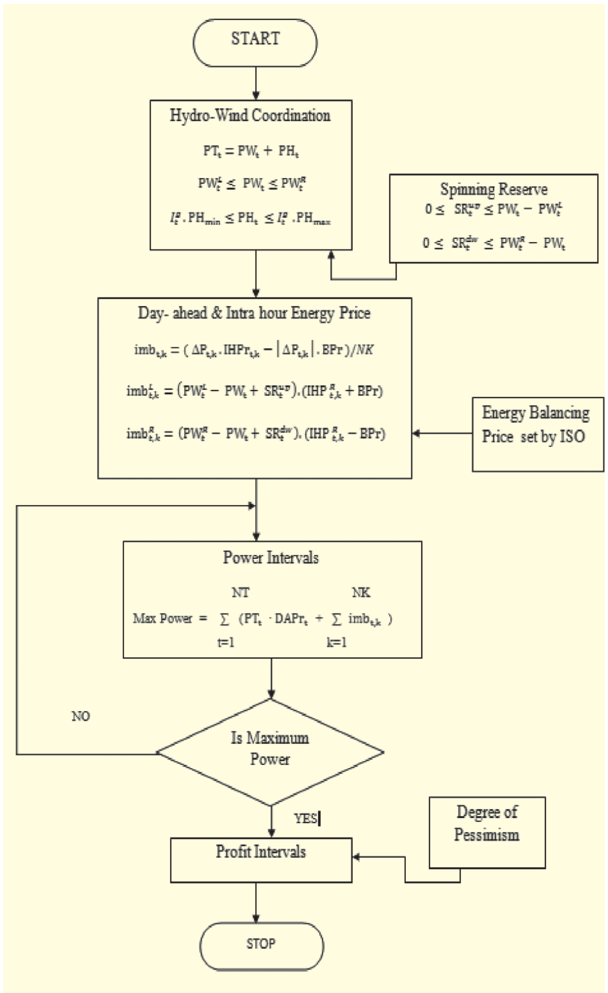

FIG. 1 FLOWCHART OF INTERVAL OPTIMIZATION TO OBTAIN THE DESIRED PROFIT INTERVALS

4.0 RESULT

The simulation coding of the interval optimization were developed using MATLAB™ 7.8.0. These results are analyzed on the price based unit commitment problem for 100 units hydro plant and 1 unit wind plant. In this the wind speed is scheduled for 24 hour time period and is converted into power using the formula (15).

$$\text{Wind Power} = \frac{1}{3}\,(\text{Wind Speed}) \qquad ....(15)$$

The generation characteristics of the wind power, hydro power, the day- ahead energy price and intra-hour energy price are represented in Table 1. It shows the minimum and the maximum possible value. These analysis are equated under interval optimization technique and the results are obtained in interval numbers.

TABLE 1

SYSTEM DATA

Time Period hrs	0 - 9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Hydro Power (kw)	5	9.75	9.70	9.65	9.50	16.0	16.25	16.50	16.05	6.25	6.05	6.115	6.15	11.70	11.75
Wind Power (kw)	0	3.26	3.95	3.7	3.53	4.6	4.73	3.3	4.43	3.73	3.71	2.71	2.43	2.46	2.43
Day-ahead Energy Price	≅ 7.5	5.13	5	5	5	5.45	5.11	5.19	5.06	6.14	7.93	7.52	5.35	5.04	5.17
Intra-hour Energy Price	≅ 30.75	22.75	48.3	22.12	22.83	19.88	22.32	22.72	23.84	26.83	25.64	24.97	54.89	55.77	22.35

4.1 Hydro - Wind Coordinated Power Output

On the implication analysis from wind speed converted to power and hydro power satisfying the constraints, are show in Figure 2. It shows the gradual power generated by the hydro units having a certain a spinning reserve in which it avoids the risk of imbalance. Since the run off forecast can be precise on daily basis the coordination input is taken for 24 hours and determined. These intervals seems to be with the largest possible range and this complete coordination enhances to firm the output. Considering from other resources it is analyzed that hydro-wind coordination has the major advantage on increasing the profit of the GENCO's. Following on these

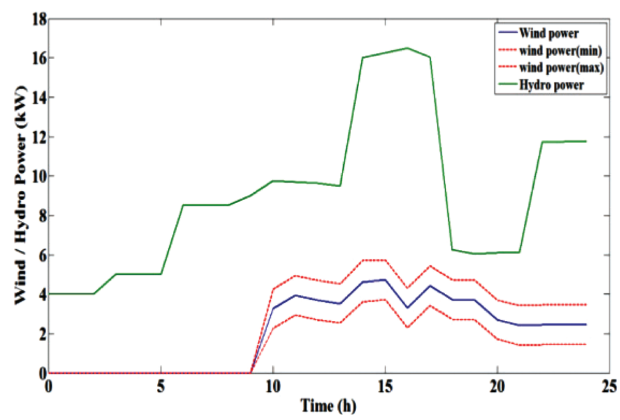

FIG. 2 HYDRO- WIND POWER FLOW

aspects the generating companies choose this combined operation so to reduce the uncertainty of the system generation. The beneficial result includes in providing high-quality power to the consumers as well to gain the profit to the required level.

4.2 Energy Price Intervals

Figure 3 and 4 shows the day- ahead and intra-hour energy price intervals. The price values are engaged from the PJM market. The day- ahead energy price (Market Clearing Price) and intra-hour energy price (Locational Marginal Price) are assumed to be in random variables. These price values are made to satisfy the constraints (7) - (10). On simulating with the base constraints, the energy price intervals are obtained and it shows the maximum and the minimum possible value. The energy balancing price is set by the ISO so as to equate with the constraints. The mid points show in Figure indicates the energy sales in between the price intervals.

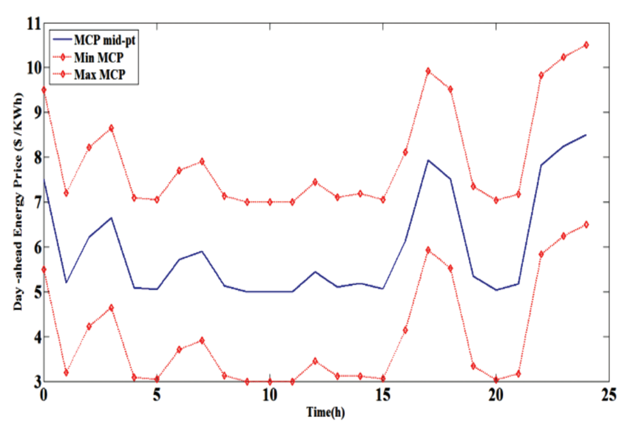

FIG. 3 DAY-AHEAD ENERGY PRICE INTERVAL

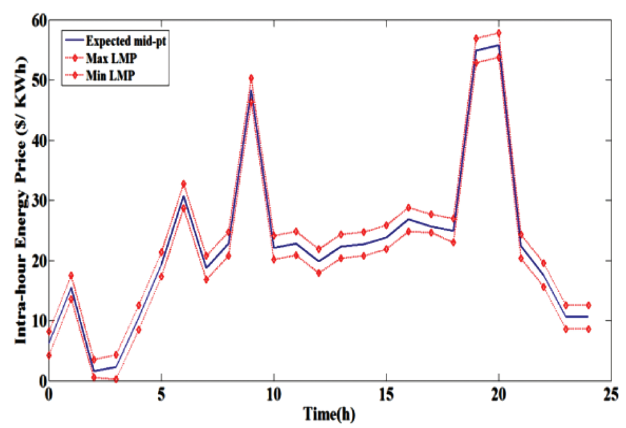

FIG. 4 INTRA-HOUR ENERGY PRICE INTERVAL

4.3 Optimistic Profit Intervals

From the results on the coordination of hydro and wind units, combining with the day ahead and intra hour energy price, the energy or power saled is shown in Figure 5. The power distributed is linked with the value set by the ISO.

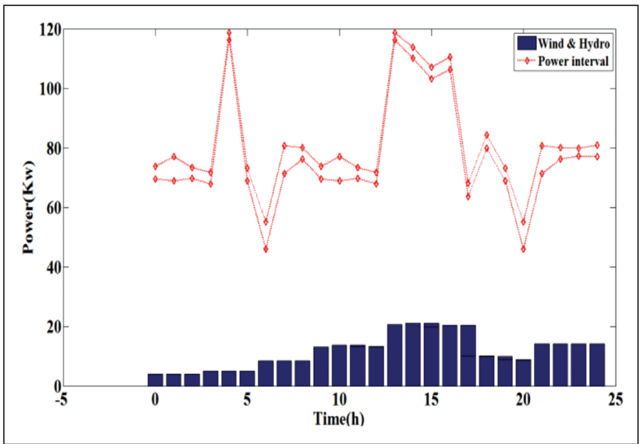

FIG. 5 POWER INTERVALS FOR THE HYDRO - WIND COORDINATION

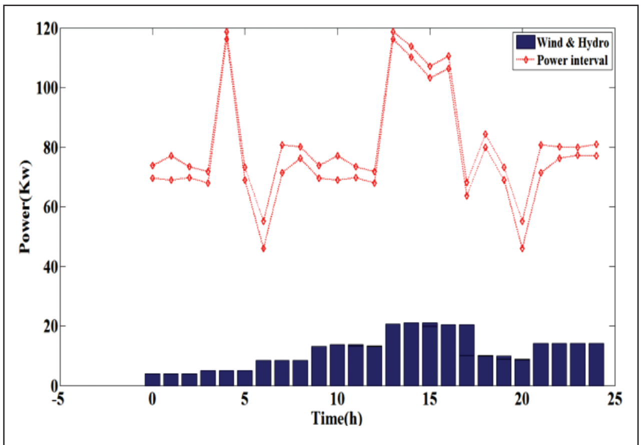

FIG. 6 PROFIT INTERVALS FOR DESIRED ENERGY SALES

Figure 5. represents the amount of energy saled for the particular hydro wind generation. If necessary it's also made available with the spinning reserve.

Figure 6 shows the profit intervals for the desired energy sales. It is also to be noted that the profit is excluding the operational costs. This makes an increase in the payoff for the generating companies. To obtain profit, the degree of pessimism is opted by the decision maker. It is that the DMtolerates in reducing the uncertainty and increases the profit intervals. These are done to firm the system performance and initiates with the reliable bid. When the degree of pessimism increases, certain adjustments are made for flexible operation of the coordination system.

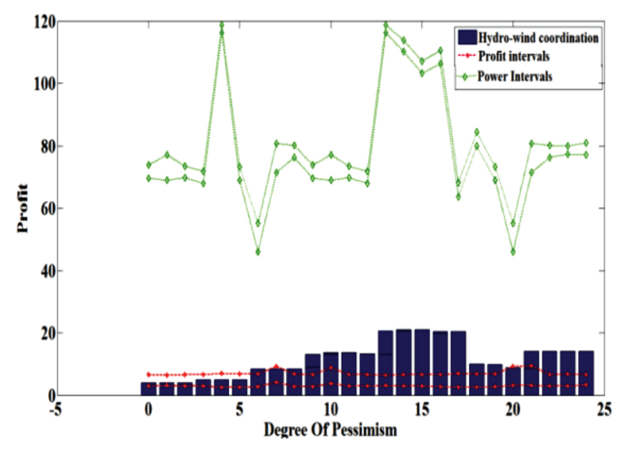

FIG. 7 POWER AND PROFIT INTERVALS FOR THE ENERGY SALES

The overall hydro- wind generation subjected to energy price intervals, the absolute power distributed and the related profit acquired is shown in Figure 7. It also relates to the reliable bid whereby reducing uncertainty. This bidding strategy introduced can be with frequent operation and better performance.

5.0 CONCLUSION

This paper represents the coordination of hydro units with wind power generation. It solves the price based unit commitment problem and aims to increase the payoff for the GENCO's. The interval optimization technique is used in solving the bidding strategy and the profits are summarized in intervals. The decision maker plays the vital role in optimistic preference ordering of interval numbers in addition to the degree of pessimism. The coordination of hydro and wind systems are considered as it provides a better performance than any other renewable resources. This is possible as the hydro units may afford with certain spinning reserve which avoids the risk of imbalance and helps to reduce uncertainty.

The variations in hydro power, wind power, day ahead energy price, intra-hour energy price are considered in interval numbers so that the profit intervals can be obtained. On comparing with the conventional technique it has the advantage of using the random variable and optimizes the enhancement of system performance. It also shows better results on computational complexity and can be applied on worst-case scenarios.

Though the interval optimization does not depend on probability distribution it is necessary to particular with the random variable selection. It also establishes the profits in interval numbers and it does not acquire the desired profit. Hence further researches are to be carried to improve in maintaining the desirable profits and make sure with accurate random variables.

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