A Novel Approach on MIP Technique for Risk Constrained Co-ordinated Scheduling of GENCO

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Abstract- **One of the major challenges associated with wind energy is the way it impacts unit commitment. With low amounts of wind, unit commitment can be treated as a deterministic problem. However, large amounts of installed wind power add a significant stochastic element to the planning of the system. This is due to the uncertainty associated with wind power forecasts. Wind resources can be managed through proper plant interconnection, integration, transmission planning, and system and market operations. Unit Commitment (UC) in electric power systems is to optimize generating resources to supply system load while satisfying prevailing constraints, such as minimum on/off time, ramping up/down, minimum/maximum generating capacity, and fuel and emission limit.**

Index Terms **– Cascaded hydro and wind coordination, unit commitment.**

I.INTRODUCTION

The success of privatization of most of the industries led people to think for the deregulation of electric power system. This yields to restructuring of currently vertically integrated utility (VIU) to the main three utilities, namely generation company (GENCO), transmission company (TRANSCO) and distribution company (DISCO). The success in the energy privatization in the countries like UK, USA, Norway and Australia has encouraged many more countries to privatize their electricity industry. India has also participated in the process and most of the states of India have restructured their electricity boards. Ever since the restructuring has taken place, the electric power industry has seen tremendous changes in its operation and governance. Electricity, being a concurrent entity, can not be stored easily. In develop countries Electricity market is already functioning and it is being started to introduce in developing countries.

The fundamental objectives behind the establishment of electricity market are the secure operation of power system and facilitating an economic operation of the system. Key entities of the electricity market are Generating companies (GENCOs), independent system operator (ISO) many a times known as system operator (SO), Transmission companies (TRANSCOs) and Distribution companies (DISCOs).

The rest of organized as follows; Section II wind and hydro power generation is discussed. Section III presents Genco's Price-Based Unit Commitment (PBUC). Section IV presents Stochastic Price Based Formation and section V presents simulation results.

II.WIND AND HYDRO POWER GENERATION

A. The Value of Wind Power Plants

The energy value that wind power plants can provide to the grid is largely a result of the reduction in electricity generated from conventional power plants, made possible by the wind plant. We can calculate the value of offset fuel consumption and emissions using an electricity production simulation model. In many cases, wind power plants can offset the need for conventional power plants.

B. Forecasting, Capacity and Risk

There are several ways to look at the effective capacity of wind power plants. In regulated markets, the term "capacity credit" is often used to describe the level of conventional capacity that a wind plant could replace.

III.GENCO'S PRICE-BASED UNIT COMMITMENT (PBUC)

The GENCO's payoff consists of energy sales minus the cost of energy production and imbalance penalties. The cost of imbalance energy could reduce the GENCO's potential payoff if the real-time energy dispatch does not match that of day ahead. A stochastic model is applied to examine the impact of high penetration of wind energy on power system operations. The auto-regressive moving average

(ARMA) time series model was considered to simulate the wind speed volatility.

RISK CONSTRAINED DAY AHEAD COORDINATION

Risk-constrained day-ahead coordination is a strategy used by GENCO for wind and cascaded hydro (storage) units. Wind energy variations could occur within minutes while the day-ahead schedule is hourly, so an intra hour-based model is proposed in this strategy to firm up the coordinated wind and hydro generation. This shows that the fast ramping and storage capabilities of cascaded hydro units could compensate wind energy volatilities.

1.GENERATION OF SCENARIOS, AND ITS REDUCTION TECHNIQUES

The Monte Carlo simulation is used to generate scenarios, and scenario reduction techniques are applied to eliminate low-probability scenarios and bundle similar ones to identify a limited number of effective scenarios while maintaining a reasonably good approximation of the original system.
Scenario reduction algorithms includes following methods

1. Fast backward method
2. Fast backward/forward method
3. Fast backward/backward method

STOCHASTIC PBUC FORMULATION WITH THE WIND-HYDRO INTRA-HOUR COORDINATION.]

In the proposed stochastic PBUC problem, there are first and second-stage variables. A first-stage variable is stated as a decision variable which is made before uncertainties are disclosed, that is, yielding identical values in all scenarios such as $P_{C,ht}$. A second-stage variable is scenario-dependent, which can be an intra hour variable depending on t, k, and s such as $P^s{}_{\Delta.wtk.}$

IV.STOCHASTIC PBUC FORMULATION

The objective of PBUC is to maximize a GENCO's payoff, which is the revenue from the sales of energy or bilateral contracts minus the operation cost of GENCO. The operation cost includes the production cost, start up/shut down costs, and imbalance energy charges incurred by wind energy variations. In this project, the coordination strategy of wind and hydro units is focused.

A. UNCOORDINATED SCHEDULING OF WIND AND HYDRO UNITS

The stochastic PBUC would maximize the GENCO's expected payoff (1), subject to prevailing constraints. The first term in the objective function is the revenue from hydro and wind energy sales to day-ahead markets. The second term represents the operation cost of hydro units which includes startup and shutdown costs. The imbalance charges for wind units included in the last two terms of (1) are $P^s{}_{\Delta,wtk}$ paid based on $\rho^s{}_{RT,tk}$ and $P^s{}_{\Delta,wtk}$ paid based on $\rho^s{}_{BP}$.
Constraints are as follows,
Maximize

$$\sum_{s=1}^{NS} p^s.PF^s$$

$$\sum_{s=1}^{NS} p^s.\begin{bmatrix} \sum_h \sum_t \rho^s{}_{DA,t}.P_{ht} + \sum_w \sum_t (y_{ht}.SU_h + z_{ht}.SD_h) \\ -\sum_w \sum_t \left(\frac{1}{NK}.\sum_k \rho^s{}_{RT,tk}.P^s{}_{\Delta,wtk} + \frac{1}{NK}.\rho^s{}_{BP}.\sum_k P^s{}_{|\Delta|,wtk}\right) \end{bmatrix}$$

$$\longrightarrow (1)$$

$$P_{ht} = F_h(q_{ht}) \longrightarrow (2)$$

$$q^{min}{}_h . I_{ht} \le q_{ht} \le q^{max}{}_h . I_{ht} \longrightarrow (3)$$

$$V^{min}{}_h \le v_{ht} \le V^{max}{}_h \longrightarrow (4)$$

$$V_{h(0)} = V_{0,h}, v_{h(NT)} = V_{NT,h} \longrightarrow (5)$$

$$V_{h(t+1)} = v_{ht} + RC_h . q_{d,h(t-T)} - q_{ht} + r_{ht} - s_{ht} \longrightarrow (6)$$

$$s^{min}{}_h \le s_{ht} \le s^{max} \longrightarrow (7)$$

$$q_{d,h(t-T)} = [q_{1(t-T)} \ldots q_{(h-1)(t-T)}\ 0\ q_{(h+1)(t-T)} \ldots q_{NH(t-T)}] \longrightarrow (8)$$

$$P_{wt} = P^s{}_{wtk} + P^s\Delta_{,wtk} \longrightarrow (9)$$

$$0 \le P_{wt} \le P^f{}_{wt} \longrightarrow (10)$$

$$0 \le P^s{}_{wtk} \le P^{f,s}{}_{wtk} \longrightarrow (11)$$

$$P^s{}_{|\Delta|,wtk} - P^s\Delta_{,wtk} \ge 0 \longrightarrow (12)$$

$$P^s|\Delta|_{,wtk} + P^s\Delta_{,wtk} \ge 0 \longrightarrow (13)$$

$$P^s|\Delta|_{,wtk} - P^s\Delta_{,wtk} \le M . \delta^s\Delta_{,wtk} \longrightarrow (14)$$

$$P^s|\Delta|_{,wtk} + P^s\Delta_{,wtk} \le M.[1- \delta^s\Delta_{,wtk}] \longrightarrow (15)$$

Since the coordinated scheduling of cascaded hydro and wind units is not considered here, the objective function of hydro-wind can be decoupled into two independent optimization problems. Other constraints include water discharge limits (3), reservoir volume (4), initial and terminal reservoir volume (5), water balance constraints for cascaded hydro units (6), and water spillage limits (7). In (6) RC_h, is the geographic reservoir connection vector with binary elements $rc_{h-h'}$, $rc_{h-h'}=1$ if the hydro unit h' is a direct up stream of unit h; otherwise $rc_{h-h'}=0$. In addition, $q^s{}_{d,h(t-\tau)}$in (8) represents the delayed water discharge to the hydro unit from upstream hydro units.

The wind speed forecast error is further represented by ARMA. The intra-hour-based wind unit constraints include hourly and intra-hour power generation schedule (9) and generation limits (10)–(11). The available wind energy is calculated using the wind speed forecast and used as input to PBUC. Equations (12)–(15) incorporate $P^s{}_{|\Delta|,wtk}$ in the stochastic PBUC problem, where M is a large positive number.

B. COORDINATED SCHEDULING OF WIND AND HYDRO UNITS

In this case, the coordinated scheduling of cascaded hydro unit with one or more wind units is considered for providing an hourly firm power dispatch. The first term in (16) shows the GENCO's revenue and the second term represents the operation cost of hydro unit. Since the hourly wind generation is firm, the imbalance energy charge will be zero. Thus, by coordination, the sum of intra-hour wind P^{s}_{wtk} and hydro P^{s}_{htk} generation is equal to the hourly generation dispatch $P_{C,ht}$ (17). Note that $P_{C,ht}$ is a scenario-independent first-stage decision variable, which is calculated before uncertainties are imposed.

$$\text{Maximize} \quad \sum_{s=1}^{NS} p^{s}.PF^{s}$$

$$= \sum_{s=1}^{NS} p^{s}.[\sum_{h} \sum_{t} \rho^{s}_{DA,t}.P_{C,ht}$$

$$-\sum_{h} \sum_{t} (yht.SUh + zht.SDh)] \longrightarrow (16)$$

$$P_{C,ht} = \sum_{\omega \epsilon Sc,h} Ps\omega tk + Pshtk \longrightarrow (17)$$

$$P^{S}_{wtk} = P^{s,f}_{wtk} - P^{c,s}_{wtk} \quad \forall \boldsymbol{\omega}, \forall \boldsymbol{t}, \forall \boldsymbol{s} \longrightarrow (18)$$

$$q_{h}^{min}.I_{ht} \leq q^{s}_{htk} \leq q_{h}^{max}.I_{ht} \longrightarrow (19)$$

$$P^{s}_{ht(k+1)} - P_{htk}^{s} \leq 60.RU_{h} / NK \longrightarrow (20)$$

$$P_{htk}^{s} - P^{s}_{ht(k+1)} \leq 60.RD_{h} / NK \longrightarrow (21)$$

$$I_{ht} - I_{h(t-1)} = z_{ht} - y_{ht} \longrightarrow (22)$$

$$z_{ht} + y_{ht} \leq 1 \longrightarrow (23)$$

$$P^{s}_{htk} = F_{h}(q^{s}_{htk}) \longrightarrow (24)$$

$$V_{h}^{min} \leq v_{htk}^{s} \leq V_{h}^{max} \longrightarrow (25)$$

$$V^{S}_{h(0)NK} = V_{0,h}, \quad v^{S}_{h(NT)NK} = V_{NT,h} \longrightarrow (26)$$

In (18), the intra hour wind power in scenario s(P^{s}_{wtk}) is equal to the wind power forecast ($P^{f,s}_{wtk}$) minus the nonnegative curtailed wind power($P^{c,s}_{wtk}$) . The intra hour hydro power generation P^{s}_{htk} is dependent on the water discharge rate which is subject to the discharge limit (19). Ramping limits (20) show that the hydro power increment in two consecutive intra hours is limited. The wind-hydro coordination with sufficient ramping provides complimentary power from cascaded hydro units to wind units to make $P^{s}_{\Delta,wtk}$ for all wind units in $S_{C,h}$. In (21) and (22), the hourly hydro unit commitment is related to startup and shutdown indicators.

The intra hour hydro power generation is dependent on water discharge in (23). The intra hour reservoir volume constraints of hydro units are given in (24) and (25). The intra hour reservoir volume in (26) is dependent on its previous intra hour value, discharge water flow in the present intra hour, inflow water flow from upstream hydro unit, inflow water flow, and spillage in each intra hour.

C. RISK ASSESSMENT

A GENCO would be concerned with the risk associated with its payoff when considering market price uncertainties. Suppose the GENCO's day-ahead target payoff is T_0. The payoff risk given in (27) is associated with the failure to meet the target payoff. The linear expression of risk (27) is represented in (28) by auxiliary binary variables

$$R^{s} = \begin{cases} T_0 - PF^{s}, & \text{if } PF^{s} < T_0 \\ 0, & \text{otherwise} \end{cases} \longrightarrow (27)$$

$$0 \leq R^{s} - [T_0 - PF^{s}] \leq M.[1 - \delta^{s}]$$

$$0 \leq R^{s} \leq M.\delta^{s} \longrightarrow (28)$$

Here, the expected downside risk is smaller than the accepted risk level. If a GENCO is not satisfied with its payoff that is below the target, an upper expected downside risk given in (29) will be appended into the PBUC formulation.

$$EDR = E(R^{s}) = \sum_{s=1}^{NS} p^{s}.R^{s} \leq \overline{EDR} \longrightarrow (29)$$

Hence, the original risk-neutral model is turned into a risk constrained model by including (27)–(28). The objective is to calculate the expected payoff while keeping the expected downside risk within an acceptable range. The target $\overline{EDR}$ should be carefully designed since a tight constraint on the expected downside risk (i.e., relatively low risk $\overline{EDR}$ or high targeted payoff) could result in an infeasible solution.

D. RISK-BASED STOCHASTIC PBUC SOLUTION

The stochastic PBUC for the cascaded hydro and wind unit coordination is solved by a MIP package (CPLEX). The deterministic PBUC solution is obtained when uncertain variables are replaced by their forecasts. If the transmission network is considered, the dimension of the stochastic PBUC can increase significantly.

V. SIMULATION RESULT

A. MIXED INTEGER PROGRAMMING

Integer programming optimizes integer function of integer variables. A modification of standard integer programming that allows non-integer function is known as mixed-integer programming (MIP). MIP treats the objective and constraint functions as continuous and the variables as integers.

Branch and bound is one of the techniques used for the solution of the integer problem. It is a technique to solve a discrete variable problem by solving a sequence of simpler problems derived from the original problem. Mixed integer-linear programming is used to determine feasible combinations of units at each scheduling point, while a novel dynamic programming approach identifies promising scheduling routes in the time domain.

B.MONTE CARLO

Intermittence and the high variability of wind make it difficult for models to adequately measure capacity credit. Capacity credit results depend heavily on what happens during the utility's peak hours.

C.INPUT DATA

1.Demand Data

Table 1 Demand data

Time(t)	Power(P_{td})	Time(t)	Power(P_{td})
1	1033	13	1273
2	1000	14	1322
3	1013	15	1233
4	1027	16	1253
5	1066	17	1280
6	1120	18	1433
7	1186	19	1273
8	1253	20	1580
9	1300	21	1520
10	1340	22	1420
11	1313	23	1300
12	1313	24	1193

The hourly demand data is given in table 1. The demand is for all the 24 hours.

3.WIND UNIT DATA

The day-ahead schedule in a GENCO with three wind farms (W1–W3) and seven hydro units in two catchments (H1–H4 in catchment 1 and H5–H7 in catchment 2)

4.WIND CAPACITY

Table 2 wind capacity

Units	W1	W2	W3
Capacity(MW)	200	200	250

The wind farm capacities are 200, 200, and 250 MW, respectively are shown in Table 2.

4. MARKET PRICE

Table 3 Market Price Forecast

Time (hrs:m)	Market Price ($/Mhr)
0:20	14.2
0:40	15.4
1:00	17.2
1:20	22.1
1:40	23.4
2:00	24.6
2:20	20.4
2:40	18.6
3:00	16.2

Day ahead market price forecasted value is given in table 3. Here the three hour coordination is taken into considerations.

5.WIND SPEED FORECAST

Table 4 Wind Speed Forecast

Time (hrs:min)	Wind speed (m/s)
0:20	12.4
0:40	11.3
1:00	9.2
1:20	6.7
1:40	6.1
2:00	7.3
2:20	8.5
2:40	10.6
3:00	11.2

Wind speed forecasted value is given in table 4. Here the wind speed varies every minutes.

6. CASES CONSIDERED IN THE DAY AHEAD SCHEDULING

Table 5 Day-ahead scheduling

CASE	COORDINATION	W1	W2	W3	RISK
1	NO	-	-	-	NO
2	YES	H2	H3	H6	YES

The above table shows the day ahead scheduling of wind and hydro units. W1, w2 and w3 represents the wind units. Similarly H2, H3 and H6 represents the hydro units. There are 2 cases are considered here. Case 1 is un coordinated system and case 2 is coordinated system.

6.1 UC FOR H2,H5 AND H6

Table 6 Case 1 Unit Commitment Scheduling

UNIT	H2	H3	H6
1	0	1	0
2	0	1	1
3	0	1	1
4	0	0	0
5	1	1	1
6	0	1	1
7	0	1	1
8	1	1	1
9	1	1	1
10	1	1	1
11	1	1	1
12	1	1	1
13	1	1	0
14	0	1	1
15	1	1	1
16	1	0	1
17	1	1	1
18	0	1	0
19	0	1	1
20	1	1	1
21	1	1	1
22	0	1	1
23	0	0	0
24	0	0	0

6.2 UC FOR H2, H5 AND H6

Table 7 Case 2 Unit Commitment Scheduling

UNIT	H2	H3	H6
1	1	1	1
2	1	1	1
3	1	1	1
4	0	1	1
5	1	0	1
6	0	0	0
7	1	0	0
8	1	0	0
9	1	1	0
10	0	0	0
11	0	1	1
12	1	1	1
13	1	1	0
14	0	1	1
15	1	1	1
16	1	0	1
17	1	1	0
18	1	0	1
19	0	1	1
20	0	1	1
21	0	1	0
22	1	1	0
23	0	0	0
24	1	0	1

Hourly scheduling for coordinated wind and hydro unit is given in table 6 and 7. Scheduling is for both the cases. In case 1 hydro unit is not considered. In case 2 hydro unit is considered. There are three wind units and seven hydro units are considered. First wind unit is coordinated with second hydro unit and second wind unit is coordinated with second hydro unit finally third wind unit is coordinated with hydro unit 6 this is shown in table 7. Here the hourly scheduling is for all the 24 hours.

In both the cases 0 indicates unit is ON and 1 indicates unit is OFF. In case 1 during 11 and 12th hour all the units are ON. Similarly during 23 and 24th hour all the units are OFF. In the case of coordinated system atleast one unit can be turned on in all the scheduling period of 24 hours.

7. Expected Payoff and Downside Risk($)

Table 8 Expected Payoff and Downside Risk($)

Case	Expected Payoff	Downside risk
1	**463,756**	**6354**
2	**756,341**	**3,000**

Expected Payoff and downside risk is given in table 8. Case 1 represents the un coordinated system and case 2 represents the coordinated system. Here the downside risk is reduced in case 1(coordinated system) and expected payoff is increased.

8. CONCLUSION

This project and its results demonstrate that the scheduling coordination of cascaded hydro and wind units can firm up wind energy, increase expected payoffs, and reduce downside risks of GENCOs. Thus, the coordination of wind and hydro scheduling would lower the wind curtailment and increase the GENCO’s payoff by mitigating the imbalance energy charges. The coordination will result in lower wind curtailment in both stochastic and deterministic scheduling solutions. It is shown that the hydro unit payoffs will decrease once they are coordinated with wind energy units. The stochastic scheduling solution would lower the GENCO’s expected downside risk as compared to the deterministic scheduling solution.

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