STOCHASTIC UNIT COMMITMENT OF WIND-THERMAL SCHEDULING WITH IMPACTS OF PHEV CHARGING PATTERNS

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Abstract— Plug-in hybrid electric vehicle technology (PHEV) take a greater share in personal automobile market and their penetration levels may bring potential challenges to electric utility and reduce the dependence on fossil fuels. However, the growth of PHEV will bring new challenges and opportunities for power system infrastructures. In this paper a stochastic unit commitment model is developed to coordinate the thermal generating unit with large scale wind power and PHEV charging loads. The stochastic model is used to simulate the power system scheduling with different charging patterns for PHEVs and it also provide ancillary services. The results shows that the coordination of wind-thermal and PHEV loads reduce the operating cost of power system and compensates the fluctuations in the wind power.

Keywords — wind thermal coordination, stochastic unit commitment, spinning reserve, plug-in hybrid electric vehicle.

I. INTRODUCTION

The government in India has commissioned research on renewable energy applications with increasing fuel prices and environmental resources under the consideration of diversifying energy sources [1]. The wind energy could be in the short term, one of the most promising renewable energy sources among the various renewable energy sources in India. It could provide a much greater proportion of energy production in places with good wind [2].

The interactions between wind power and PHEVs [3] have complicated implications on power system operations. The concept allows V2G vehicles to provide power to help balance by valley filling (charging at night when demand is low) and peak shaving (sending power back to the grid when demand is high). The charging patterns of PHEVs will impact the power system operation and scheduling. Charging a large number of PHEVs may cause shortages in electricity and price spikes in the power market [4], [5].

The National Renewable Energy Laboratory (NREL) examines [6] the interactions between the wind power and PHEVs which focuses on the probabilistic generation capacity expansion which is determined by the reserves provided by PHEVs. Deterministic unit commitment is a traditional approach used in industry which deals with the unit generation schedule to minimize the operating cost while satisfying some constraints and the solution may deviate from the economic optimum. In this proposed work, Stochastic unit commitment model [7] is used which addresses the generator failures and load forecasting inaccuracies and are incorporated into the model as stochastic factors.

Traditional unit commitment dispatch only generation not load. Load dispatch plays an important role in reducing the operating cost of power system and PHEVs (electric vehicles) could be an excellent demand dispatch [8]. Wind is usually stronger at night and PHEVs use the nighttime wind generation by charging at night. Also PHEV loads will also able to feedback power like a storage when the vehicle is charging its battery.

Generally unit commitment problem is a combination of two problems. One determines the generating units to be committed and other actually focuses on the amount of generation from each of these committed units. In this work we develop a two stage stochastic unit commitment model with impacts of PHEV charging patterns. First stage of the problem corresponds to the commitment
statues of all thermal generating units considering the decision variables like generation dispatch, wind power output and second stage corresponds to the PHEV load dispatch.

Vehicle-to-grid [9], [13] describes a system in which plug-in electric vehicles, such as electric cars (BEVs) and plug-in hybrids (PHEVs) communicate with power grid to sell demand response services by either delivering electricity into the grid or by throttling their charging rate. There are three versions of the vehicle to grid concept they are fuel cell, PHEV and a solar vehicle. In this work, PHEV is used as a vehicle to technique where vehicles serve as a distributed battery storage system to buffer power. Plug-in hybrid electric vehicles (PHEVs) — cars, sport utility vehicles, pickup trucks, and others, that can be recharged from an ordinary electricity outlet in one’s garage or elsewhere.

II. Overview of PHEV Loads

PHEV can operate in either charge depleting or charge sustaining mode. In charge depleting mode the vehicle is driven by electrical motor and battery and in the latter one the vehicle is driven by internal combustion engine to provide power. The All Electric Range (AER) of the vehicle decides the charging capacity of the battery. PHEVs offer the potential to reduce both gasoline consumption and associated emissions. According to some estimates, PHEVs that could travel up to 60 miles on a battery charge on electric energy stored in their batteries without recharge (PHEV60s) could reduce CO2 emissions by 50% and petroleum consumption by more than 75%. The block diagram for this analysis is shown below.

PHEVs are expected to be able to travel 20 to 60 miles purely on electric power without recharge, which will require a larger and more efficient battery than current hybrids have. PHEVs would be fully charged within the period of 6 hours.

PROBLEM FORMULATION

The wind-thermal system involves the allocation of generation among wind plants and thermal plants so as to minimize the total production costs while satisfying various constraints. In this, to address the uncertainty in wind power output a two stage stochastic unit commitment is proposed. The first stage problem corresponds to current decision making and it cannot be changed in real time that is second stage. Therefore the second stage problem corresponds to real time generation dispatch. The decision variables in the first stage are commitment statuses of thermal generating units and the PHEV load dispatch considers in second stage. The two stage stochastic unit commitment problem is formulated as,

A. Objective function:
The objective function is to minimize the expectation cost of the power system operating while simultaneously satisfying some prevailing constraints. Unserved loads for the entire planning period are incorporated as penalties into the objective function.

\[
\min \sum_i \sum_t (STC_i + SDC_i) + \sum pr \\
\left( \sum_i \sum_t F_i(P_i) + \sum_{j \in L_{PHEV}} \sum t \rho_j \left( L_{D,j} - \sum L_{j} \right) \right) \\
+ \sum_{j \in L_{PHEV}} \rho_j \left( L_{D,j} - \sum_{t \in \text{Char}_j} L_{j} \right)
\]

(1)

Where,

- \( F_i(P_i) \) : Generation Cost
- \( \rho \) : Penalty price for unserved load
- \( L \) : Load dispatch
- \( L_D \) : Electric energy requirement
B. Constraints:
1) Start-up and shut down constraints: The start-up cost is a function of number of hours the generator has been turned off. The typical value of shut down cost is zero. This cost is considered as a fixed cost. STC will be zero during optimization process if the unit does not change its status from off to on at hour t.

2) Power balance: The essential scheduling problem of the electric power system is to balance supply with demand. So hourly generation and load dispatch in each scenario must satisfy the power balance constraint.

\[ \sum_{i} W_{wt} + \sum_{j} P_{i} = \sum_{j} L_{j} \]  (2)

3) Unit capacity constraints: in this the generation must be within the minimum and maximum power limit. It should not be violate these limits.

\[ P_{i}^{min} \leq P_{i} \leq P_{i}^{max} \]  (3)

4) Ramping constraints: Ramp rate limits [10], [11] restrict the difference of power generations in two adjacent hours. Ramp down rate is maximum generation output in a minute that unit is able to decrease in an hour. Ramp up rate is maximum generation output in a minute that is able to increase in an hour.

\[ -RD_{i,t} \leq P_{i,t} - P_{i,t-1} \leq RU_{i,t} \]  (4)

5) Reserve constraints in the system: Contingencies may affect the security of the power system. Spinning reserve which may be used to address the inaccuracies associated with the load forecasting or potential failures.

\[ \sum_{i} SR_{i} + \sum_{j} SR_{j} \geq SR_{Dj} \]  (5)

6) Wind power constraints: wind power is different than power generated [12] by thermal units because of its limited controllability. The relationship between the actual generation and available wind power is represented by this wind power constraint.

\[ W_{wt} \leq W_{max,wt} \]  (6)

Where,

- \( W_{wt} \) Actual dispatched wind power
- \( W_{max,wt} \) Forecasted hourly maximum wind power of the wind farm

Also, the actual wind power always depends on the wind speed. The relationship between the wind power and wind speed is given by

\[ W_{wt} = \begin{cases} \omega_{r} & \text{if } v_{r} \leq v \leq v_{out} \\ (v - v_{in})/\omega_{r} & \text{if } v_{in} \leq v \leq v_{r} \\ 0 & \text{else} \end{cases} \]  (7)

7) PHEV Load Charging Balance: PHEV loads can be dispatched within the charging period and satisfy the constraint below.

\[ \sum_{t \in \text{Char}_{T}} L_{\mu} \leq L_{Dj} \]  (8)

8) PHEV Load Hourly Charging Limit: The charging rate for each PHEV Load, which is dependent on the technical parameters of charging facilities.

\[ L_{\mu} \leq \text{char}_{R_{j}} \]  (9)

9) Reserve provided by Vehicle-to-Grid: PHEVs are one of the vehicle-to-grid techniques which not only consume electricity but also introduces some benefits in the power systems. Many studies [13]-[15] have focused on two directional power flow however there are still technical challenges are present. Here PHEV provide ancillary services to the power system which includes reserve and regulation. In this work, PHEVs provide 10 minutes of spinning reserve to the power system. The reserve provided by PHEV is not like conventional plants which increases their outputs but decreasing or shifting the scheduled electricity demands of PHEVs. This constraints is represented below.

\[ SR_{j} \leq L_{j} \]  (10)

IV. SOLUTION METHODOLOGY

A. Coordination of wind-thermal system algorithm

To deal with wind-thermal generation dispatch concurrently, the proposed algorithm decomposes the coordination problem into wind and thermal sub-problem.

A simple procedure based on an equal incremental cost rule is used to estimate the wind generation solution for initialization. The sequential dispatch for solving the wind sub-problem is also used to calculate the total operation cost of the WTGs.
The coordination algorithm involves the following steps:
Step 1: Read system data.

Step 2: Determine the feasible region of total wind power generation.

Step 3: Initial total wind power generation estimate $P_{WT}^0$

Step 4: Set $P_{WT} = P_{WT}^0$

Step 5: Compute the minimum operation cost of WTGs using sequential dispatch.

Step 6: Calculate the system spinning reserve requirements.

Step 7: Minimum operation cost of thermal units is computed using LR method

Step 8: Check if there is any improvement in total production cost? If no more improvement can be achieved, then stop; otherwise, project $P_{WT}$ and go to Step 5.

To determine the optimal wind power penetration level and to minimize the total production cost while satisfying the various constraints of the system is the main objective of this algorithm. The overall problem solution is obtained by coordinating between the solution of the thermal and wind generation sub problems.

B. Flow Chart for coordination algorithm

C. LR PROCEDURE

Lagrangian Relaxation is an optimization technique used to solve unit commitment problem. It decomposes the main complex mathematical programming problem into simple sub problems that are additively separable by relaxing the hard constraints. Each sub problem is coupled through common lagrangian multipliers, one for each period. Each sub problem is solved separately. The lagrangian multipliers at each iteration are updated until a near optimal solution is found. The quality of the solution is characterized by the duality gap. The duality gap is the spread between the primal and dual objective function solution.

The Lagrangian Relaxation technique is suitable for large scale power systems and both demand and spinning reserve requirement are satisfied through Lagrange multipliers. It is also easy to incorporate other constraints such as import/export limits and tie line capacity limits into the dual sub problem.
FLOW CHART OF LR METHOD

Fig 3: Flow chart of LR method

V. NUMERICAL RESULTS

To examine the advantages of the proposed method, six unit test system is considered, which consists of equality, inequality and wind power constraints and the losses are neglected. For the six unit system 24 hour load demand is considered. The input data for individual units are given in table I. The six unit system is dispatched in the 24 hour basis. The demand data for 24 hour is given in table II and ramp rate limits are given in table III. All the computations are performed on PC Intel core i3 processor using mat lab software.

TABLE I
GENERATING UNIT CAPACITY AND COEFFICIENTS

<table>
<thead>
<tr>
<th>Unit</th>
<th>Min(MW)</th>
<th>Max(MW)</th>
<th>Fuel components</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>500</td>
<td>A&lt;sub&gt;i&lt;/sub&gt;, B&lt;sub&gt;i&lt;/sub&gt;, C&lt;sub&gt;i&lt;/sub&gt;</td>
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<tr>
<td>2</td>
<td>50</td>
<td>200</td>
<td>0.0095, 10.0, 20.0</td>
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<tr>
<td>3</td>
<td>80</td>
<td>300</td>
<td>0.0090, 8.5, 22.0</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>150</td>
<td>0.0090, 11.0, 20.0</td>
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<td>5</td>
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<tr>
<td>6</td>
<td>50</td>
<td>120</td>
<td>0.0075, 12.0, 19.0</td>
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TABLE II
DEMAND DATA FOR 24 HOUR

<table>
<thead>
<tr>
<th>Hour</th>
<th>Load</th>
<th>Hour</th>
<th>Load</th>
<th>Hour</th>
<th>Load</th>
<th>Hour</th>
<th>Load</th>
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<td>1</td>
<td>960</td>
<td>7</td>
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<td>800</td>
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<td>830</td>
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<td>560</td>
<td>8</td>
<td>920</td>
<td>14</td>
<td>850</td>
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<td>9</td>
<td>610</td>
<td>15</td>
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<tr>
<td>4</td>
<td>870</td>
<td>10</td>
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<td>870</td>
<td>17</td>
<td>790</td>
<td>23</td>
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<tr>
<td>6</td>
<td>740</td>
<td>12</td>
<td>900</td>
<td>18</td>
<td>680</td>
<td>24</td>
<td>970</td>
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TABLE III
RAMP RATE LIMITS

<table>
<thead>
<tr>
<th>Unit</th>
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<th>UR</th>
<th>DR</th>
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<tr>
<td>6</td>
<td>110</td>
<td>50</td>
<td>90</td>
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</table>

RESULTS FOR SIX UNIT SYSTEM

The total generation cost for 24 hour scheduling with wind power system and without wind power system is given in Table IV and their corresponding convergence characteristics is shown in fig 4. The cost indicated in the table IV is rupees per hour.
TABLE IV
TOTAL COST FOR 24 HOUR

<table>
<thead>
<tr>
<th>Hour</th>
<th>With wind</th>
<th>Without wind</th>
<th>Hour</th>
<th>With wind</th>
<th>Without wind</th>
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</thead>
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<td>11390</td>
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<td>6247</td>
<td>14</td>
<td>8808</td>
<td>10052</td>
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<tr>
<td>3</td>
<td>6371</td>
<td>7405</td>
<td>15</td>
<td>8385</td>
<td>9576</td>
</tr>
<tr>
<td>4</td>
<td>9900</td>
<td>10293</td>
<td>16</td>
<td>7127</td>
<td>7848</td>
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<tr>
<td>5</td>
<td>5453</td>
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<td>17</td>
<td>8603</td>
<td>9340</td>
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<tr>
<td>6</td>
<td>8350</td>
<td>8758</td>
<td>18</td>
<td>7608</td>
<td>8073</td>
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<tr>
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<td>9340</td>
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<td>8614</td>
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<td>12</td>
<td>9431</td>
<td>10655</td>
<td>24</td>
<td>10333</td>
<td>11514</td>
</tr>
</tbody>
</table>

Fig. 4 shows the cost comparison of conventional system and wind-thermal system in which red colour indicates the power system without considering wind and blue colour indicates the wind-thermal coordination which lower than the previous one.

VI. CONCLUSIONS

The goal in this work is to develop a stochastic unit commitment model to coordinate wind-thermal system with PHEV loads to reduce the operating cost of power system. In this work initially the unit commitment problem is solved by lagrangian relaxation method without considering wind power system and after that the conventional system is coordinated with wind power system again the wind thermal system is coordinated with PHEV loads. This paper also includes ancillary services provided by PHEVs. The results shows the coordination of three shows the smart charging of PHEV reduce the operating cost of power system. Presently a three unit system is considered as case study and theoretical results are calculate by Lagrangian relaxation method. The detailed results obtained by lagrangian relaxation method with wind-thermal system is compared with the system after the coordination of PHEV loads and the results shows the smart charging of PHEV loads reduces the overall cost of the system.

VII. NOMENCLATURE

- **i**: Index of generating unit
- **j**: Index of electricity load
- **t**: Index of hour
Index of wind farm

Load dispatch

Wind power

Spinning Reserve of unit (MW)

Operating reserve of unit (MW)

Start-up cost of a unit

Shut-down cost of a unit

Maximum wind power (MW)

Penalty price for unserved load

Maximum ramp up/down (MW/hour)

Electric energy requirement (MWh)

Spinning reserve requirement (MW)

Operating reserve requirement (MW)

Set of charging period

Charging speed

Fuel Cost

REFERENCES


