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# Evaluating the impact of sub-hourly unit commitment method on spinning reserve in presence of intermittent generators

Mehdi Kazemi [a], Pierluigi Siano [b, *], Debora Sarno [b], Arman Goudarzi [c, a]

[a] School of Electrical, Electronics, and Computer Engineering, Mapúa Institute of Technology, Manila, Philippines
[b] Department of Industrial Engineering, University of Salerno, Fisciano, Italy
[c] School of Electrical, Electronic and Computer Engineering, University of KwaZulu-Natal, Durban, South Africa

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ABSTRACT

This paper presents an algorithm to deal with thermal Unit Commitment which takes into account the intermittency and volatility of the renewable energies such as wind and solar energies. Dynamic Programming (DP) integrating Priority Listing order (PL) based on Best Per Unit Cost (BP) was applied to commit the thermal units in an isolated island with generators based on renewable sources. In this work, the effects of a high time resolutions such as 60, 30, 15, 10 and 5 min on production costs, reserves and intermittent generators are investigated. In order to demonstrate the capability of the proposed algorithm, two cases were studied. Firstly, a test system composed of ten diesel generators, three wind turbines and one Photovoltaic (PV) power plant is examined and then the IEEE 118-bus test system, integrating wind and PV power plants, is considered. The presented simulation results show that a proper schedule for each generation unit can be reached at a time resolution closer to real time unit commitment and economic dispatch while a high level of reliability can be guaranteed by assuring practical constraints fulfillment.



## 1. Introduction

One of the most important issues regarding power system operation is the optimal scheduling of the diesel units. The Unit Commitment (UC) in an autonomous grid becomes more complicated in case of involvement of renewable energies, such as wind and solar energies, which are intermittent and volatile in nature. Indeed, renewable energies are an attractive alternative to generate the electricity allowing the reduction of the greenhouse gases and emissions. Nevertheless, they introduce more constraints in the problem formulation, such as minimum diesel loading and ramp-up and down rates, and imply the enlargement of physical reserves to cope with the uncertainty and unpredictability of renewable energy in order to maintain a high level of reliability of the system. Since inherent intermittency and volatility of renewable resources affect renewable energy production, in order to increase the penetration of these resources, while maintain the reliability of the system, needs more flexible units with fast response. In this regard, the system operators rely on power plants that can supply demand on the same timescale as variations of renewable outputs and therefore generator manufacturer are trying to improve the some abilities of generation units like ramp rate limits and minimum generation levels [1]. Then, the operation objective is to find the best trade-off between production costs and reliability of the system, even limiting the penetration of renewable energy which is proportional to the reserves' requirements.

The UC problem can be solved by using different methods included in two main categories such as heuristic methods and evolutionary algorithms. Priority List, Augmented Lagrangian Relaxation, Dynamic Programming (DP) and the Branch-and-Bound algorithm, belonging to the first optimization group, have been used to solve the classic UC problem. Since the beginning of the last decade, methods classified in the second group, such as Genetic Algorithms (GAs), Simulated Annealing (SA), Analytic Hierarchy Process (AHP), and Particle Swarm Optimization (PSO) have been also used to solve the UC problem [2].

A methodology based on GAs has been presented by T. Senjyu et al. to solve the UC of thermal units integrated with wind and solar power in which the Best Per Unit Cost (BP), that is a function of production cost coefficients, was used to sort the generators' order

* Corresponding author.
*E-mail addresses:* mehdikazemi77@gmail.com (M. Kazemi), psiano@unisa.it (P. Siano), desarno@unisa.it (D. Sarno), goudarzia@ukzn.ac.za (A. Goudarzi).

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**Nomenclature**

| | |
|---|---|
| $FC$ | Final production cost |
| $To$ | Number of time periods |
| $N_D$ | Number of diesel generator |
| $N_{WT}$ | Number of wind turbine |
| $N_{PV}$ | Number of PV generator |
| $t$ | Index for time intervals, $t = 1,2,\ldots,To$ |
| $i$ | Index for diesel generator, $i = 1,2,\ldots,N_D$ |
| $j$ | Index for wind turbine, $j = 1,2,\ldots,N_{WT}$ |
| $k$ | Index for PV generator, $k = 1,2,\ldots,N_{PV}$ |
| $e_i(t)$ | Is a vector which describes the status of $i$th diesel generator |
| $e_i^D(t)$ | Denotes the availability of $i$th diesel generator |
| $e_j(t)$ | Is a vector which describes the status of $j$th wind turbine |
| $e_j^W(t)$ | Denotes the availability of $j$th wind turbine |
| $e_k(t)$ | Is a vector which describes the status of $k$th PV generator |
| $e_k^{PV}(t)$ | Denotes the availability of $k$th PV generator |
| $RD_i(t)$ | Spinning down reserves |
| $P_{D_i}^{min}$ | Minimum power output of $i$th diesel generator |
| $P_{D_i}^{max}$ | Maximum power output of $i$th diesel generator |
| $P_D^*(t)$ | Total available diesel generation |
| $X_i^{on/off}$ | Is the time for which $i$th diesel unit has been on/off at stage t |
| $T_i^{on/off}$ | Minimum up/down time of $i$th diesel unit |
| $csh_i$ | Cold start hour of $i$th diesel generator |
| $hc_i$ | Hot startup cost of $i$th diesel generator |
| $cc_i$ | Cold startup cost of $i$th diesel generator |
| $UR_i$ | Maximum rated ramp-up |
| $DR_i$ | Maximum rated ramp-down |
| $UR_i(t)$ | Ramp-up capacity of $i$th diesel generator at each stage $t$ |
| $DR_i$ | Ramp-down capacity of $i$th diesel generator at each stage $t$ |
| $\underline{P_L}(t)$ | Minimum diesel loading |
| $P_W^*(t)$ | Total available wind generation |
| $P_{PV}^*(t)$ | Total available PV generation |

[3].

A hybrid approach which is a combination of branch and bound algorithm with a Dynamic Programming (DP) has been presented by Chun-Lung Chen et al. to commit the thermal units in an isolated hybrid power system consisting of wind and thermal plants [4].

It has also been demonstrated mentioned by J. Wang [5] that the cumulative wind power might not be intermittent even if the single wind farm can be intermittent within a day period. However, the electric power generated by a wind farm and even the aggregated wind power output of a wider system can vary significantly on sub-hourly time scales, particularly at high wind penetrations and for small isolated system [6]. A limitation of previous researches is that the intra-hour impact of renewable energies has not been considered in UC and Economic Dispatch (ED) which leads to inaccurate operational cost computing.

An approach which is focused on the ramp capability with an interval resolution of 5 min has been proposed by N. Navid, and G. Rosenwald and utilized in Security Constraints Economic Dispatch (SCED) study for both Single Period (SP) and Time Coupled Multi Period (TCMP). In this approach the amount of ramp capability can be adjusted based on forecasted deviations and historical uncertainties in order to respond to the net load. The authors demonstrated that the proposed approach is a viable option to provide increased response capability from the same set of supplies for both SP and TCMP [7]. A comparison has been made by E. Ela, and M. O'Malley between TCMP and SP in a Real Time Market (RTM) and it has been shown that the TCMP has a better solution for efficiency, reliability and reduction of production price [8].

In a recent work UC and ED problems were solved stochastically for a 6-h time horizon. Improved bender decomposition is deployed to show the impacts of increased temporal resolution of 10, 15, 30 and 60 min on the operational cost. A comparison has been made between deterministic and stochastic UC-ED with hourly and sub-hourly resolutions. It has been illustrated that sub-hourly resolution can reduce the dispatch cost if the UC is solved stochastically [9].

J.P. Deane et al. utilized the power systems modeling tool PLEXOS to show the variability of the renewable generation and it has been illustrated that the inability of thermal units can be captured by means of a more accurate resolution. A time resolution of 5, 15, 30 and 60 min in UC and ED was considered for one year and it has been depicted that a higher resolution implies a higher generation cost [10].

The importance of energy storage in reducing cycling burden has been explored by C. O'Dwyer, and D. Flynn [11]. The authors deployed PLEXOS in UC and ED to investigate the impact of a high wind energy penetration (with a capacity of 42%) on a conventional plant cycling in sub-hourly (15-min) resolution and they have found that energy storage can reduce cycling and improve the performance of the system while a significant cost saving can been obtained [11]. Key limitations derived from the above literature are given below:

- Minimum diesel loading has not been considered
- Ramp rates taken into account in previous studies are based on [12].
- Sub-hourly variability of the spinning reserve in presence of renewable energies has not been investigated

The previously mentioned limitations have been taken into account in the proposed method. Another important innovative of the proposed method is the combined use of Dynamic Programming (DP) integrated with Priority Listing order (PL) based on Best Per Unit Cost (BP), it's worth noting that this hybrid method has not been utilized into any other published article.

The new method is, in fact, based on combination of DP and Priority Listing (PL) in accordance with Best Per unit cost ($2a_ic_i + b_i$) and is called DP-BP. In order to show the capability of the presented method to solve UC and ED on an hourly basis, a comparison has been made with different methods such as complete enumeration DP (DP-CE) and full load average cost DP (DP-FA) with the same exact conditions for a given case study. After illustrating the capability of the suggested method, different time resolutions (5, 10, 15, 30, 60 min) have been considered to simultaneously optimise the UC and ED and facilitate the integration of renewable energies into the grid.

## 2. Problem formulation

### 2.1. Formulation

The main objective of the proposed method is to schedule diesel