A general assessment of the impacts of variable power generation in an integrated power grid

by

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B.Sc., Kabul University, 2013

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

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Carl R.Ice College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2021

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Abstract

With the increasing concerns for the environment, there is a growing demand to replace conventional thermal generators with renewable energy resources. Large-scale penetration of renewable resources such as wind and solar imposes significant challenges on the stability and reliability of existing power systems. Due to their variable and uncertain nature, they have fluctuating generation outputs at multiple timescales. System operators face difficulties determining the appropriate scheduling for the generating units and providing sufficient reserve requirements to balance load and generation. Therefore, the optimal scheduling and dispatching of the generating units in an integrated power system necessitate efficient mitigation approaches.

This report is a general assessment of the impacts of renewable energy sources, like wind and solar, on an existing power grid. It also describes the deterministic and stochastic unit commitment methods currently used to economic dispatch and deals with wind and solar fluctuations. For a better illustration of the variability and uncertainty impacts of variable generation, an IEEE RTS-96 is solved with an energy scheduling simulation tool (FESTIV) to provide deterministic results.

Table of Contents

List of Figures

List of Tables

Introduction

Growing environmental concerns over the utilization of conventional resources of power generation have resulted in integrating renewable resources. In addition to being eco-friendly, several other benefits have made renewable sources a viable alternative for the conventional generating units. Among the different kinds of renewable generations, wind and solar have experienced remarkable growth due to their feasibility. Despite providing substantial positive outcomes to the environment, they also impose considerable challenges on the power system's reliability and stability. Unlike conventional generating units, renewable sources, such as wind and solar, have uncertain and variable nature, and depending on weather, their production varies with time. These uncertainties create challenges for system operators to balance generation and demand. Therefore, it requires advanced mitigation strategies to maintain power system stability [1].

With increasing variable generation in the existing power infrastructure, some advanced strategies and potential solutions to the aforementioned issues have emerged, such as; advanced forecasting, demand response, flexible generation, balancing area cooperation, fast scheduling, and dispatch. The essential considerations in selecting methods to cope with renewable variability and uncertainty depend on the method's cost-effectiveness and the existing grid's characteristics. One of these methods to address these integration challenges in an economically efficient manner is advanced forecasting. Forecasting the production of wind and solar with advanced simulation tools can decrease their uncertainty. It also helps the grid operators to commit and de-commit units more efficiently and prepare for extreme situations. The amount of reserve needed for the system can also be determined by forecasting, which can help reduce the cost of balancing. The other mentioned methods are explained in reference [2]. Many other studies on possible challenges of renewable uncertainty and variability necessitate power system flexibility, like sufficient power ramping capability and reserve for unpredictable load imbalance. Any failure in providing adequate reserves and the requirements needed for system flexibility results in; power balance violations, frequency deviations, Area Control Error(ACE), renewable energy curtailments, and eventually blackouts [3]. Unit commitment problem is typically solved to determine the short-term scheduling of thermal generation units to supply the forecasted power demand considering the operational costs. However, as the variability and uncertainty due to renewable penetration increases, it requires enhanced solution methods for the unit commitment problems. Some efficient scheduling strategies have evolved in past years to improve the unit commitment paradigm. One of those strategies is the deterministic unit commitment, which researchers have utilized for the co-optimization of energy and ancillary services [4,5]. In a deterministic unit commitment, only wind power output forecast is considered and the associated uncertainty is managed by the allocated reserve requirements when needed. Under increased penetration of renewable generation, a stochastic or probabilistic approach is used to deal with uncertainties. In the stochastic method, instead of allocating amounts of reserves for the uncertainty, they explicitly consider the uncertainty by using a set of discrete scenarios and probabilities [6]. Both deterministic and stochastic unit commitments are used to cope with renewable power fluctuations and to minimize the overall operational cost.

This report's fundamental objective is to present a general introduction to the impacts of renewable integration to the existing power system, an overview of deterministic and stochastic unit commitments, their similarities and differences. It also includes a brief introduction to (FESTIV), an energy scheduling simulation tool. To carry out the numerical results for the deterministic unit commitment, a modified Reliability Test System (RTS96) [7] is solved with

FESTIV. Eventually, the numerical results are discussed and analyzed. The rest of the report is organized as follows: Literature review, Methodology, Results, Discussion, and Conclusion.

Literature Review

Unit commitment (UC) is one of the essential operational problems in power systems. It is an optimization process that is used to minimize the production cost by committing and de-committing optimum generation units. System operators choose a commitment schedule for the generation units to meet the demand over a certain period of time. Unit commitment problem has been commonly solved for the thermal generation units to supply the forecasted demand while respecting some necessary physical constraints such as; ramping limit, generation capacity, minimum up and down time, and transmission flow limit [8]. However, the increasing integration of renewable energy to the existing power infrastructure has created more complexity to the unit commitment problem. The concerns are mainly due to the uncertain and variable nature of renewable resources, specifically wind and solar. Therefore, system operators need appropriate methods and tools for short-term scheduling of the units to satisfy the load and system reliability. In power systems, where there is more conventional generation than renewable, a unit commitment solution can provide an acceptable response by dedicating a certain amount of reserve capacity to compensate for load forecast errors. However, more penetration of renewable energy results in additional uncertainty in the system, therefore unit commitment solutions can no longer assure the reliability and stability of the power system [9]. One of the significant effects of replacing conventional sources with wind generation on the power grid's reliability is the short-term frequency response. Modern wind energy conversion machines are decoupled from the grid by back-to-back voltage-based converters, so they cannot provide the required inertial response. Consequently, the lack of inertial response in an unbalance load and demand situation can result in a large rate of change of frequency or steady-state deviation from the nominal frequency. Paper [10] investigates these impacts in detail and presents control metrics to support wind turbines in the short-term frequency response.

Several papers have been published regarding different methods to mitigate the uncertainty and variability of renewables. In reference [11], an overview of the short term wind prediction models has been presented. The model is categorized into Numerical Weather Prediction (NWP) and the statistical approach. Power system operation mode is described as the status of power system operation, determined by the generator outputs, load demand, transmission, and related power flow in a particular time, such as day or hour. Generally, there are many operation modes in the annual power system operation, and they are the basis for operation and planning. Traditionally, these modes follow empirical patterns. However, high penetration of renewable energy will make the power system operation mode highly variable and diversified. So, the modes no longer follow the empirical experience. A data-driven method is proposed by Hou et al. in [12] to identify the pattern of operation modes and analyze the impact of renewable integration. Currently, deterministic and stochastic optimization approaches are utilized to cope with uncertainty and renewable power fluctuations. Deterministic unit commitment is based on traditional unit commitment model, and it is usually used to economic dispatch. In a deterministic unit commitment, only the forecasted wind power output is considered and the associated uncertainty is not included directly. The associated wind fluctuations are managed by the allocated reserve requirements when needed. To minimize the operation cost, the commitment scheduling of the units are planned for a specific time horizon after considering the required constraints. Compared with the deterministic, the stochastic unit commitment explicitly considers the uncertainty by using discrete scenario methods. The uncertainty problem is then directly solved after it is converted into the deterministic one involving multiple wind scenarios [13]. More recent efforts have introduced different scenario-based unit commitment approaches, considering the stochastic wind power. In reference [14], Li et al. presents an improved Lagrange relaxation algorithm to obtain the dual problem of the generator model. Later, the scenario method is used to deal with wind uncertainty based on wind power interval prediction. Another stochastic optimization model for day-ahead scheduling was proposed by Wu et al. [15]. This study uses the hourly demand response (DR) for managing renewable energy sources.

Methodology

In order to gain a better analysis of the deterministic unit commitment, a modified IEEE RTS-96 study case is solved with FESTIV [16] scheduling simulation tool, and the numerical results are analyzed. A brief introduction to the FESTIV scheduling is tool is given below.

FESTIV stands for Flexible Energy Scheduling Tool for Integrating Variable generation. It is a multi-timescale steady-state power system operation tool used for scheduling resources considering the demand and reliability needs of the integrated power system.

FESTIV uses five different scheduling sub-models, namely:

- the day-ahead security-constrained unit commitment (DASCUC),
- the real-time security-constrained unit commitment (RTSCUC),
- the real-time security-constrained economic dispatch (RTSCED),
- the automatic generation control (AGC), and
- the security-constrained reserve pick-up (SCRPU).

Each of these sub-models is configurable by the user, and they are integrated within FESTIV at different timescales. The sub-models also evaluate the power system at various time resolutions, they allow the user to create appropriate timing configurations for any specific study. The main goal of FESTIV tool is to better understand the variability and uncertainty impacts of variable generation (VG), like wind and photovoltaic solar power. FESTIV utilizes two main platforms, Matrix Laboratory (MATLAB) and General Algebraic Modeling System (GAMS). It also uses Microsoft Excel for the input cases and output parameters. For more detail information about FESTIV refer to [16].

FESTIV generates several outputs from a normal simulation. However, few key metrics are discussed here that are related to this report for analysis.

- Unadjusted Production Cost: The total cost of the system is called the Unadjusted Production Cost, and it is computed at the end of the simulation.
- Adjusted Production Cost: Adjusted Production Cost is obtained from the Unadjusted Production Cost, after some processing.
- Revenue: Revenue is related to all sources on the system after the Locational Margining Price is paid.
- Profit: Profit is the difference between the total revenue, and the total cost of all resources.
- Start-Up Cost: Amount of expense associated with starting a generator.
- Area Control Error (ACE): Area Control Error (ACE) at any given time period is defined as the difference between the sum of total generation and total load.
- CPS2: CPS2 is the abbreviation for Control Performance Standard 2. It is a North American Electric Reliability Corporation (NERC) standard that calculates the amount of intervals where the absolute value of ACE surpasses the predefined value.
- Absolute Area Control Error in Energy (AACEE): AACEE is the absolute value for ACE. It indicates the total amount of imbalances occurring during the study period in either direction.
- Standard Deviation of ACE: It indicates the distribution of ACE for the study period.
- Generator Cycles: Generator Cycles specify the total number of times where a generator had to change its direction from increasing power output to decreasing or vice-versa.

The input case IEEE RTS-96 includes a total number of twenty-five active conventional generating units, with a total capacity of 3105 MW, and one wind power generation with a capacity of 130 MW during this study period.

Results

The key FESTIV outputs for the deterministic unit commitment are summarized in Table 1, and Figures 1 & 2.

Table 1. FESTIV Results for Deterministic Unit Commitment

Unadjusted Production Cost	172 595.76 $
Profit	25 948.14 $
Start-Up Costs	1 827.60 $
Generator Cycles	147
CPS2 Violations	0
CPS2	100%
Absolute ACE in Energy (AACEE)	67.7086 MWH
ACE Standard Deviation	4.0764

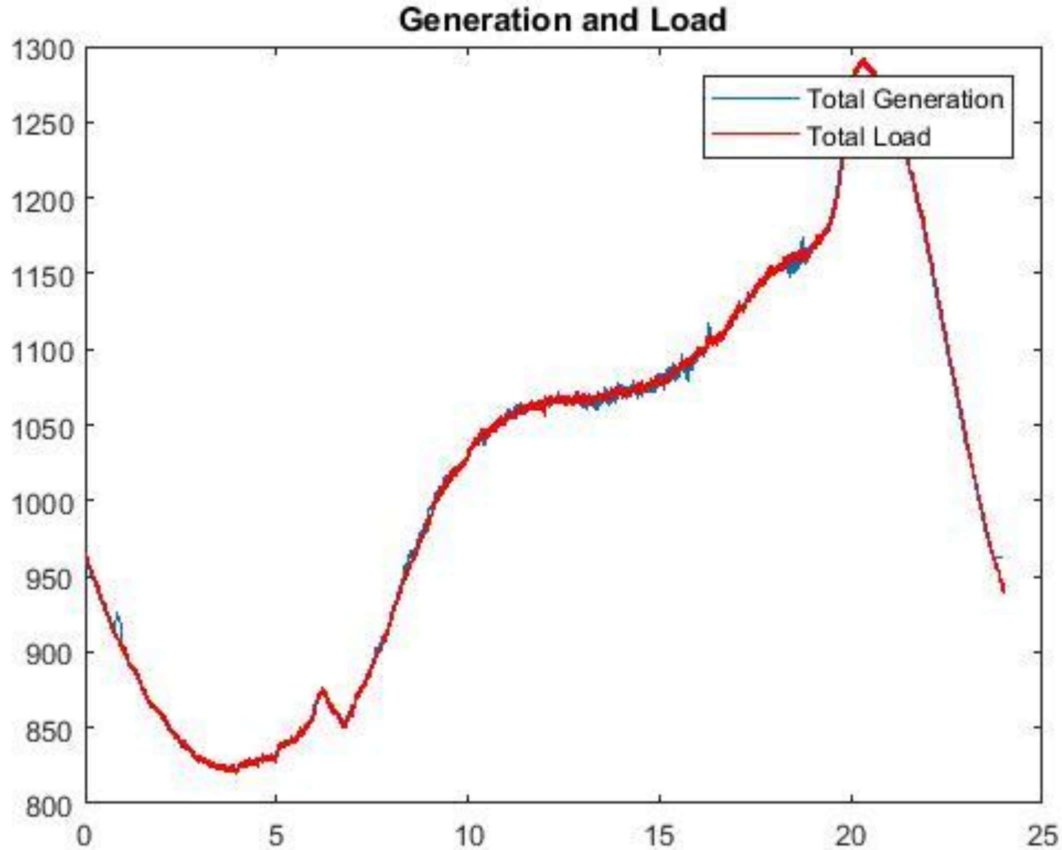

Figure 1. Total Generation and Load

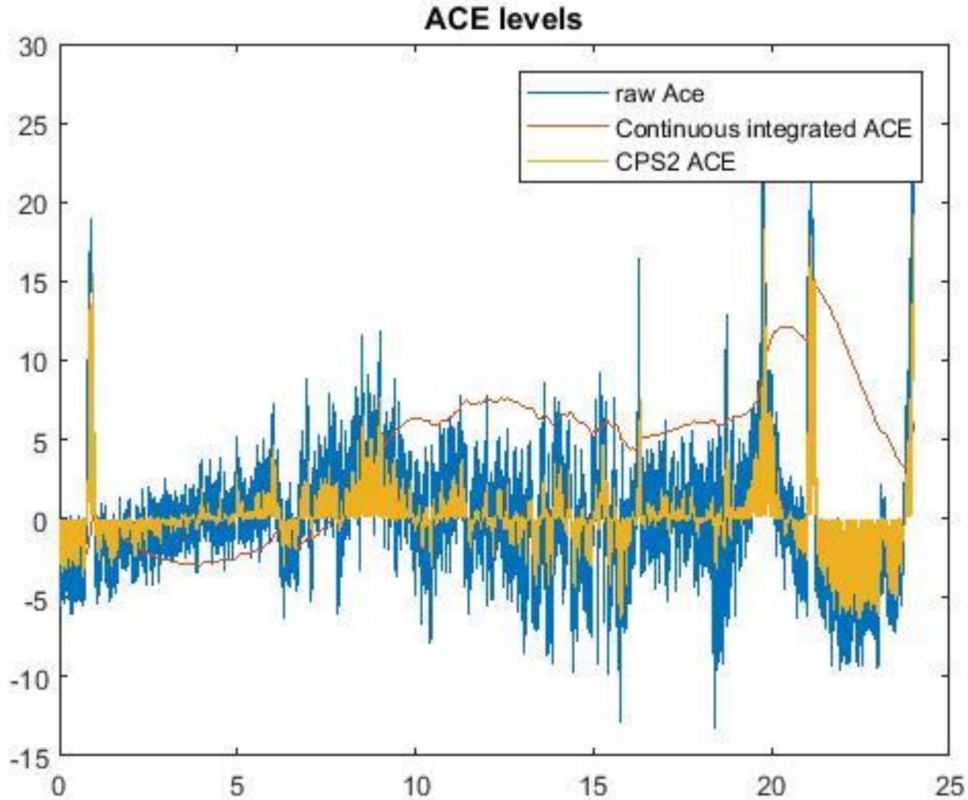

Figure 2. Area Control Levels

Discussion

The results in Table 1 for the deterministic unit commitment indicate no violations of CPS2 and an acceptable margin of ACE. Figure 1 shows the graph of load demand and generation with little imbalances throughout the simulation. As discussed in the literature review section of this report, less penetration of renewable energy in an existing power grid is managed by deterministic unit commitment. The associated wind fluctuations are handled by providing reserve requirements when needed. This simulation includes a small amount of wind generation (130MW), so it does not have large uncertainties. As the variable penetration increases, the deterministic approach will not be consistent anymore with acceptable outcomes. It requires a precise stochastic unit commitment that includes discrete scenarios for wind uncertainties. In reference [17] Palani et al. presents a stochastic security-constrained unit commitment using a progressive hedging algorithm to schedule the generation units for highly integrated power grids.

In conclusion, considering the results, the deterministic unit commitment approach is used for low penetration of variable generation in an existing power grid. For highly penetrated power systems, the stochastic approach is more accurate.

Conclusion

This report is a general analysis of the impacts of integrating a high penetration of variable power generation in an existing power grid. The variability and uncertainty of renewable energy sources like wind and solar need to be analyzed properly to utilize the appropriate mitigation approaches. Table 1 shows that deterministic unit commitment is efficient in an integrated power grid with more conventional units and fewer renewables. However, with the massive penetration of renewable energy sources like wind and solar, the stochastic security-constrained approach is utilized to deal with more uncertainties and fluctuations. There are on-going researches to discover better mitigation methods for more efficient unit commitments with renewables in the future.

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