Applied Energy 203 (2017) 816–828

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Chronological operation simulation framework for regional power system under high penetration of renewable energy using meteorological data

Shiwu Liao, Wei Yao *, Xingning Han, Jinyu Wen, Shijie Cheng

State Key Laboratory of Advanced Electromagnetic Engineering and Technology, School of Electrical and Electronic Engineering, Huazhong University of Science and Technology, Wuhan 430074, China

HIGHLIGHTS

- A three-step chronological operation simulation framework (COSF) is proposed.
- The COSF generates wind and solar output profiles with meteorological data.
- Time-domain partitioning and a roll-back mechanism are used to improve the efficiency of COSF.
- Simulation results verify the accuracy and computation efficiency of the COSF.

ARTICLE INFO

Article history:
Received 8 January 2017
Received in revised form 24 June 2017
Accepted 28 June 2017

Keywords:
Chronological operation simulation
Power system operation
Meteorological data
Unit commitment
Simulation framework

ABSTRACT

Chronological operation simulation (COS) is an essential tool for planning and analyzing power systems under high penetration of renewable energy. Conventional COS methods heavily depend on the availability of renewable power output data to obtain accurate results, and often require hours or even days of computational time while the sequential simulation could easily get infeasible for power systems with intensive flexibility. To cover the absence of output data for newly proposed wind and solar projects and accelerate the computation speed, this paper proposes a novel COS simulation framework for regional power systems with high penetration of renewable energies using meteorological data. The proposed simulation framework consists of the following three steps: data preparation, modeling and solving, and result output. In the data preparation step, wind, solar power output profiles and heat demands are converted from public accessible meteorological data. Then in the modeling and solving step, a unit commitment based COS model for simulating the hourly operation of power and heat sectors is proposed, and the proposed model is solved with a time domain partitioning (TDP) and a rollback mechanism to accelerate the computation speed as well as avoiding infeasible solutions. The accuracy of the wind and solar power output converted from meteorological data is verified through comparing with measured power output. Moreover, the feasibility and accuracy of utilizing the proposed COS framework to simulate the operation of a real regional power system is also verified through the 2015 annual operation statistics of the Northwest China Grid.

1. Introduction

As a major solution to curb the CO_2 emission, renewable energy is developing rapidly all over the world. In 2015, 63 GW wind and 50 GW solar were installed over the globe [1–3], which was unprecedented for the wind and solar industry. To achieve the target set in the COP21 of keeping global warming less than 2 °C above the preindustrial level [4], renewable energies such as the wind and solar will continue to grow rapidly. Therefore, evaluating the potential of renewable energy has become a key area of interest within energy planning and policy making. A crucial element in the development of renewable energy is often to show coherent technical analyses of how renewable energy can be implemented, and how the renewable energy affects other parts of the energy system. Such analyses require simulation methods that can give answers to these issues by modeling the operation of the energy systems [5,6].

* Corresponding author.
E-mail addresses: liaoshiwu@gmail.com (S. Liao), w.yao@hust.edu.cn (W. Yao), xingning.han@gmail.com (X. Han), jinyu.wen@hust.edu.cn (J. Wen), sjcheng@hust.edu.cn (S. Cheng).

http://dx.doi.org/10.1016/j.apenergy.2017.06.086
0306-2619/

Incorporating large amounts of intrinsically variable renewable power will heavily affect the chronological operation of power systems. On the other hand, the intra-interval characteristics of power system operation will also restrict the integration of renewable energy. Therefore, among all methods developed for analyzing the renewable energy integration in energy systems, chronological operation simulation (COS) is an essential tool because it could simulate the chronological interactions between the renewable generations and the power system [7]. The COS simulates the operation of energy systems by finding the least-cost solution of generating sufficient energy to meet demand in a sequential way, namely year around operations are simulated by consecutively running short-term simulations (e.g. daily or weekly simulations) to find the optimal solution for each time interval given the solution of the previous time interval. The solution is constrained by transmission limits, generator operation characteristics (e.g., startup costs, ramp rates, and maintenance outages), and reserve requirements to meet intra-interval generation-demand imbalances. Typically, COS is used to simulate operations on an annual horizon to capture the seasonal variability of load and renewable resource. As illustrated in Fig. 1, COS is widely adopted by all participants of the power system construction, operation and administration. With the growing penetration of renewable energy in power systems, it is essential to have an accurate and reliable COS framework to quantify the generation potential and grid-accommodation potential of proposed renewable projects or pledged renewable targets. Currently, computer tools like BALMOREL and EnergyPLAN are widely adopted to carry out the COS [8–10], and plenty of researches about the renewable integration are performed based on the COS [11–15]. Although these tools and researches provide a feasible way of adopting COS to analyze the renewable integration in power systems, current COS methods still have two bottlenecks constraining their applications in analyzing planned renewable projects or evaluating future energy targets, and in simulating large-scale power systems with very intensive flexibilities.

For the COS, renewable power output profiles are required [16,17]. However, for newly proposed projects or future renewable targets, no historical renewable power output data are available. Moreover, the historical wind and solar power outputs with high temporal resolution are not made public at most places in the world. Hence, how to obtain wind and solar power output from alternative data sources is important for COS of regional power system integrated high penetration renewable energy.

Besides the heavy dependence on renewable output data, the computation efficiency is also a bottleneck for the COS. Owing to the large number of generators in regional grids, the computation of a sequential COS still could take several hours or even a few days [18,19]. In addition, caused by the intensive flexibility of power systems with renewable energy deeply penetrated, the sequential simulation could easily get infeasible solutions at any time interval during the annual simulation [20,21], then there will be no complete COS results available for applications.

To address the bottlenecks of renewable output profile dependence and computation efficiency in the COS, this paper proposes a simulation framework that obtains wind and solar output from public accessible meteorological data and simulates the annual operation of regional power systems fast and reliably. The proposed framework consists of three steps: data preparation, modeling and solving, and result output. In the data preparation step, a public accessible meteorological database, which provides hourly wind speed, surface irradiance, and surface temperature data, is adopted to obtain the hourly wind, solar power output, and the heat load for combined heat and power (CHP) units. After all input data are prepared, the modeling and solving step proposes a COS model for simulating the hourly operation of combined power and heat sectors, and adopts a time domain partitioning (TDP) method and a rollback mechanism to simulate the year around operation. With the proposed COS model and solving strategy, the computation speed is significantly accelerated and infeasible results can be avoided. After the modeling and solving step gets finished, results from all parallel processes are combined in the result output step. The accuracy of wind and solar output profiles converted from meteorological data is verified through comparing with the measured output from practical wind and solar projects. And the COS result of Northwest China Grid in 2015 obtained from the proposed framework is verified in good consistency with the statistical data released by China National Energy Administration (NEA) [22,23] and the State Grid Corporation of China [24]. Compared with existing studies, the main contributions of this paper are four folds:

- A novel COS framework for analyzing the integration of renewable energies into power and heat systems is proposed. Compared with the existing COS tools, the proposed framework can analyze newly proposed renewable projects and future energy targets accurately, and can avoid infeasibility and reduce the computation time for analyzing large-scale power systems with very intensive flexibilities. Moreover, the proposed framework can be used to investigate the potential renewable curtailments in the future and to aid the selection of techniques for reducing the curtailments.
- A method that can obtain wind, solar power output and heat load for CHP units from public accessible meteorological and geographical database is proposed, which makes the proposed

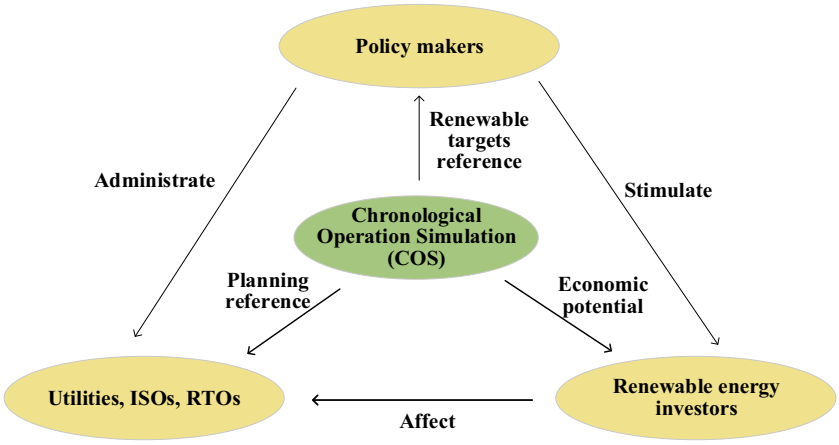

Fig. 1. Applications of COS in power system.