Foreword for the Special Section on Power System Planning and Operation Towards a Low-Carbon Economy

INCREASES in greenhouse gas (GHG) emissions are the major cause of climate change (global warming), which poses a huge threat to our society in the foreseeable future. Development of a low-carbon economy has become prevailing and essential. Many countries throughout the world have been making their economy more climate-friendly and less GHG emissions. In its roadmap to a competitive low-carbon economy in 2050, the European Union (EU) has planned to cut most of its GHG emissions by utilizing clean technologies and renewable energy resources [1]. In developing countries such as China, wind generation capacity is expected to exceed 100 GW by 2020, and is developed primarily to reduce pollutants and GHGs [2].

The electric power system is a major source of carbon dioxide and other GHG emissions, mainly during the energy conversion process. De-carbonization of the power sector is critical and fundamental in confronting the challenges of climate change. However, with in-service lives as long as several decades, the electric power infrastructure has been largely built with various forms of conventional generation technologies, which lead to an intensive "carbon lock-in" effect in the future [3], [4]. For example, thermal generating capacity accounted for 82.5% of the total generation in China in 2011 [5]. Moreover, generation scheduling in China is based on pre-defined production quotas following the "equal shares" principles for all thermal power plants [6], which results in heavy energy consumption and high GHG emissions. In comparison, in developed countries such as those Nordic ones, the existing electricity markets are designed for large-scale conventional generating units, which may not be sufficient to manage the challenges brought by the high share of fluctuating and less predictable renewable power generation [7].

There is a growing consensus that changes are needed in power system planning and operation to achieve a low-carbon economy. One example is the new real-time electricity market developed and demonstrated in the EcoGrid project in EU allowing the participation of small end-consumers and small-scale distributed energy resources (DER) in power system operation operations to negate the generation fluctuation introduced by renewable energy [7]. In China, energy-saving generation dispatching model has been implemented since 2007 for facilitating energy-saving and for reducing of GHG emissions [6]. In [8], the concept of "carbon emission flow in networks" was proposed for analyzing the correlation between energy consumption and carbon emissions. A low carbon power generation expansion model for reducing CO_2 emissions is developed in [4].

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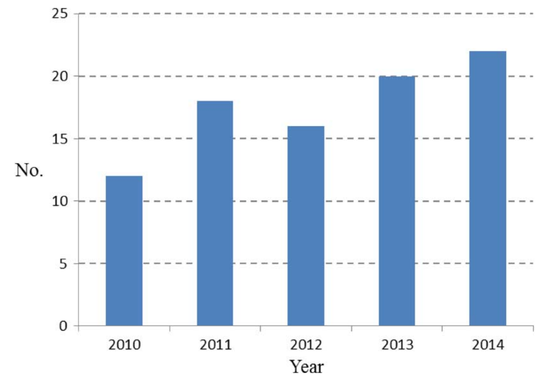

Fig. 1. Number of journal papers containing "low carbon" and "power system" in IEEE Xplore.

The relevance and timeliness of the topic of "low carbon" in power systems is evident in the IEEE Xplore statistics as shown in Fig. 1. The figure illustrates the number of journal papers in the IEEE Xplore containing the keywords "low carbon" and "power system" in the last five years.

This special section is dedicated to address this need and is composed of 9 papers.

The topics covered by the papers are outlined as follows:

1) power system planning models;
2) power system operation methods and market behavior analysis;
3) risk assessment and emission management.

Power System Planning Models: Hozouri *et al.* have developed a combinatorial planning model to maximize wind power utilization by jointly operating the wind power generation system with pumped hydro energy storage (PHES). A multi-objective (MO) optimization framework is proposed to properly deal with wind energy curtailment cost, total social cost, and also the revenue of storage units as some unavoidable factors in power system planning studies.

Park and Baldick have proposed a stochastic generation capacity planning model incorporating wind energy and simulate its impact on GHG emission reduction. The model is formulated as a two-stage stochastic problem for procuring more wind energy and lowering GHG emission, where the first stage makes the generation capacity expansion decision and the subsequent operating points of the units are found at the second stage.

Natural gas plays an important role in the power industry for reducing GHG emissions and pollutions. To increase the overall system efficiency and reduce the uncertainties, gas system and power system should be planned in an integrated manner. The paper by Qiu *et al.* proposes a novel expansion co-planning

(ECP) framework, modeled as a mixed integer nonlinear optimization problem.

The paper by Konstantelos and Strbac assesses the potential for flexible technologies such as phase-shifting transformers and storage technologies to constitute valuable interim measures within a long-term power system planning strategy. Implementing such flexible technologies not only provides valuable transmission services but also lowers the risks associated with subsequent decisions when facing uncertainties of high penetration of renewable energy generation in the future.

Power System Operation Methods and Market Behavior Analysis: Spinning reserves (SR) are very important for securing power system operations. Carbon capture plants can largely reduce GHG emissions and might also affect the requirement for SR. Lou *et al.* have developed a multi-period optimization model for coordinating the generation, carbon capture, and SR provisions. The effects of carbon trading prices on the overall cost and optimal SR requirement are also analyzed by the authors.

LaMadrid *et al.* have proposed a stochastic optimal power flow model for endogenous definition of optimal operating reserves. Their model includes several innovations, including inclusion of the carbon impacts of generator ramping; previous such models have assumed that emissions were only a function of generation level. The model is used to explore the economic and GHG emissions impacts of adding storage and wind to the system, of including carbon penalties and ramping costs in the objective function.

The paper by Huang *et al.* analyzes market participants' behaviors in emission trading (ET). A hybrid interactive simulation methodology based on the complementary features between experimental and agent-based computational methods was proposed to simulate human behavior related problems in ET, which can improve the market efficiency.

Risk Assessment and Emission Management: The paper by Jia *et al.* develops a hierarchical risk assessment method to consider the impacts of active distribution network with distributed generation (DG) on probabilistic risks of transmission system. The risk indices used in the paper include expected energy not supplied, probability of load curtailment, expected frequency of load curtailment, and severity index. In the proposed method, a time sensitivity analysis is adopted to study the influence of DGs' capacity, dispersion, and location together with the outage probability of components on system risks.

The uncertainties and correlation of regional loads and renewable energy resources make regional carbon emission management (RCEM) increasingly challenging and necessary. Wang *et al.* develops a multi-objective RCEM model based on probabilistic power flow (PPF) considering correlated variables to reduce the total carbon emissions, control regional carbon emissions, prevent probabilistic congested lines, and select wind farm locations.

We would like to express our appreciation to all authors for their innovative and original work. We are grateful to all reviewers for their thoughtful comments, which have improved the quality of the papers. We also wish to express our gratitude for the Editor-in-Chief's support and suggestions during the process.

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