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Electrical power planning and scheduling in Taiwan based on the simulation results of multi-objective planning model

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ABSTRACT

Based on the solitary electrical power system typically used in Taiwan, this study employed the constraint method, which is a multiobjective planning approach, and a set of non-inferior solutions with the associated marginal rate of substitution, which aimed to minimize power generation costs and CO_2 emissions. The objective was to simulate and verify the feasibility of historical power generation scheduling. Subsequently, this study simulated power generation scheduling for a future target year and observed the power generation behavior under various circumstances, to determine how power departments can satisfy power-supply demands while reducing CO_2 emissions. This study also provided suggestions for decision-making units to plan the future supply of electric power and assess reductions in CO_2 emissions. The study results show that extending the operating period of nuclear power units is the optimal solution for reducing CO_2 emissions in 2025. If the fluctuation in fixed costs caused by replacing existing power generator sets with new sets is not considered, increasing the efficiency of electric power generating sets can effectively reduce power generation costs and CO_2 emissions. The increase amount of natural gas used to generate power repressed the supply of renewable energy, causing the cost to increase without significantly reducing CO_2 emissions. The marginal rate of substitution for the relationship between total power generation costs and CO_2 emissions becomes moderately flat because as the number of electric power generating sets, which can be manually scheduled, in the power generation system decreases, the cost of reducing CO_2 emissions increases.

1. Introduction

Demand for electric power and the innovation of technological products are increasing. Because of advances in technology and the prosperity of society, electricity has become a necessity in daily life. However, the fact that electrical power cannot be easily stored is a difficult challenge to overcome. Without the ability to store electricity, it is difficult to satisfy the demand for electrical power, for which a constant supply is required. The planning and installation of large-scale power plants and devices, such as electrical power transmission and distribution systems, usually requires a substantial amount of lead time and a huge investment of capital.

In addition, as an island nation, Taiwan is unable to obtain electricity from external sources. Therefore, it is crucial for the Taiwanese power industry to perform accurate predictions of the demand for electrical power before power plants are installed and to establish appropriate plans for power development and scheduling. Accordingly, investment in power facilities can be appropriately distributed to meet the demands of industries and households without wasting resources or allowing power plants to become idle as a result of overinvestment.

Many studies have reported that emissions caused by the burning of fossil fuels have changed the proportions of components in the Earth's atmosphere. Among these components, the emission of carbon dioxide (CO_2) has been the most frequently addressed and debated upon. Upward trend in CO_2 emissions, and this is an improvement over the World Economic Outlook (WEO) Current Policies Scenario and is in line with the worst-case scenario presented by the Intergovernmental Panel on Climate Change (IPCC)[6] in the Fourth Assessment Report (2007), which projects that emissions will stimulate a worldwide average temperature increase of between 2.4 °C and 6.4 °C by 2100. Growing global energy demand from fossil fuels plays a key role in the upward trend in CO_2 emissions (Fig. 1). Since the Industrial Revolution, annual CO_2 emissions from fuel combustion substantially increased from near zero to over 30 $GtCO_2$ according to 2010 [1]. In addition, an analysis of the total energy consumed in Taiwan showed that electrical power accounted for the highest proportion, 48.6%, in 2010. In addition, coal-fired units were the main power supply structures in Taiwan, accounting for 49.91% in 2010, which caused the level of CO_2 emissions from the power sector to surpass that of other sectors (Fig. 2). Hsu and Chen [2] urged Taiwan's power sectors to reduce CO_2

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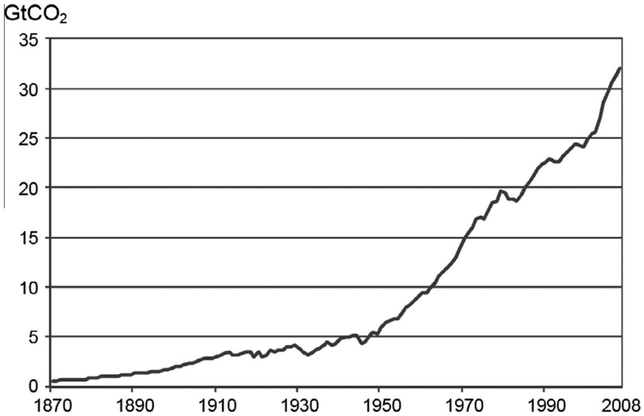

Fig. 1. Trend in CO_2 emissions from fossil fuel combustion.

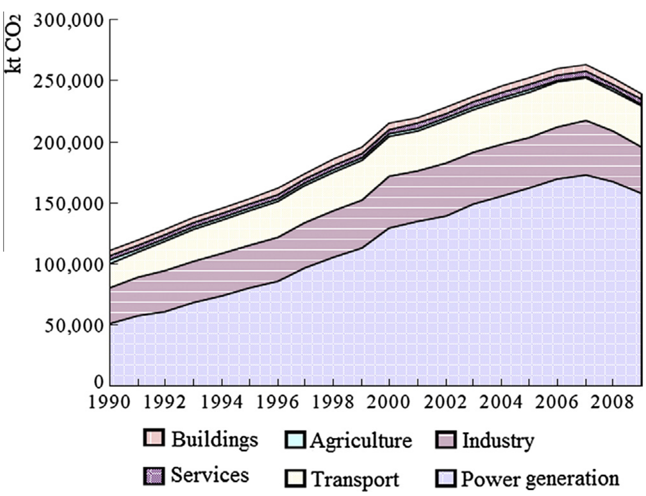

Fig. 2. CO_2 emissions in Taiwan according to sector.

emissions. A multi-objective mix integer model for a power generation strategy in Taiwan is proposed. This model can be used to develop strategies for future generator set expansion and to study the influence of limiting CO_2 emissions.

To develop a thorough, adequate plan for an electrical power supply system, national decision makers must consult the opinions of experts and consider the recent trends in international power development and emerging environmental awareness; therefore, a long-term power plan that meets requirements is subject to change. In this study, a multi-objective planning method was applied to construct an electrical power supply model. Historical data and various energy policies, as well as restrictions on the emission of CO_2, data from civilian power plants, and cogeneration in the open market, were incorporated in the model for analysis. A simulation based on various projected circumstances was performed to identify the optimal electric power supply operation, which provides a reference for future planning in power development. Therefore, this study focused on the following:

1. The application of a multi-objective planning method to construct an optimal model of electrical power supply.
2. Estimation of the abatement cost of CO_2 emissions and electricity generation costs.
3. Simulation and analysis under various circumstances to provide feasible suggestions to decision-making institutions for formulating policies.

Numerous predictions, analyses, and investigations on the developmental status of the electrical power industry have been conducted in previous studies. For example, Hsu and Chen [2] and Catalão et al. [3] have proposed a practical approach for profit-based unit commitment (PBUC) with emission limitations. Under deregulation, unit commitment is a cost minimization problem rather than a profit-based optimization problem. Trade-off curves between profit and emission are obtained for different energy price profiles to aid decision makers in emission allowance trading.

Chatterjee et al. [4] used harmony search (HS), which is a derivative-free real-parameter optimization algorithm. We propose a novel approach for accelerating the HS algorithm. The potential of the proposed algorithm was assessed by conducting an extensive comparative study of the solutions obtained for four standard combined economic and emission dispatch problems of power systems.

Ganguly et al. [5] presented a novel dynamic programming approach for the multi-objective planning of electrical distribution systems. In this planning, the optimal feeder routes and branch conductor sizes of a distribution system are determined by simultaneously optimizing cost and reliability.

Lai [6] established a power load forecasting model by using a back-propagation artificial neural network based on regional development situations to forecast future electricity demand in various regions. In addition, based on regional electricity demands and the potential supply sources of electricity, Lai established an electrical power supply programming model based on a multiple-objective programming model for electrical power supply planning. The results showed that the pressure of the electricity pricing rate adjustment is unavoidable, because the power industry must respond to the ascending trend of electricity generation costs, and that gas power generation units owned by the Taiwan Power Company will be the most substantially affected by the operation of privately owned power plants. In addition, when policy instruments for regulating the proportions of power generation are insufficient, an open strategy of competition, in which the structure of an electrical power supply is determined by the market, may be a possible compromise.

Antunes and Oliveira [7] adopted the mixed integer linear programming method in multiple objective programming to establish a power generation expansion programming mode in which the objective functions contain minimized costs of total power expansion, minimized environmental impact, and minimized environmental costs. The results indicate that combined cycle units using natural gas constitute a favorable option for power expansion.

Chang [8] conducted an industrial input–output analysis and adopted the multiple objective programming method to establish a 3E model focusing on the interrelationship among energy, the environment, and economic development. The model is mainly applied in the power sector, and the objective of this model is to maximize economy, minimize energy consumption, minimize power generation cost, and minimize CO_2 emissions. According to the simulation performed by the power sector, the future expansion of nuclear power remains uncertain, despite the reduction of power generated by coal-fired units because of increasingly strict CO_2 emission reduction goals.

Nakawiro [9] adopted a conventional power generation installed capacity plan and repeatedly tested and studied the most effective combination for power generation to satisfy the anticipated electricity demand in Thailand. By considering issues concerning fuel supply safety and the environment, Nakawiro simulated the power installed capacity plan from 2011 to 2025. The study indicated that the national energy security risk may increase if Thailand excessively relies on natural gas to generate