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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　　博士（工学）　　氏名　Lukwesa Biness

学 位 論 文 題 名

Study on effective measures of power fluctuation mitigation for wind and solar power and electricity prices toward a predetermined social optimum
(風力・太陽光発電の効果的な出力変動抑制対策と社会最適誘導電力料金に関する研究)

The development of variable renewable energy (VRE), which includes wind and solar photovoltaic (PV), is essential for reducing greenhouse gas (GHG) emissions and increasing energy security. The decline in the costs of VRE technologies, coupled with supporting policies such as a feed-in tariff (FIT) policy, has contributed to the rapid growth of VRE deployment. However, the integration of large-scale VRE poses a challenge to power supply systems due to fluctuations in VRE power output. Therefore, economical and technologically effective ways of integrating high shares of VRE into the power supply system need to be carefully considered. The effective integration of VRE in power supply systems should ensure that the effects of VRE power output fluctuations are minimized. The fluctuation reduction measures considered in this research include the geographical distribution of VRE locations, the introduction of battery storage, and the increase in power transmission capacity. This research investigates the effective combination of power fluctuation reduction measures toward optimum social costs of power supply. Further, the research employs a combined total and partial optimization approach to increase the utilization of VRE electricity in the power supply. The objectives of this research are: (i) to determine the effective combination of technological measures to suppress the VRE power output fluctuations and the increase in power supply costs when high VRE shares are integrated, and (ii) to elucidate the effective conditions of electricity prices required to achieve optimum VRE electricity utilization. This dissertation consists of 5 chapters as follows:
Chapter 1 summarizes the literature review and provides the objectives of the research.
Chapter 2 presents 2 linear programming-based optimization models which were developed for the analysis and a description of the case study area. The models include a total optimization and a partial optimization model. The total optimization model is employed to examine the effects of power fluctuation mitigation measures on the integration of large-scale VRE in power supply systems. The objective function is the total cost of power supply, which includes investment, operation and maintenance, and variable costs of power generation, energy storage, and power transmission systems. The model minimizes the total cost of the power supply. The partial optimization model is employed to optimize the power transmission and distribution (PTD) company. The objective function is the PTD company costs, which include the cost of electricity purchase and the cost of installation and maintenance of battery storage and power transmission systems. The partial optimization model minimizes the PTD company costs.
Chapter 3 is a study on effective measures for power fluctuation mitigation of geographically distributed wind and solar power. This study considers power fluctuation mitigation measures including

the introduction of battery storage and an increase in the power transmission capacity. The study employs a total optimization approach to determine the effective combination of fluctuation reduction measures toward the minimized total cost of power supply. The results show that for high VRE shares, combining the geographical distribution of VRE locations with the introduction of battery storage and an increase in power transmission capacity effectively suppresses the increase in power supply cost. The variation of power supply costs and the VRE share can be categorized into three tiers. The first tier, up to 40 % VRE share, can be achieved by only optimizing the geographical distribution of the VRE locations. For the second tier of VRE share (40 % to 60 %), increasing the transmission capacity is effective to suppress the increase in the power supply cost and the excess power generation. In the third tier (60 % to 80 %), the effect of the introduction of battery storage is effective and is similar to the combined measures. Therefore, the selection of the appropriate measures for the integration of 60 % to 80 % VRE shares depends on government policies. The results also indicate that the introduction of battery storage facilitates the integration of large-scale solar PV while increase in the transmission capacities enables the integration of large-scale wind power. Further, in addition to battery storage and power transmission enhancement, a thermal energy backup system such as a combined heat and power (CHP) system may be effective in suppressing the increase in the total cost of power supply.

Chapter 4 is a study on electricity prices for power supply toward an optimum target of VRE electricity utilization. In chapter 3, a model of the entire power supply system is determined through a total system optimization approach. However, actual power supply systems operate by the partial optimization of individual components of the power supply system. Therefore, in this chapter, a partial optimization approach is employed to investigate the effect of electricity prices on the utilization of VRE electricity by the PTD company. The partial optimization model is used in this analysis and the objective function is the PTD company costs. The model minimizes the PTD company costs which include the cost of electricity purchase and the cost of battery storage and power transmission systems. The results show that the VRE share depends on the electricity prices. Higher prices of backup thermal power increase the utilization of VRE electricity by the PTD company. Further, the results indicate that the price difference between thermal and VRE electricity prices is a key factor in determining the utilization of VRE electricity. A price difference to obtain a target of 80 % VRE share is 54 JPY/kWh. However, considering the rate of VRE share increase, a lower price difference of 30 JPY/kWh is more effective and obtains a 76 % VRE share. In addition, higher prices of backup thermal power increase the costs for the PTD company on the power purchase and the installation of battery storage and power transmission systems, while the revenues of power generation companies increase. To reduce the costs for the PTD company, additional measures such as carbon tax, cheaper VRE electricity prices, and subsidies to the PTD company may be effective to incentivize the costs of battery storage and the increases in the power transmission capacities.

Chapter 5 is the conclusions of the study on the effects of a combination of power fluctuation reduction measures and the study on electricity prices for power supply toward optimum VRE utilization.