Evaluation of the Optimal Power Generation Mix with Regional Power Interchange considering Output Fluctuation of Photovoltaic System and Wind Power Generation

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***Abstract* — This research presents the evaluation on the impact of photovoltaic (PV) system and wind power generation into optimal power generation mix in Hokkaido, Tohoku and Tokyo region, explicitly considering these regional power interchange. The analysis is derived from the development of large-scale linear programming model which identifies the optimal power generation mix directly incorporating intermittent output characteristics of solar and wind power generation in ten minutes' time interval on a daily basis through one year. The effect of regulation on carbon dioxide emissions is investigated focusing on the scale of deployment of those renewable power generations into the power system.**

***Keywords* — Optimal power generation mix, Solar photovoltaic system, Wind power generation, Output fluctuation, Power interchange, Carbon dioxide emissions**

I. INTRODUCTION

As an effective measure tackling with energy security and global warming issues, renewable energy is paid to attention, and widespread deployment especially PV and wind power generation are expected.

In Japan, PV system is installed at 2.63GW in 2009, and Japanese government establishes a target of PV capacity deployment more than 28GW by 2020. In order to achieve this goal. Japanese government is expected to politically and financially support its installment.

On the other hand, the notable thing to analyze wind power generation is that northern part of Japan, namely Hokkaido and Tohoku area, potentially embrace the largest wind power endowment in Japan, such as that Hokkaido and Tohoku area incorporate 35GW out of 65GW in onshore wind power potential in Japan, while Tokyo area, neighboring region to those northern regions, has the largest electricity demand among Japan's utility companies. In order to analyze the effective deployment of wind power to realize that Tokyo area accommodates wind power resources endowed in those neighboring regions, therefore, it is necessary to take into account the transmission capacity of regional power interchange among the regions.

II. OBJECTIVE

In this study, the optimal power generation mix is simulated and widespread adoption of PV and wind power generation in power system considering regional power interchange are investigated focusing on Eastern Japan, comprised of Hokkaido, Tohoku and Tokyo area. In the simulation the output fluctuation of PV and wind power generation is taken into consideration.

The three regions of Eastern Japan is the regional boundary in our analysis and inter-regional power transmission capacities are elaborately considered. Power transmission capacity between Tokyo and Tohoku area and those inflexibility restricts the power interchange between the regions. Inter-regional power connection, hence, should be taken into consideration.

III. METHODS

A. Optimal Power Generation Model

In this model, under various assumptions, power generation capacity and its operation supply equipment are specified through the minimization of total power generation cost, mainly consisting of facility cost and fuel cost. Linear Programming method is adopted to calculate. This methodology is a specific class of mathematical problems, in which a linear objective function is either maximized or minimized subject to various linear constraints. Regarding electricity demand, derived from typical electric power load profile, electricity load curve is developed so that peak electricity demand and electricity demand in each day can be approximate to the actual observed value. The load curve is prepared on ten minutes interval in 365 days.

B. Operating Ratio of Photovoltaic System

Hourly data of sunlight and rainfall, etc. are available from AMeDAS. Employing these data allows us to estimate the quantity of solar radiation that poured down over the solar battery and the electric power output of PV system. The time resolution of the evaluation is ten minutes interval, and detailed output fluctuation of PV are fully considered.

C. Operating Ratio of Wind Power Generation

AMeDAS provides the data of the wind velocity as well, which enable to estimate the wind velocity actually converted into electricity considering the height of the hub of a general pinwheel and to assess the operating ratio utilizing the performance curve of the pinwheel.

D. Power Interchange Capacity

Actual installed capacity of power transmission line between Hokkaido and Tohoku area is 0.6GW and that from Tohoku to Tokyo area is 5GW, and, from Tokyo to Tohoku, 1.3GW.

In this paper, the power transmission capacity between Hokkaido and Tohoku is assumed to be fixed. On the other hand, the upper limitation of the power transmission capacity between Tohoku and Kanto is assumed to be 10% of the peak of the power demand in each receipt region. Namely, power interchange capacity from Tohoku to Tokyo is assumed to be 6.34GW and that from Tokyo to Tohoku is 1.51GW. Since literature is not available describing a construction cost of power transmission line, that value is set to 0 yen/kW with inter-regional losses of power transmission lines homogeneously assumed at 0.1%.

IV. RESULT OF ANALYSIS

A. Present Condition

The substantial change was observed in the power generation mix in the Tohoku and Tokyo region due to the earthquake that had occurred in March 11, 2011 and the resulting shutdown of numerous nuclear and thermal power plants in those regions.

B. Sensitivity in the Capacity of Nuclear Power Generation

The optimal power generation mix before and after the earthquake was calculated.

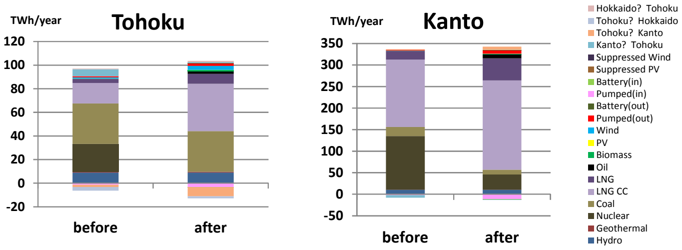

Fig.1.2 Annual generation by simulation

The operational suspension of nuclear power plant eventually increases the proportion of thermal power generation in Tohoku and Tokyo area, and confirm that thermal power plant plays an alternative role instead of nuclear power. Furthermore, nuclear shutdown after the earthquake causes the increase in carbon dioxide emissions by about 30 percent, principally because nuclear is replaced by thermal powerplant.

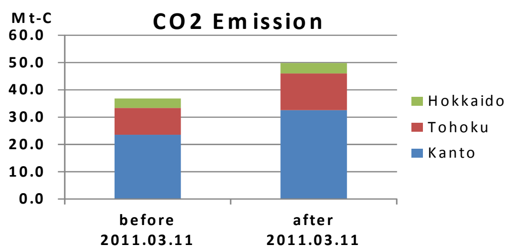

Fig.3 the Amount of Carbon dioxide Emission

C. Regulation of Carbon Dioxide Emissions

CO2 regulation case is assumed as 20% reduction case, 40% reduction case, 60% reduction case and 80% reduction case, with no regulation case (denoted free) adopted as a reference.

CO2 restriction encourages the adoption of PV and wind power generation and the scale of inter-regional power transmission as well. Moreover, it should be noted that PV power generation boosts up greatly after the earthquake where there is massive shutdown of nuclear power plant.

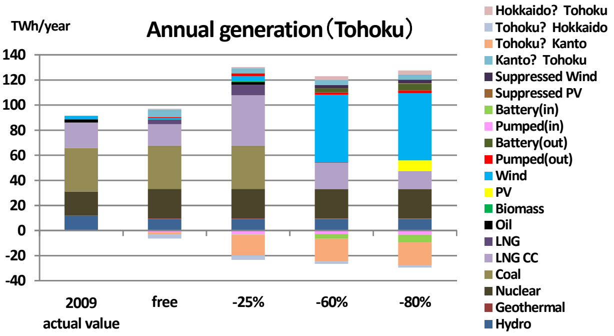

Fig. 4. Annual generation (before the earthquake)

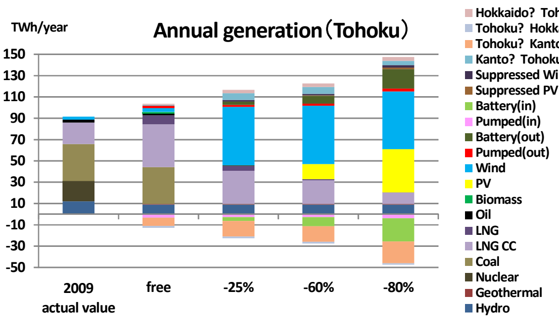

Fig. 5. Annual generation (after the earthquake)

V. SUMMARY

As a result of simulating the power supply situation after the earthquake, thermal power generation such as coal-fired and LNGCC are deployed greatly in place of nuclear, which consequently the soaring in carbon-dioxide emissions by around 40 percent. On the other hand, it is confirmed in our analysis that wind power generation is effectively adopted through regional power interchange which leads to the carbon dioxide reduction in Eastern Japan. As additional important finding, PV system, a high cost power supply option, is introduced in large quantities in Tokyo if a carbon dioxide regulation is severely arranged, therefore it suggests that the introduction of PV system will progress even more under the further cost reduction backed by the further technological advancement.

As our future agenda, more detailed technological description of power system is required particularly under massive adoption of intermittent renewable. When PV and wind power generation are introduced widespread in the system with a steep weather condition, it is expected that it negatively influences on the voltage, the frequency and the stabilization of the power supply system. Therefore it is necessary to develop a model incorporates the technological impact of widespread renewable energy on the stabilization of power system.

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