Simulation Analysis for Massive Deployment of Variable Renewables employing an Optimal Power Generation Mix Model

Ryoichi Komiyama, The University of Tokyo, +81-3-5841-0582, komiyama@n.t.u-tokyo.ac.jp
Saeko Shibata, , The University of Tokyo, +81-3-5841-0582, shibata@esl.t.u-tokyo.ac.jp
Yasumasa Fujii, The University of Tokyo, +81-3-5841-0249, fujii@n.t.u-tokyo.ac.jp

Overview

In order to address climate change and energy security issues as represented by global warming and the political instability in oil producing countries, great attention has been utilizing renewable energy, such as solar photovoltaic (PV) and wind power. This paper describes the development of optimal power generation mix model which is capable of analyzing the impact of intermittent solar and wind power generation on electric power system in the resolution of 10 minutes during 365 days a year, and simulates the massive deployment of PV and wind power in Japanese electricity market under future nuclear energy scenario after Fukushima nuclear accident.

Methods

The authors develop optimal power generation mix model for the daily load curve in time resolution of 10 minutes on 365 days a year under various technical constraints using linear programming technique. The focus in this paper is Japan's electricity grid in 2030 in order to consider the lead-time for massive deployment of renewable and to do the sensitivity analysis on nuclear power plant. The minimization of the objective function comprised of annual facility and fuel cost allows us to identify the best mix of power generation and required capacity of power plants. Although Japan's power system is dominated by 10 privately-owned utility companies and individual service area of the utility is interconnected through transmission line, we assume no interchange transmission constraint and, hence, Japan's whole power generation mix is optimized as one area. The number of the constraints in linear programming is about 2.5 million and that of endogenous variable is approximately 1 million. PV and wind power output are estimated at 10 minutes' time resolution using Japanese meteorological database called AMeDAS. Aggregate PV output pattern as a whole in Japan is calculated as weighted-average of the pattern in each AMeDAS observation site on abandoned firmland area (Fig.1), and aggregate wind pattern in Japan is estimated as weighted-average on local wind resource endowment (Fig.2).

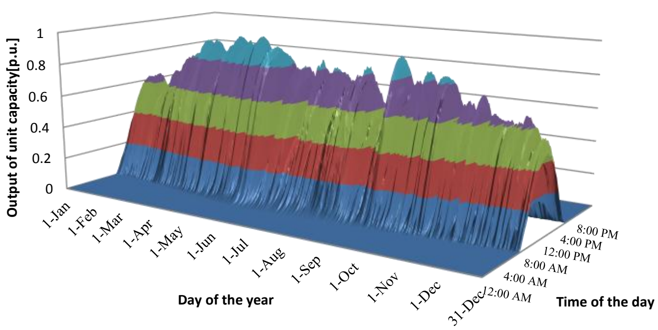


Fig.1 PV output pattern of Japan in 365 days at 10 minutes' interval (2007)

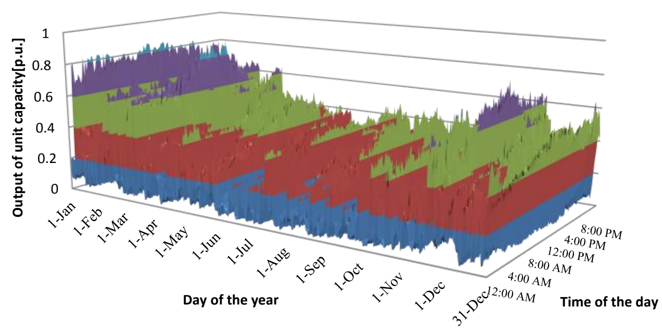
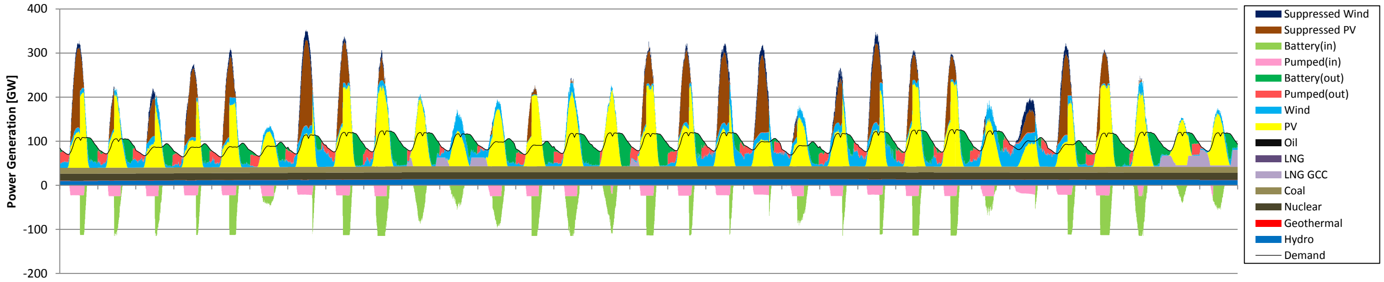


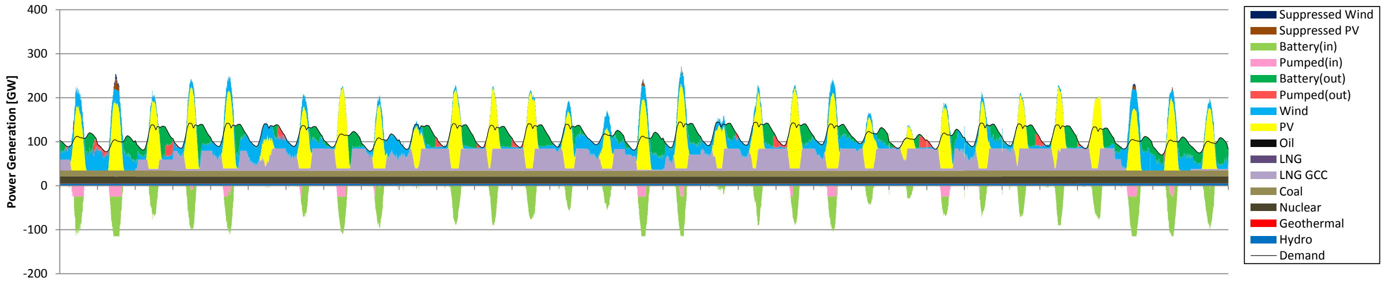
Fig.2 Wind output pattern of Japan in 365 days at 10 minutes' interval (2007)

Results

Simulation results reveal that intermittent fluctuation derived from high penetration level of those renewables is controlled by quick load following operation by natural gas combined cycle power plant, pumped-storage hydro power, stationary NAS battery technology and the output suppression of PV and wind power. It turns out, in addition, that the operational configuration of those technologies for the intermittency differs significantly depending on the renewable output pattern in each season as shown in Fig.3. The results show as well that massive penetration of the renewables does not necessarily require the comparable scale of stationary NAS battery capacity.



(a) May



(b) December

Fig. 3. Monthly power generation profile of Japan in 2030 at 10 minutes' interval.

Conclusions

In this paper, optimal power generation mix in Japan is analyzed in the time resolution of 10 minutes 365days a year, taking into account the output variability of PV and wind power generation, under possible nuclear scenario after Fukushima Daiichi nuclear power accident. In this modeling framework, technological implication are obtained in this analysis that intermittent fluctuation derived from high penetration level of variable renewables is comprehensively controlled by quick load following treatment by natural gas combined cycle power plant, pumped-storage hydro power, stationary NAS battery technology and the output suppression of PV and wind power. It turns out to be necessary to coordinate and optimize the operation of multiple technological measures dynamically for the control of intermittent resources. However, the operational configuration of those measures for the fluctuation differs depending on the seasonal variation of PV output. In winter season with less sunlight, for example, the variability of PV output is managed almost without its output curtailment, and quick control of gas combined cycle is not necessary in summer season under enough PV generation. The results show as well that massive penetration of the renewables does not necessarily require the comparable scale of battery capacity.

References

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