

博士論文

STUDY ON THE LIMITATION OF RENEWABLE ENERGY PERFORMANCE
AND ITS IMPACT ON PUBLIC GRIDS UNDER DIFFERENT POWER SUPPLY
SYSTEM

再生可能エネルギーの導入における地域の受入限界や
系統電力への影響に関する研究

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Study on the Limitation of Renewable Energy Performance and Its Impact on the Public Grids Under Different Power Supply System

ABSTRACT

In the context of energy shortages and safe supply requirements, renewable energy has been developing steadily in recent years. Among them, the power sector plays an important role in energy conservation and emission reduction. The development of renewable energy can not only reduce the use of fossil energy, but also increase the rate of energy self-sufficiency. Japan's current energy self-sufficiency rate is only 8%. After the implementation of the FiT system in 2011, renewable energy has experienced explosive growth. Among them, PV and wind energy have shown a leading position in growth. Photovoltaic and wind energy are also called variable renewable energy because of their variable power generation characteristics. Their large-scale introduction affects the stability of the grid, so this research is dedicated to studying the interaction between renewable energy, power demand, grid, and energy storage system to maximize the use of VRE.

In Chapter 1, RESEARCH BACKGROUND AND PURPOSE OF THE STUDY. The research backgrounds of energy resources are introduced in Chapter1, which is including the current status and bottleneck of integrational energy development. As well as the significant of developing variable renewable energy. Then, the development and status of renewable energy in world and Japan is well introduced. It is essential to developing renewable energy in the power generation sector to dealing with the problem of energy security and fossil fuel shortage. At last, the research purpose and logical framework is shown in order to support reviewers understand the content of this paper.

In Chapter 2, LITERATURE REVIEW OF VARIABLE AND RENEWABLE ENERGY. The relevant research of this paper is well reviewed in this Chapter. The development of renewable energy in power systems, including the variable renewable energy studies and its hybrid with pumped storage system studies. Besides, the evaluation indicator used in this paper is also well explained further. At lase, the energy management tool of EnergyPLAN models is reviewed. According to the previously study, the current paper contributes to combined them and promote it in the integration potential of renewable energy.

In Chapter 3, METHODOLOGY. The keyword of this paper is load in demand side, electricity generator in supply side, power grid, and storage system. Therefore, the methodology employed including, evaluation indicators of VRE on the power grid, PHS installed capacity prediction, and EnergyPLAN model are summarized in Chapter 3. It helps us to understand the interplay of load in demand side, electricity generator in supply side, power grid, and storage system to seek a ideal electricity production compositions.

In Chapter 4, DATA RESOURCE AND ENERGY CONVERSION ANALYSIS. The data resource mainly focus on the distribution of research area, the composition of power generation in research area, electricity production profiles, and economic cost. Kyushu, Tokyo, Kansai, and Hokkaido with different power proportions, electricity demand profiles, and renewable energy resources are selected to compared and analysis. The energy conversion of fossil fuel to renewable energy is adopted whist.

In Chapter 5, ASSESSMENT OF RENEWABLE ENERGY INTEGRATION IN SUPPLY SIDE. This chapter evaluated the impact of PV and wind on the public electricity supply system when they are introduced into the grid. A method of predict the maximum penetration of renewable energy and its impact on the public electricity supply system is explained in Chapter 3, which is capacity credit and dynamic investment payback period. The results indicate that the capacity credit increases with an increase in PV and wind shares in the grid. However, it seems to be saturated when the share of PV and wind power in the grid reaches 25% and 60%, respectively. Compared with the wind integration in Kansai and Hokkaido, the PV penetration in Kyushu and Tokyo reaches saturation more rapidly. In addition, PV shows more power suppression, which prolongs its payback period compared to wind energy. The significant difference in the results of capacity credit and DIPP is limited by the characteristics of power demand in mixed regions and the relevance of renewables distribution.

In Chapter 6, ASSESSMENT OF DEMAND SIDE IN VRE INTEGRATION. The impact of a reduction in load demand on renewable energy in the Japan public power grid under a state of emergency declaration (April to May 2020) is compared. Research area is distributed in Kyushu, Tokyo, Kansai, and Hokkaido. The results are shown that the consumption profiles and amounts of power consumption reduction are different in different areas. Tokyo shows the largest share of reduced load, followed by Kansai, Kyushu, and Hokkaido. The load reduction was mainly seen during the day, which reflects the differences in people's activities relative to the same period in 2019. Different means of power dispatch, including power generators, energy storage systems, and transmission lines are used and compared in terms of responses to the changes in electricity consumption profile. Besides, the overall fall in total load demand and the change in load sequence affected the integration and curtailment of PV power generation and consequentially caused the electricity price to drop. This Chapter clarifies the effects of COVID-19 on the public power grids of Japan. Further, it establishes the impact on policymakers in relation to the development of renewable energy.

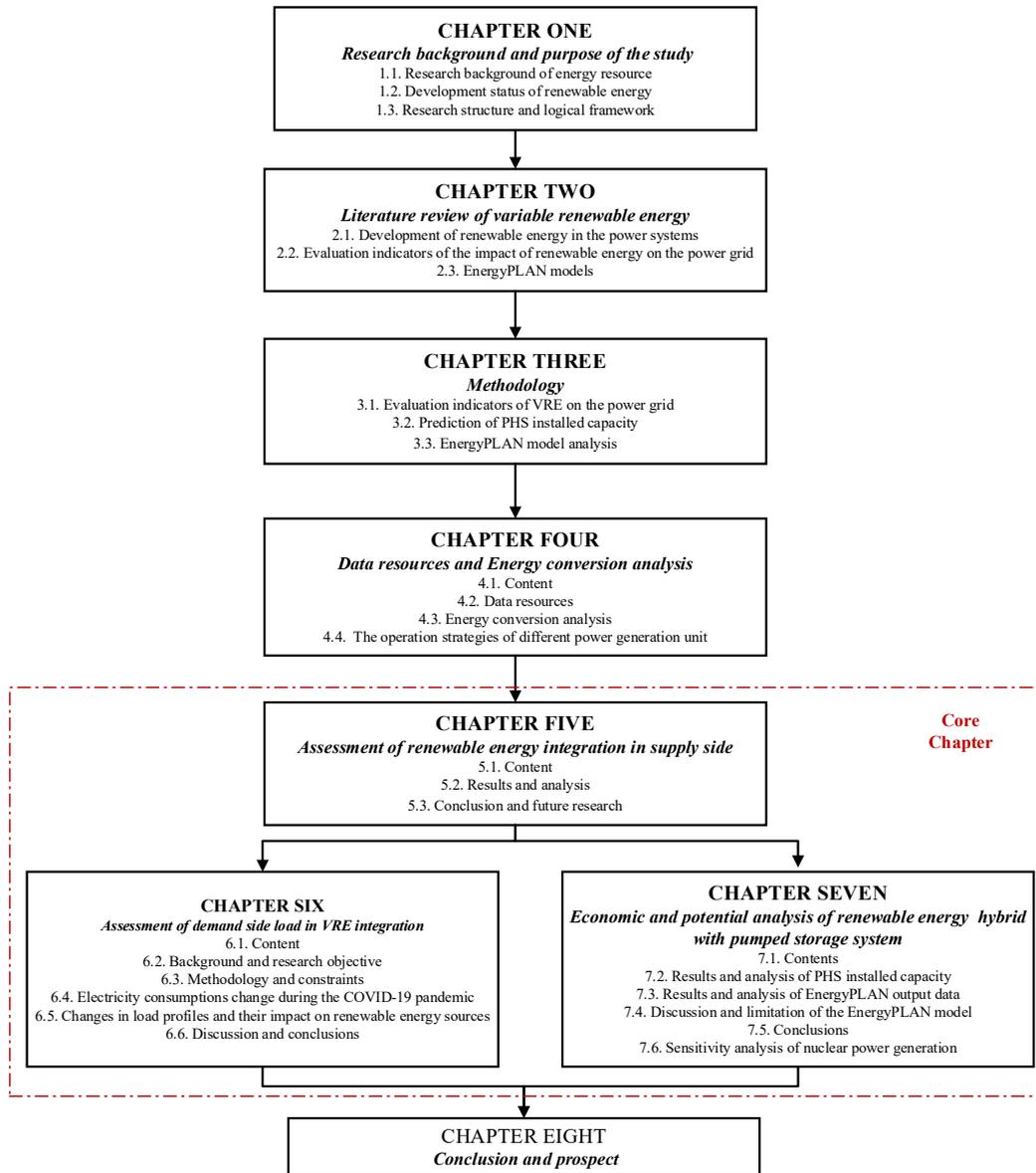
In Chapter 7, ECONOMIC AND POTENTIAL ANALYSIS OF RENEWABLE ENERGY HYBRID WITH PUMPED STORAGE SYSTEM. The pumped storage system is used in the energy management system in order to promote the integration of renewable energy integrations. the existing small and medium-size dams in Japan is exploited to expend the capacity of PHS installed.

Combining with the phase-out of thermal power, analyze the basic load power supply equipment contributes to regional VRE penetration. Its energy conversion analysis is introduced in Chapter 3. Kyushu and Hokkaido power grids with different power generation structure and electricity demand profiles as case study. Scenario settings are based on hourly power demand and supply curves using the EnergyPLAN tool. The result shown that the installed capacity potential of small and medium-sized pumped storage in Kyushu and Hokkaido is 18GW and 20GW, respectively. PHS can reduce RES suppression and thermal power operation while providing a share of grid stability. The reduction of the initial installation of thermal power improves the penetration of RES and the operation rate of PHS. the average power generation cost decreases with the reduction of thermal power installation capacity. Besides, the addition of PHS is first higher and then lower than the scenario without energy storage equipment. Under the same RES share, the maximum cost of Kyushu is 16yen / kWh and that of Hokkaido is 26yen / kWh. Attributed to the nuclear power in Kyushu, which accounts to 25% share of power generation. The penetration of VRE in the future public grid and its impact on other power generation units are covered.

In Chapter 8, CONCLUSION AND PROSPECT. A summarized of each Chapter is concluded.

徐 婷婷 博士論文の構成

Study on the Limitation of Renewable Energy Performance and Its Impact on the Public Grids Under Different Power Supply System



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CHAPTER 6: ASSESSMENT OF DEMAND SIDE LOAD IN VRE INTEGRATION

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Nomenclature

| Label | Unit | Description |
|-------|------|--|
| IEA | - | International energy agency |
| LNG | - | Liquefied natural gas |
| GDP | - | Gross domestic product |
| RPS | - | Renewable portfolio standard |
| ITC | - | Investment tax credit |
| PTC | - | Production tax credit |
| FiT | - | Feed-in tariff |
| FIP | - | Feed-in premium |
| DIPP | - | Dynamic investment payback period |
| VRE | - | Variable renewable energy |
| PHS | - | Pump storage system |
| FY | - | Fiscal year |
| RPS | - | Renewable Portfolio Standard |
| EIA | - | National Environmental Impact Assessment |
| LCOE | - | Levelized cost of energy or electricity |
| RLDC | - | Residual load duration curves |
| LDC | - | Load duration curve |
| CRL | - | Cumulative residual load |
| PtG | - | Electricity-to-gas |
| PES | - | Primary energy supply |
| PV | - | Photovoltaic |
| DSM | - | Demand-side management |
| MGSS | - | Minimum grid stability share |

| Label | Unit | Description |
|-------------------|---------|--|
| MGSPS | - | Minimum grid stabilization production share |
| CEEP | - | Critical Excess Electricity Production |
| RE | - | Renewable energy |
| JHU | - | Johns Hopkins University |
| UHV | - | Ultra-high voltage |
| PRC | - | Polynomial regression curve |
| X | - | Guaranteed load reduction without PV integration |
| Y | - | Guaranteed load reduction with PV integration |
| P | Yen/kWh | Electricity price |
| P_b^t | MWh | Power flow from base-load plants |
| P_m^t | MWh | Power flow from flexible plants |
| VRE_{direct} | MWh | Directly integrated VRE power generation |
| $load_{grid}^t$ | MWh | Total grid load |
| P_{VRE}^t | MWh | Total VRE production |
| overproduction(t) | MWh | Curtailed VRE production |
| T2 | h | Starting hours of excess electricity |
| T1 | h | Finishing hours of excess electricity |
| RLDC(t) | MWh | Residual load demand |
| P_t | Year | Dynamic investment payback period of PV or wind |
| i_t | % | Annual interest rate |
| t | h | Time unites |
| C_0 | Yen/kWh | Initial investment |
| C_1 | Yen/kWh | Annual revenue |
| η | % | Total efficiency of PHS power generation |

| Label | Unit | Description |
|-----------------|------------------|--|
| η_{TG} | % | Efficiency of turbine generator |
| η_{TP} | % | Efficiency of pumping facility |
| V_0 | 10^3m^3 | Effective water storage capacity |
| V_1 | 10^3m^3 | Potential pumped storage |
| H | M | Head conditions |
| S | MW | Capacity of installed capacity |
| P | MWh | Capacity of power generation |
| P_y | MWh/y | Total power generation for a year |
| $PHS_{storage}$ | kWh | Storage capacity of electricity power |
| V | m^3 | Volume of upper reservoir, |
| g | m/s^2 | Gravitational acceleration |
| h | m | Head between upper and lower reservoir |
| C | kW | Rated power generation |
| η | % | Overall efficiency |
| E_{out} | MWh | Total electricity produced from the research objective |
| E_{in} | MWh | Total electricity consumed |
| e_{stab} | MWh | Total electricity production from grid stabilizing units |
| d_{stab} | % | Minimum grid stabilization production share |
| i | h | Time unit |
| $dispatch^i$ | MWh | Flexible thermal power generators |
| $discharge^i$ | MWh | The amount of electricity pumped by PHS |
| $charge^i$ | kWh | The amount of electricity generating by PHS |

| Label | Unit | Description |
|------------------|-------------------|---|
| η_{pump} | % | Water pump efficiency |
| $\eta_{turbine}$ | % | Turbine efficiency |
| C_{pump} | MW | Maximum capacity of pump |
| $C_{turbine}$ | MW | Maximum capacity of turbine |
| $supply^i$ | MWh | Total electricity generation by all power sectors |
| $nuclear^i$ | MWh | Power generated by nuclear energy |
| RES^i | MWh | Power generated by RES energy |
| ρ | kg/m ³ | Density |
| $Price$ | Yen | Average price of fuel at per unit |
| LHV | MJ/kg | Lower heating value of coal, oil, and LNG |
| θ | % | Efficiency of thermal power plant electricity generation |
| P_{cons} | MWh | Power generation from base-load plants |
| P_{flex} | MWh | Flexible generators that can adjust their output to adapt to the situation of the PV and power grid |
| PV_{direct} | MWh | Directly accommodated PV |
| $Load_{direct}$ | MWh | Total electricity demand |
| P_{PV} | MWh | Total PV power generation |
| $output$ | MWh | Total electricity generation on the supply side |
| $trans$ | MWh | Flow of power transferred across regional transmission lines |