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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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

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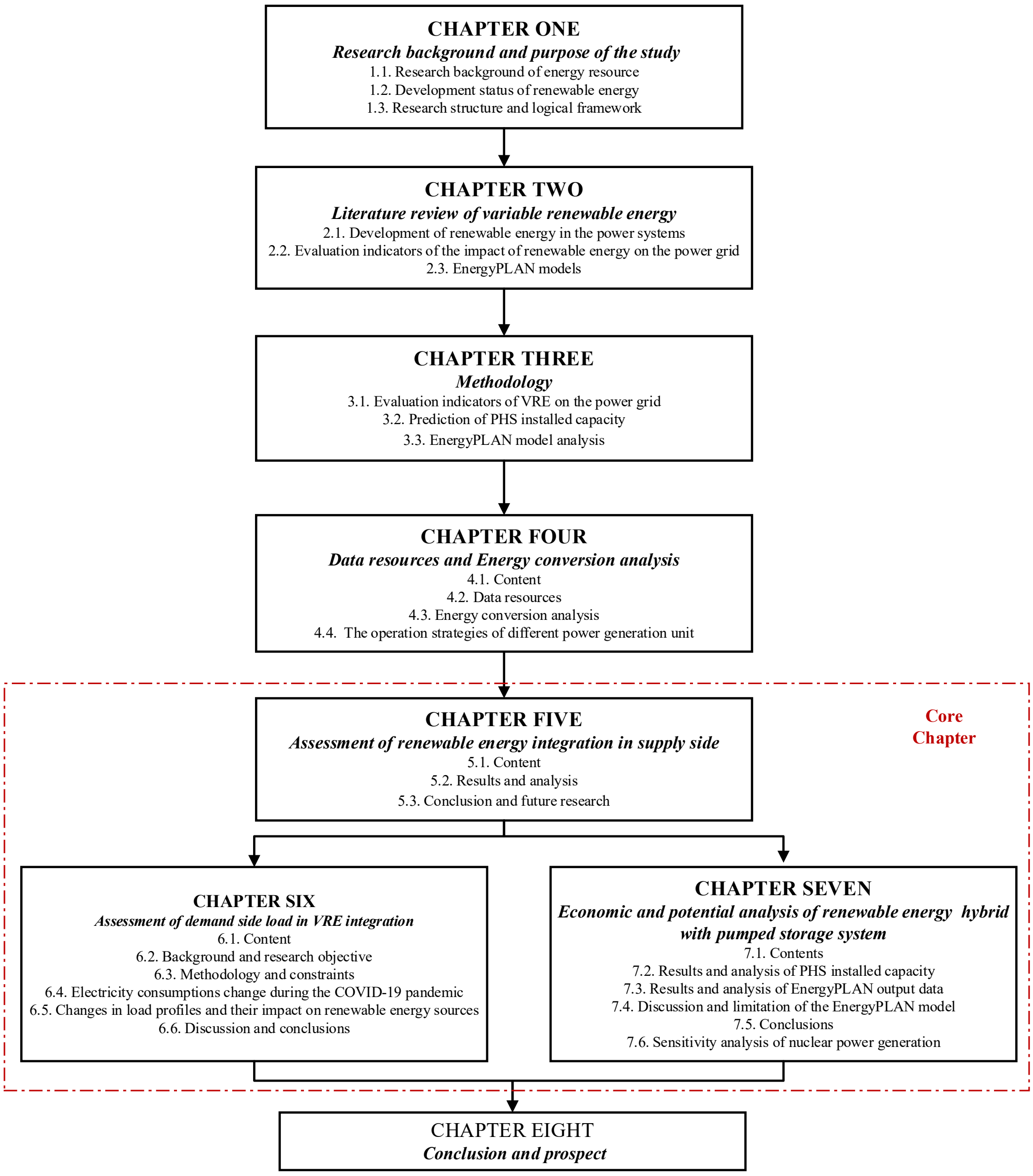

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Nomenclature

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
$\mathrm{P}_{\mathrm{b}}^{\mathrm{t}}$	MWh	Power flow from base-load plants
$\mathrm{P}_{\mathrm{m}}^{\mathrm{t}}$	MWh	Power flow from flexible plants
VRE_{direct}	MWh	Directly integrated VRE power generation
$\mathrm{load}_{\mathrm{grid}}^{\mathrm{t}}$	MWh	Total grid load
$\mathrm{P}_{\mathrm{VRE}}^{\mathrm{t}}$	MWh	Total VRE production
$\mathrm{overproduction(t)}$	MWh	Curtailed VRE production
T2	h	Starting hours of excess electricity
T1	h	Finishing hours of excess electricity
$\mathrm{RLDC(t)}$	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