

Optimization of the Western Canada Power Grid

Incorporation of Renewable Energy

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Economics

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Introduction

In order to improve the environmental quality, many countries are phasing out coal-fired power plants and integrate **renewable** energy into **power grid**.

For example, Alberta will phase out all coal-fired power plants and replace two-thirds of the lost electricity production by renewables by 2030.

The **goal** of current research is

- ⊙ understand the economic consequences of integrating renewable energy
- ⊙ design policies to achieve an optimal generation mix
- ⊙ determine the costs and benefits of using renewable energy sources (RES) to reduce greenhouse gas emissions

The capacity of renewables such as wind and solar energy have been grown rapidly along with that the cost decreased continuously

It is challenging the stability and reliability of power system.

- ⊙ intermittency of renewables:

- rely on other dispatchable power sources as backup
- huge amount of capacity payments

- ⊙ disrupt electricity systems:

- almost zero marginal production cost
- the investment of conventional assets decline

Research Context

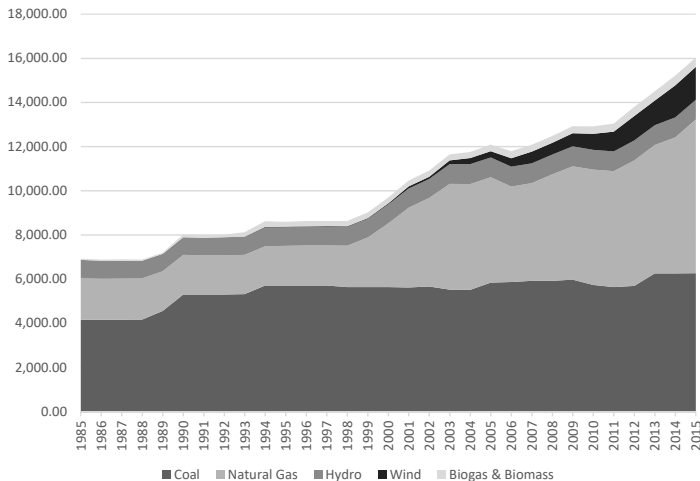


Figure 1: Alberta Generation Sources

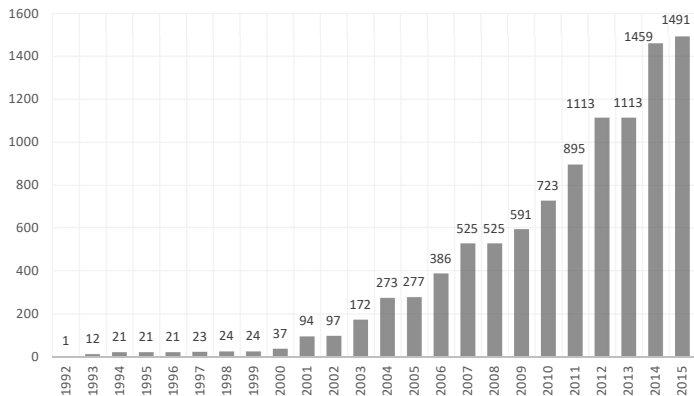


Figure 2: Alberta Wind Installed Capacity

Research Context

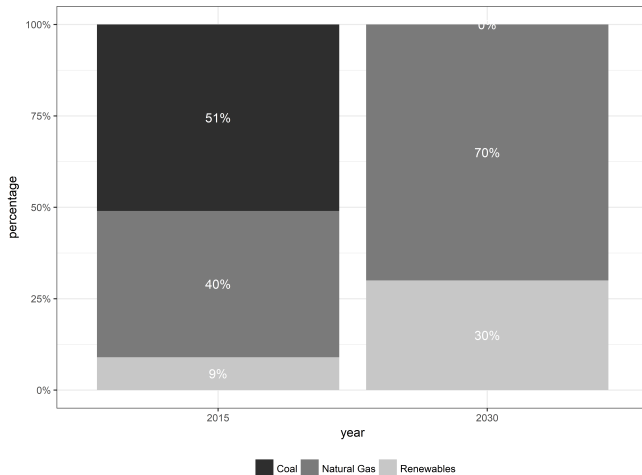


Figure 3: Change in Alberta Capacity

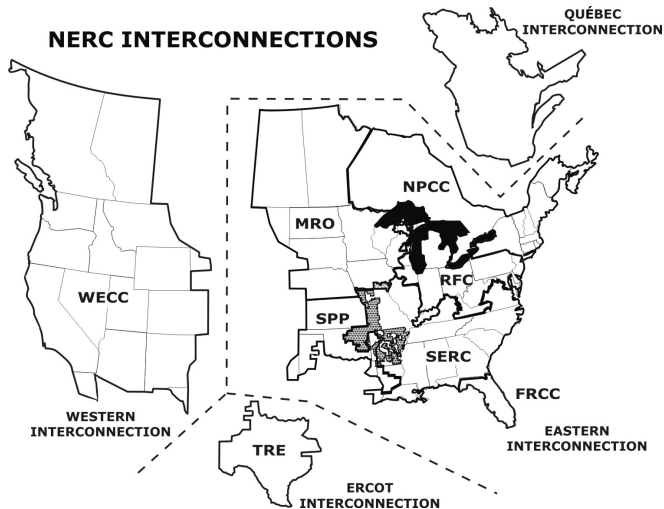


Figure 4: Interconnections of Alberta and other jurisdictions

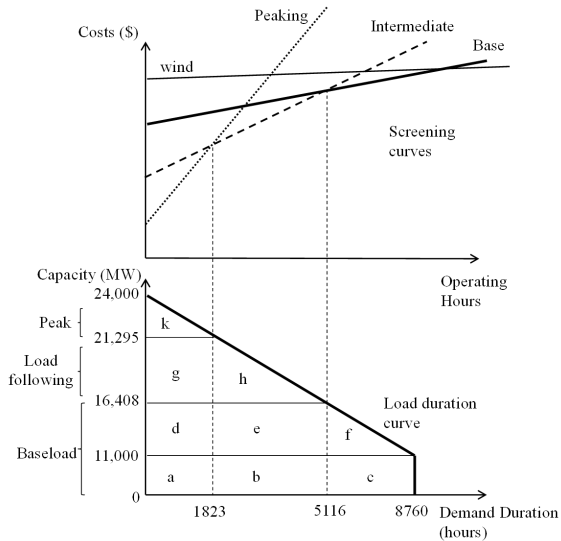
- ⊙ explore the viability of relying on wind power to replace upwards of 60% of electricity generation in Alberta that would be lost if coal-fired generation is phased out
- ⊙ examine the effect of flexible storage of electricity in Alberta power system with wind and solar sources
- ⊙ investigate economic cost of electricity source by calibration

Research Methods

Load Duration Curve and Screening Curves

- ⊙ The load duration curve captures the structure of the load: the peak load, intermediate load and the based load
- ⊙ The screening curves are the cost curves for generation assets
 - intercept represents fix cost
 - slope represents the variable cost/marginal cost
- ⊙ By allocating the lower cost dispatchable generating unit, grid operator can achieve the **least cost** generating mix

Load Duration Curve and Screening Curves



- ⊙ A grid model is developed to examine the allocation of renewable and non-renewable generating sources
- ⊙ The objective of optimization is to maximize the total operation profit or minimize total operation cost
- ⊙ Optimization is subjected to load conditions, technological constraints, decarbonization requirement and tax/subsidy policy

$$\begin{aligned}\Pi = & \sum_{t=1}^T [P_{A,t} D_t - \sum_{i=1}^I (OM_i + b_i + \tau \phi_i) Q_{i,t} \\ & + \sum_{k=1}^K [(P_{k,t} - \delta) X_{k,t} - (P_{k,t} + \delta) M_{k,t}]] \quad (1) \\ & - \sum_{i=1}^I (a_i - d_i) \Delta C_i, \\ & i \in \{coal, CTgas, wind, etc\}, \\ & k \in \{BC, MID, SK\}, \\ & t \in \{1 : 8760\},\end{aligned}$$

$$\sum_{i=1}^I Q_{i,t} + \sum_{k=1}^K [M_{k,t} - X_{k,t}] \geq D_t, \quad \forall t = 1, \dots, T; k \in \{BC, MID, SK\}, \quad (2)$$

$$Q_{i,t} - Q_{i,t-1} \leq C_I \times R_i, \quad \forall i, t = 2, \dots, T; \quad (3)$$

$$Q_{i,t} - Q_{i,t-1} \geq C_I \times R_i, \quad \forall i, t = 2, \dots, T; \quad (4)$$

$$Q_{i,t} - Q_{i,t-1} \geq C_I \times R_i, \quad \forall i, t = 2, \dots, T; \quad (5)$$

$$M_{k,t} \leq TRM_{k,t}, \quad \forall k, t = 1, \dots, T; \quad (6)$$

$$X_{k,t} \leq TRX_{k,t}, \quad \forall k, t = 1, \dots, T; \quad (7)$$

$$Q_{i,t}, M_{k,t}, X_{k,t} \geq 0, \quad \forall k, i, t = 1, \dots, T; \quad (8)$$

$$M_{k,t} \leq TRM_{k,t}, \quad \forall k, t = 1, \dots, T;$$

$$X_{k,t} \leq TRX_{k,t}, \quad \forall k, t = 1, \dots, T;$$

$$Q_{i,t}, M_{k,t}, X_{k,t} \geq 0, \quad \forall k, i, t = 1, \dots, T;$$

Calibration by Positive mathematical programming

- ⊙ construct economic cost functions or production function of energy resources for grid optimization modeling
- ⊙ actual observed base-year operating levels can be recovered with calibrated cost functions in optimization
- ⊙ resulting nonlinear model is used for policy analysis

Data



- ⊙ Alberta's hourly load data from 2005 to 2016 from Alberta Electric System Operator (AESO)
- ⊙ hourly wind speed data for 17 locations from 2006 to 2015 from Statistic Canada
- ⊙ hourly solar data for 28 locations from 1996 to 2005 from Canadian Weather Energy and Engineering Datasets (CWEEDS)

Load Data

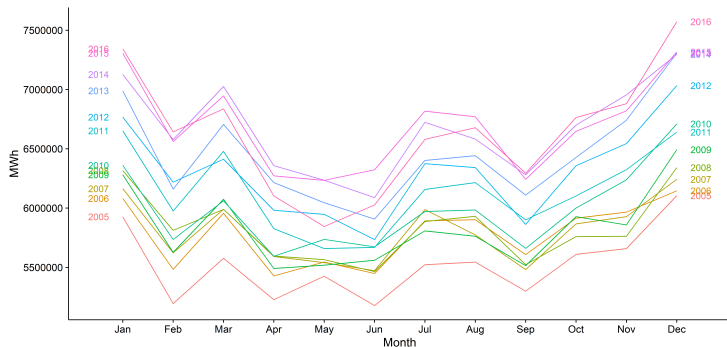


Figure 5: Alberta's load 2005 to 2016 from AESO

Solar Data

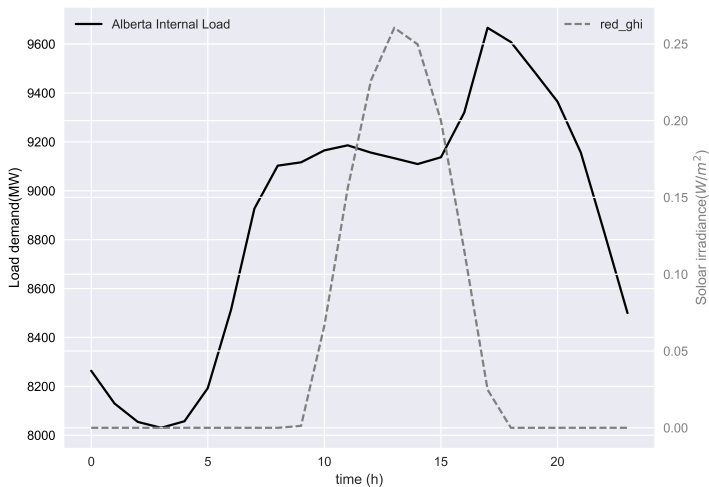


Figure 6: Average Load and Solar Irradiance in January

Dissertation Outline

- ⊙ **Chapter 1** Background
- ⊙ **Chapter 2** General method of MP, PMP, Simulation
- ⊙ **Chapter 3** Load Duration Curve and Screening Curves: A Framework for Analysis
- ⊙ **Chapter 4** Wind and Emission Reduction Targets
- ⊙ **Chapter 5** Hybrid Renewable Energy Systems with Battery Storage
- ⊙ **Chapter 6** Calibration of Electricity Cost for Power System Optimization
- ⊙ **Chapter 7** Conclusion

Time Line



Time	Chapter
2017 Summer	Chapters one
2017 Winter	Chapter two: General methods of MP, PMP, and simulation
2017 Winter	Chapter three: Load Duration Curve and Screening Curves
2018 Spring	Chapter four is based on an existing paper
2018 Spring	Chapter five is under the second stage of research
2018 Summer	Chapter six is at its early stage
2018 Winter	Chapter seven

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END