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Electrical Networks of the Azores Archipelago

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Engineering and Public Policy

Electrical and Computer Engineering

Carnegie Mellon University

Pre-Conference Workshop Presentation,

8th CMU Electricity Conference

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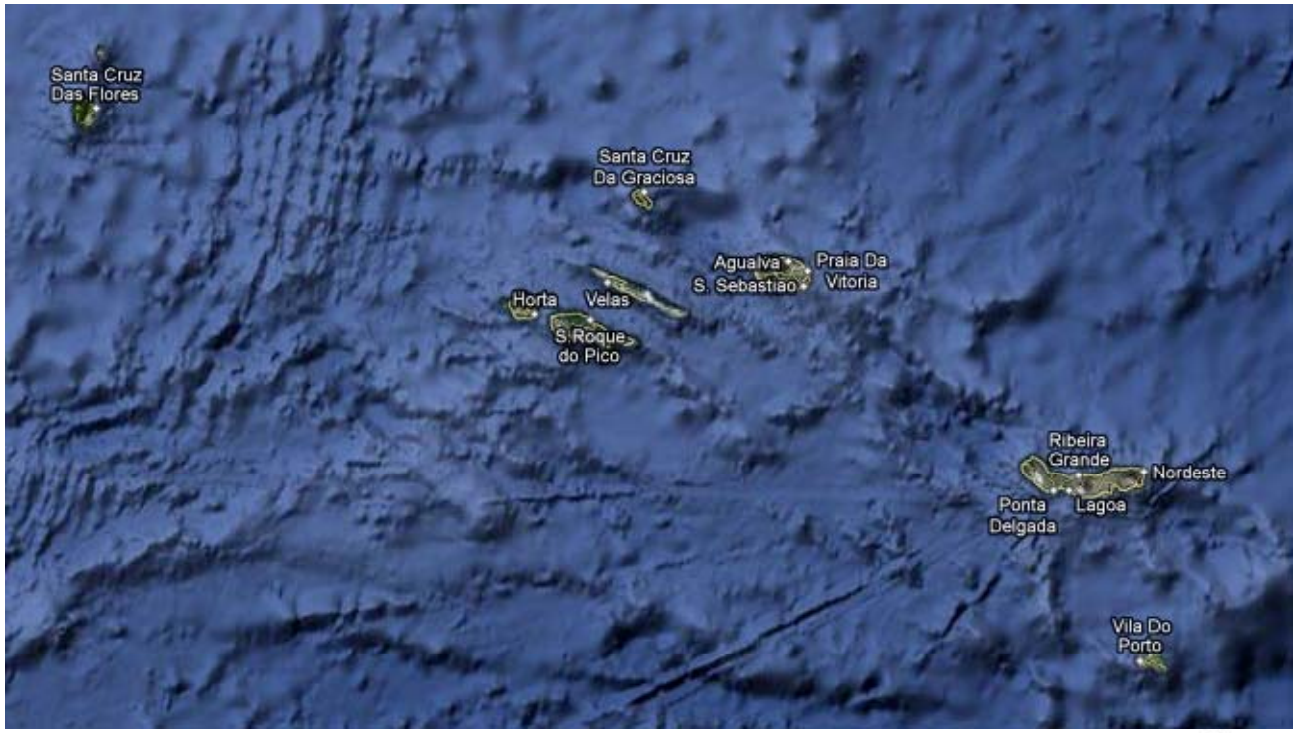
Talk outline

- Introducing Azores Archipelago
- Electrical characteristic
  - Flores Island
  - Sao Miguel Island
- Conclusions and future outlook

Azores Archipelago

- Azores Archipelago consists of nine islands located in the middle of North Atlantic Ocean

- It has a population of approximately 254,000 inhabitants and its area is around 2,350 km².



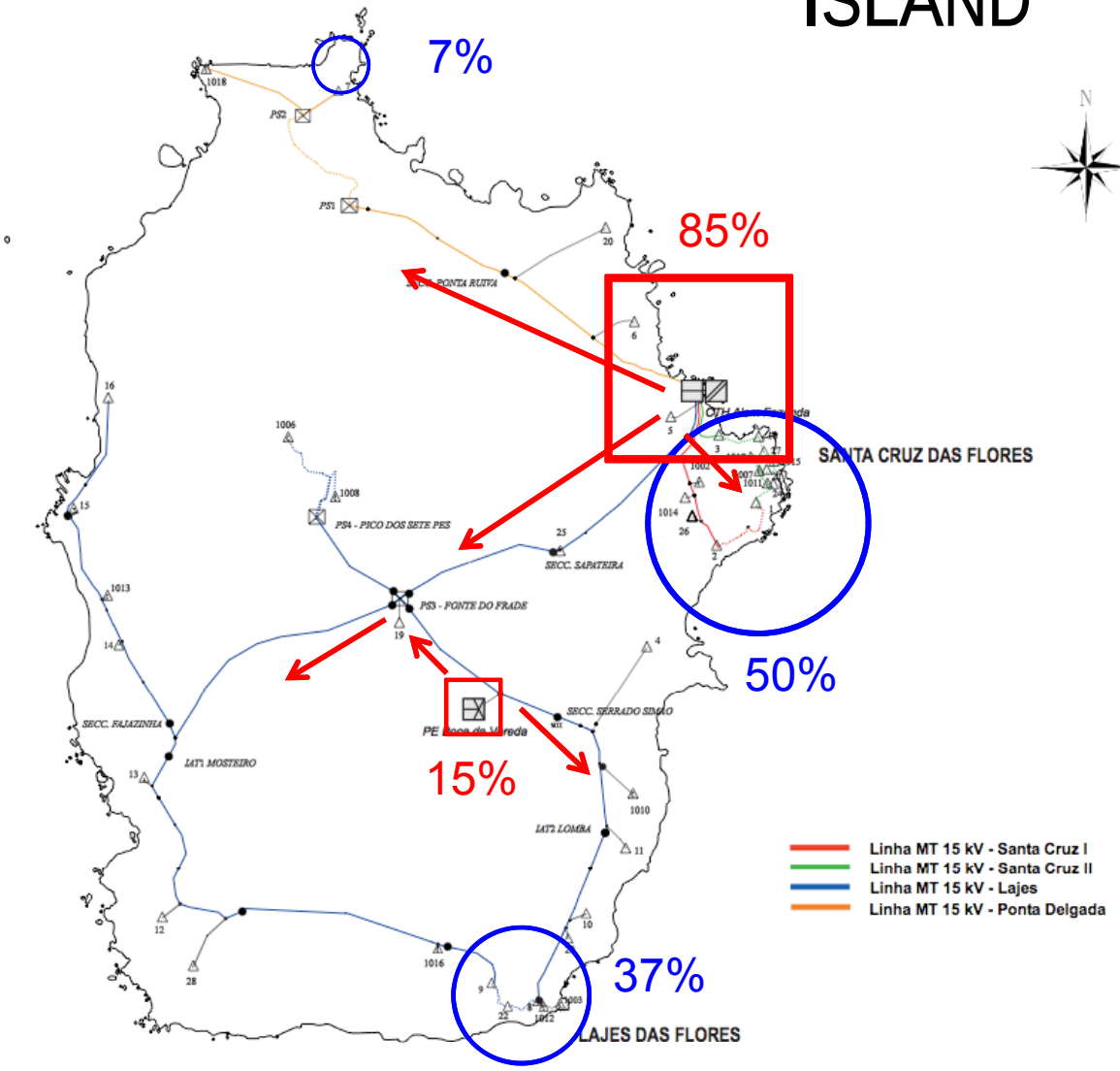
Source: EDA

Flores Island

- One of the smaller islands of the western group of Azores Archipelago
- It has an area of 143 km²
- A population of approximately 4000 inhabitants

Source: EDA

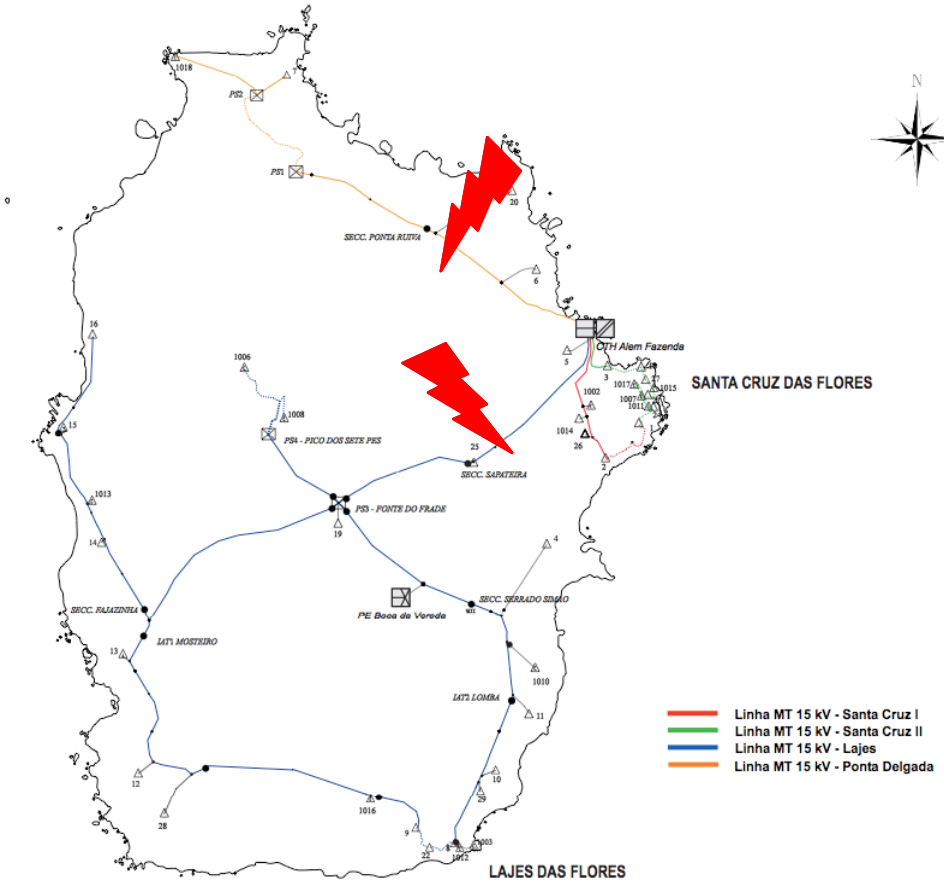
ELECTRICAL CHARACTERISTICS OF FLORES ISLAND



- Radial 15 kV distribution network
- Total demand : ~2 MW
- Demand in the town of Santa Cruz: >50%
- Demand in the vicinity of the airport of Flores (Lajes Das Flores): ~37%
- Demand in the town of Ponta Delgada: ~7%
- The rest dispersed throughout the island: ~6%
- Four diesel generators with capacity : 2.5 MW (>50%)
- Four hydro power plants with an overall capacity : 1.65 MW (~35%)
- Two synchronous wind plants with a total capacity : 0.65 MW (~15%)

[1] M. Honarvar Nazari and M. Ilić, "Electrical Networks of Azores Archipelago", Chapter 3, Engineering IT-Enabled Electricity Services, Springer 2012.

ELECTRICAL CHARACTERISTICS OF FLORES ISLAND



- Flores does not have control center
- Diesel generators are regulating frequency
- N-1 reliability is not satisfied

[1] M. Honarvar Nazari and M. Ilić, “Electrical Networks of Azores Archipelago”, Chapter 3, Engineering IT-Enabled Electricity Services, Springer 2012.

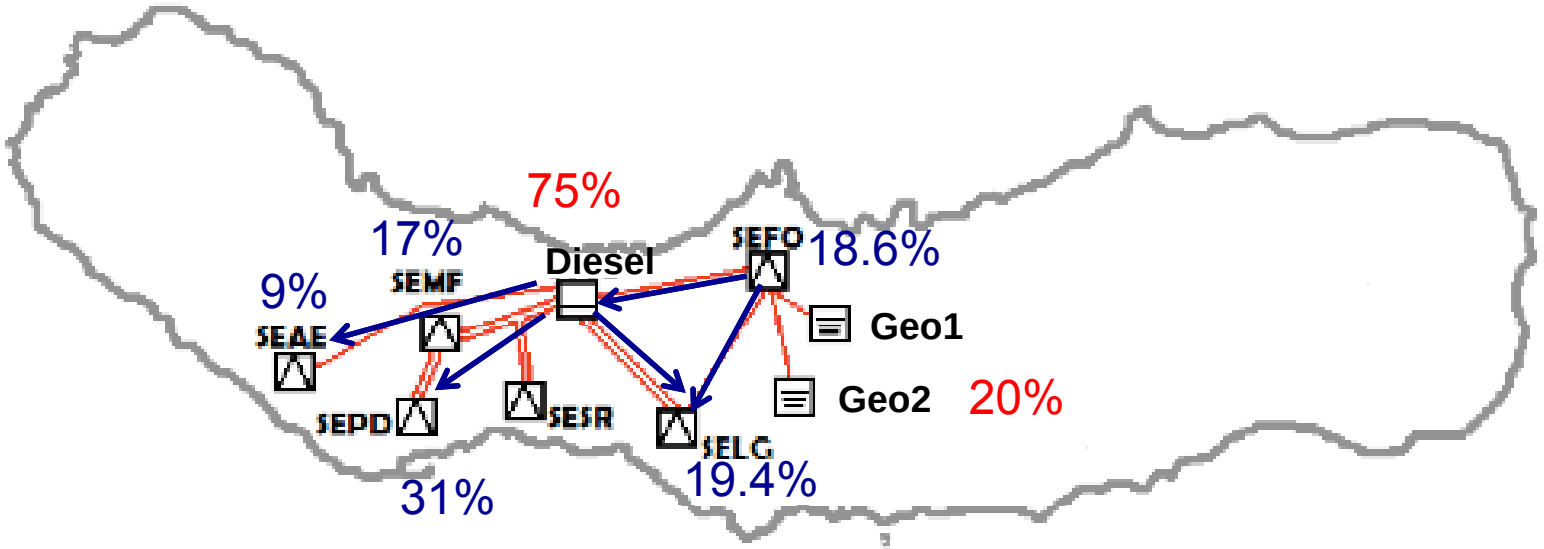
Sao Miguel Island

- Capital and Larges Island of Azores Archipelago
- It has an area of 744 km²
- A population of approximately 140,000 inhabitants

Source: EDA

ELECTRICAL CHARACTERISTICS OF SAO MIGUEL

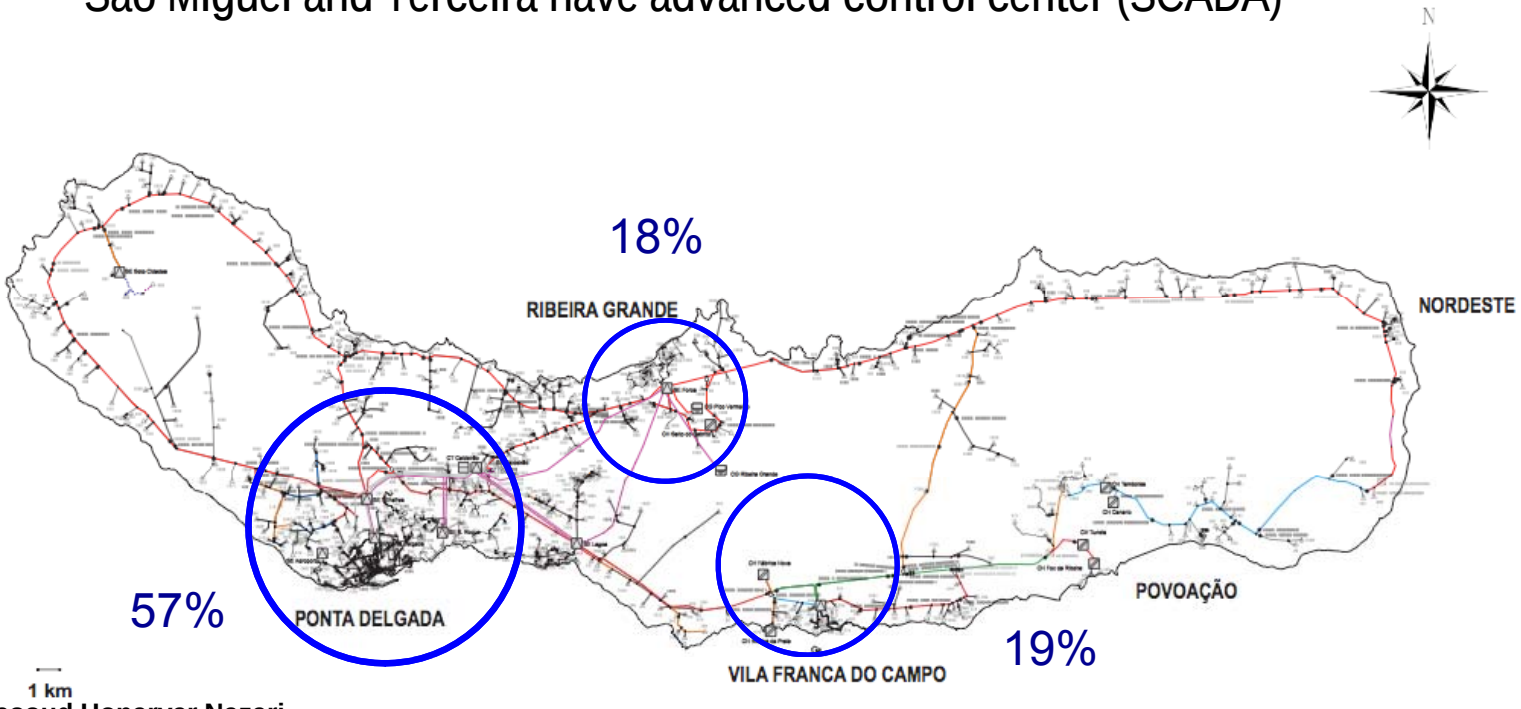
- Ring 60 kV transmission network
- Total demand : ~70 MW
- Two large diesel generators with total capacity : 97 MW (75%)
- Two large geothermal plants with total capacity : 27 MW (20%)
- 7 small hydro power generator with total capacity : 5 MW (5%)



[1] M. Honarvar Nazari and M. Ilić, "Electrical Networks of Azores Archipelago", Chapter 3, Engineering IT-Enabled Electricity Services, Springer 2012.

ELECTRICAL CHARACTERISTICS OF SAO MIGUEL

- Ring 30 kV and 10 kV distribution network around the island
- Diesel generators are the only fully controllable generators
- Diesel generators are regulating frequency
- Sao Miguel and Terceira have advanced control center (SCADA)



[1] M. Honarvar Nazari and M. Ilić, "Electrical Networks of Azores Archipelago", Chapter 3, Engineering IT-Enabled Electricity Services, Springer 2012.

CONCLUSIONS AND FUTURE OUTLOOK

- N-1 reliability criteria is not satisfied in radial distribution systems like Flores Island
- Installing normally open switches and/or new DGs at right locations can ensure reliability
- Future outlook is to find optimal locations for new switches and/or new DGs to ensure N-1 reliability criteria

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Generation and Demand on the Islands of Flores and São Miguel

Jonathan Donadee, Jhi Young Joo,
RemcoVerzijlbergh, and MarijaIlic

Pre-Conference Workshop Presentation,
8th CMU Electricity Conference
March 12,2012

Outline

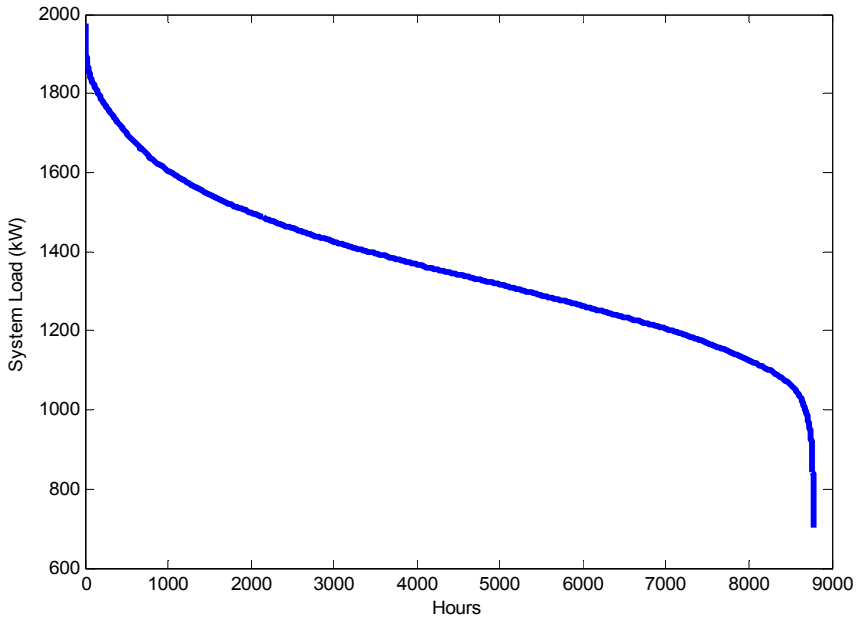
- System Load Data
  - Flores
  - Sao Miguel
- Generation Data
  - Flores Generation
    - Hydro
    - Wind
  - Sao Miguel
    - Geothermal
  - Ramp Rates
  - Costs
- Wind Data

Load Data

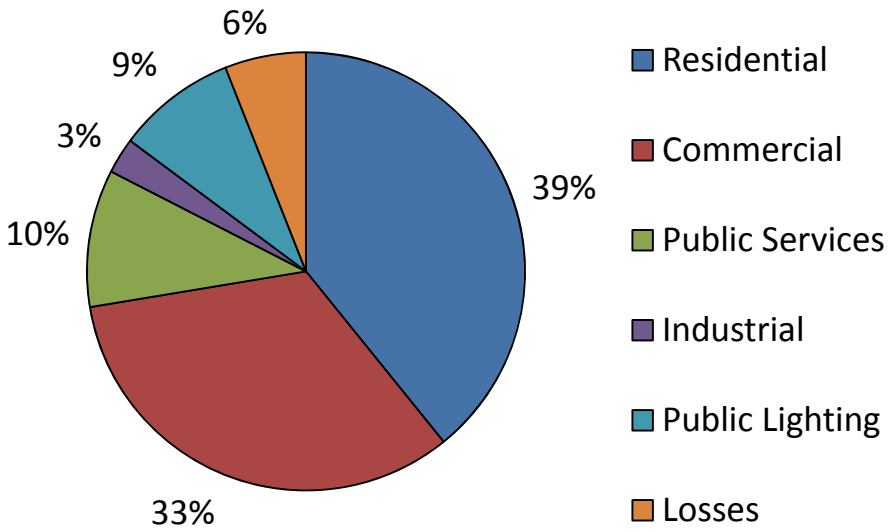
- Average Power Data from Local Utility, EDA
  - Half-hourly data points
  - Given for each generator
  - Generator output was aggregated to model system load
- For simulations on a ten minute timestep the load was to be assumed constant over half hour
- Missing data replaced by data from similar days
  - Same day of the week and month

Flores Island Load (2008)

Load Duration Curve

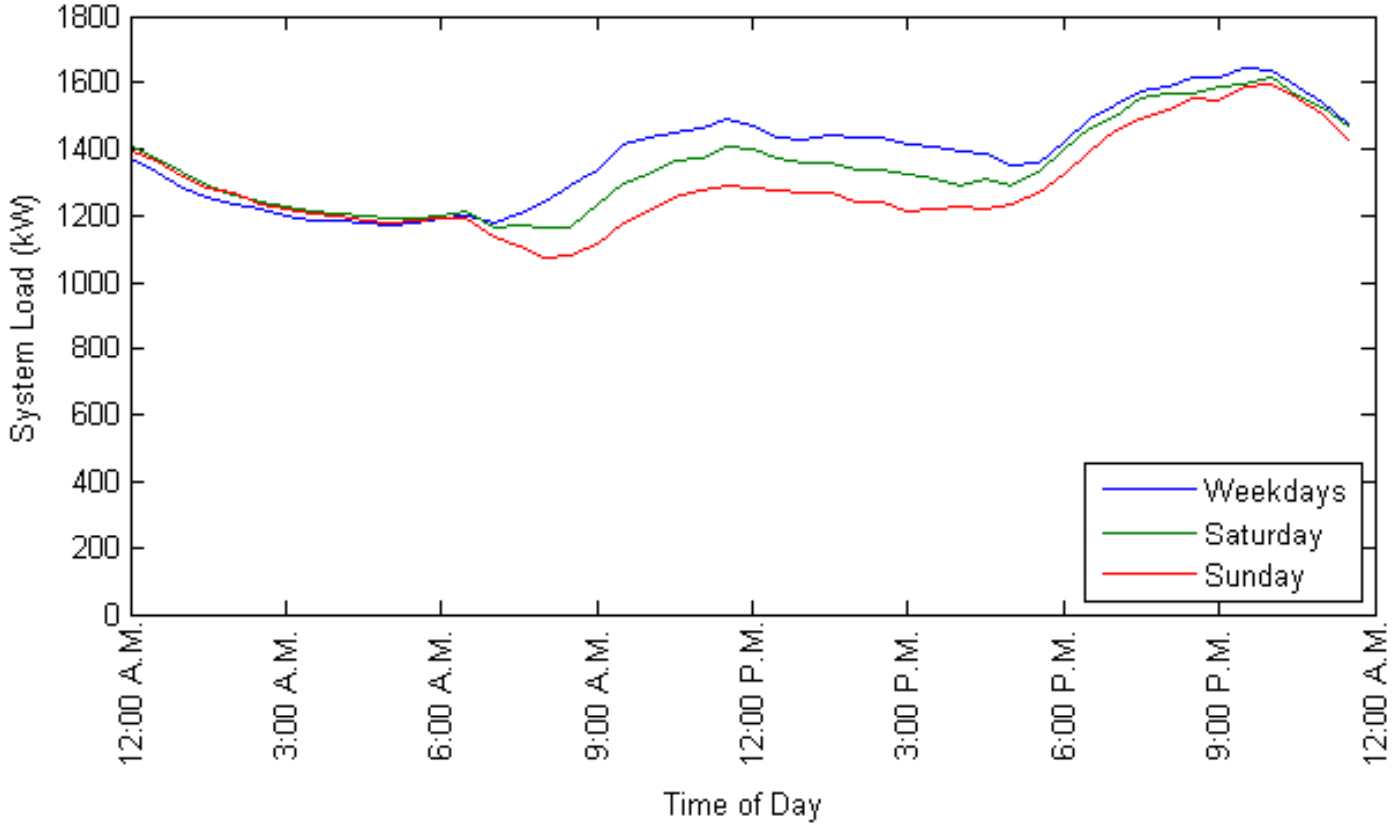


Energy Consumption by Consumer Type

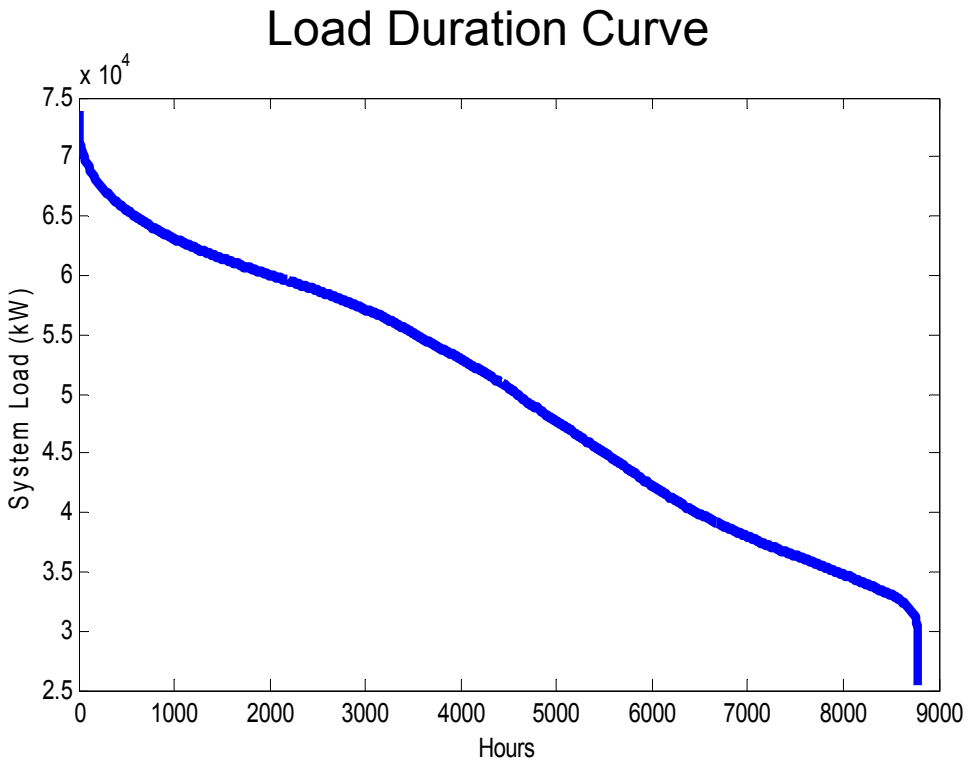


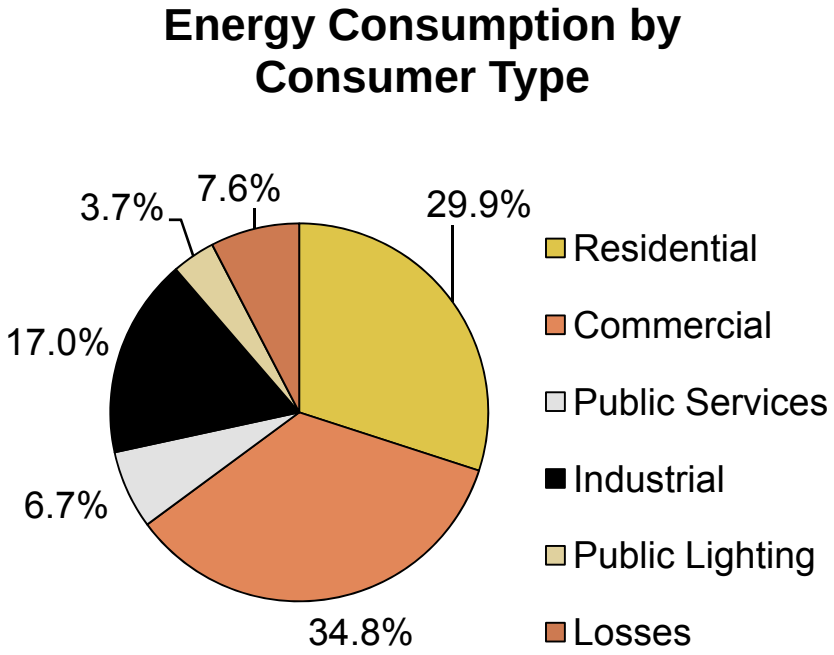
- Total Energy Consumed 11.6 GWh
  - 4.5 GWh residential
- Peak Load of 1,978 kW

Flores Island System Load Profile



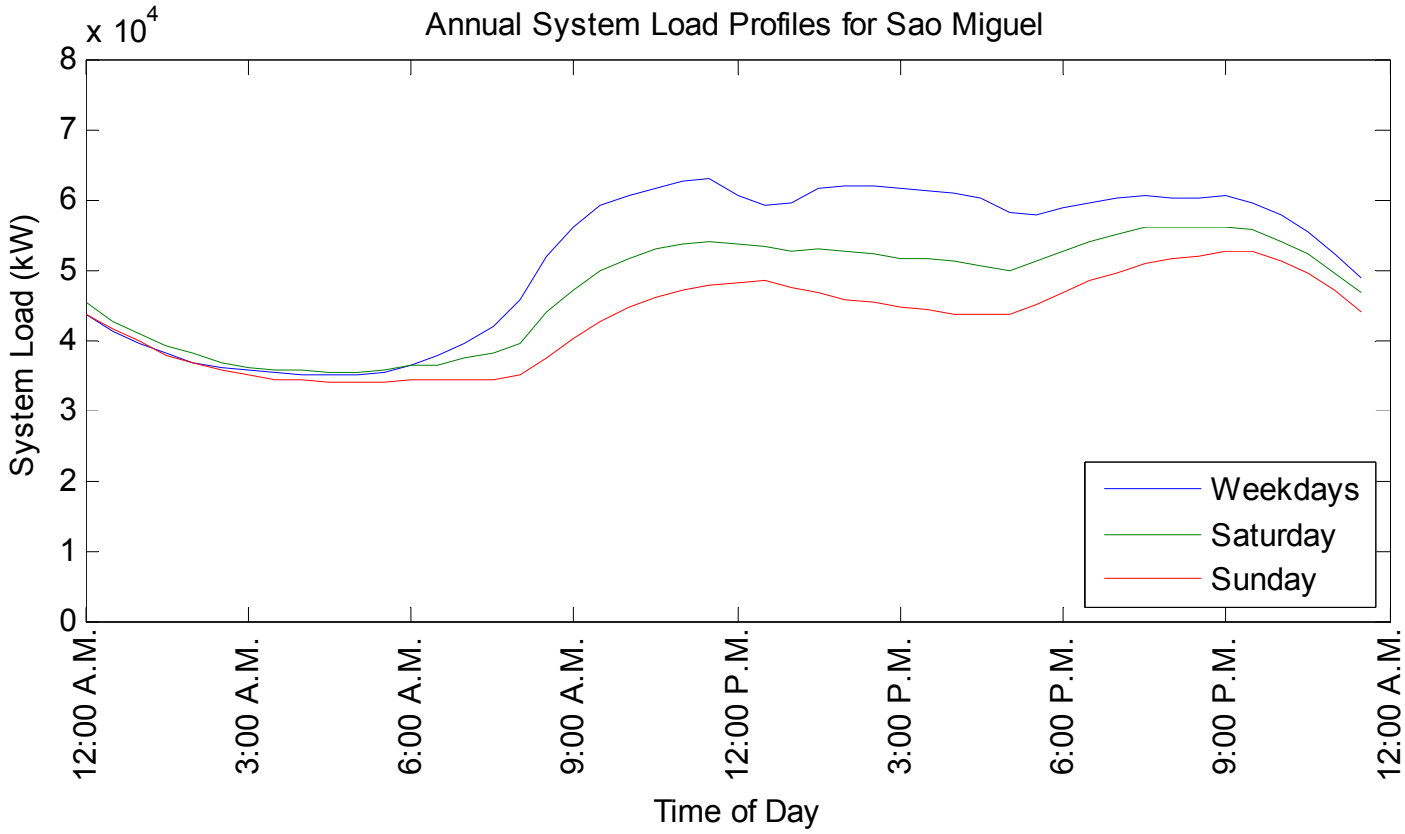
São Miguel Load (2008)





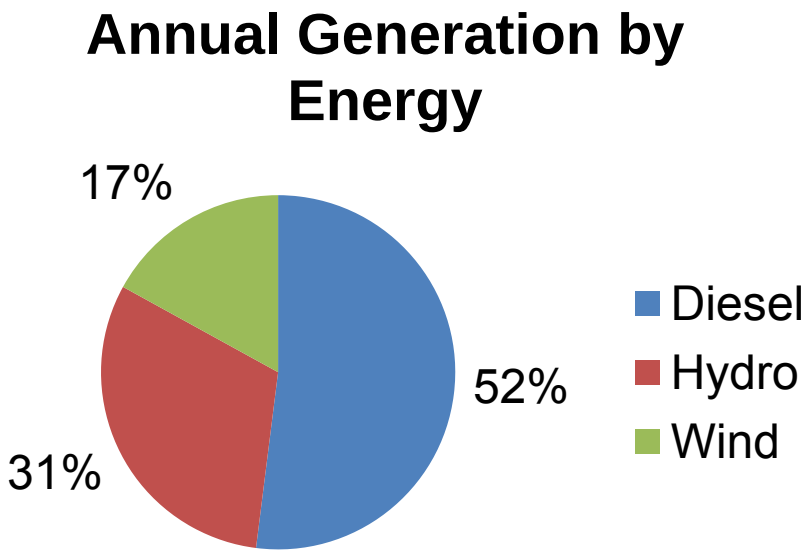
- Total Energy Consumed 441GWh
  - 132 GWh residential
- Peak Load of 73.9 MW

São Miguel System Load Profile



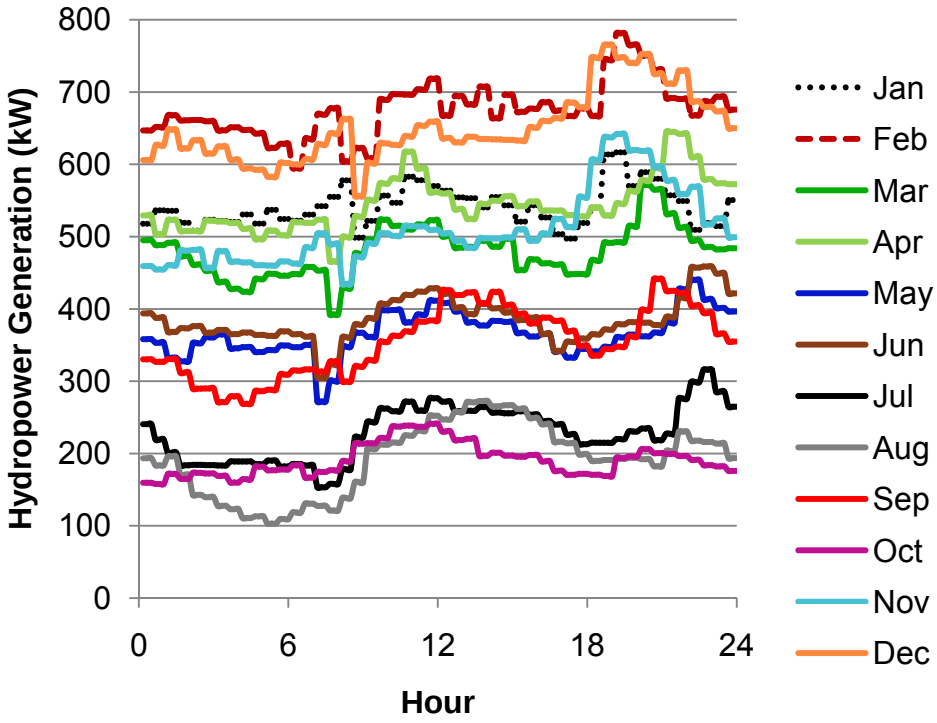
Flores Power Generation

Power Plant	Type	Pmin (MW)	Pmax (MW)
Além-Fazenda	Diesel	0.18	0.5
		0.18	0.5
		0.18	0.5
		0.28	0.7
Boca da Vereda	Wind		0.33
			0.33
Além-Fazenda	Hydro		0.371
			0.371
			0.371
			0.76

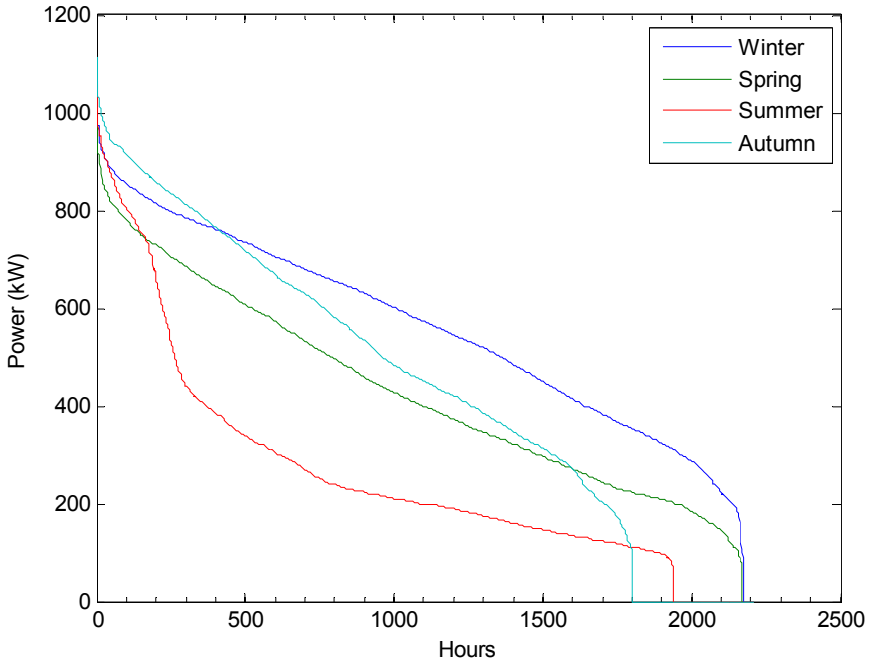


Flores Island Hydro Power

Monthly Generation Profiles



Seasonal Output Duration



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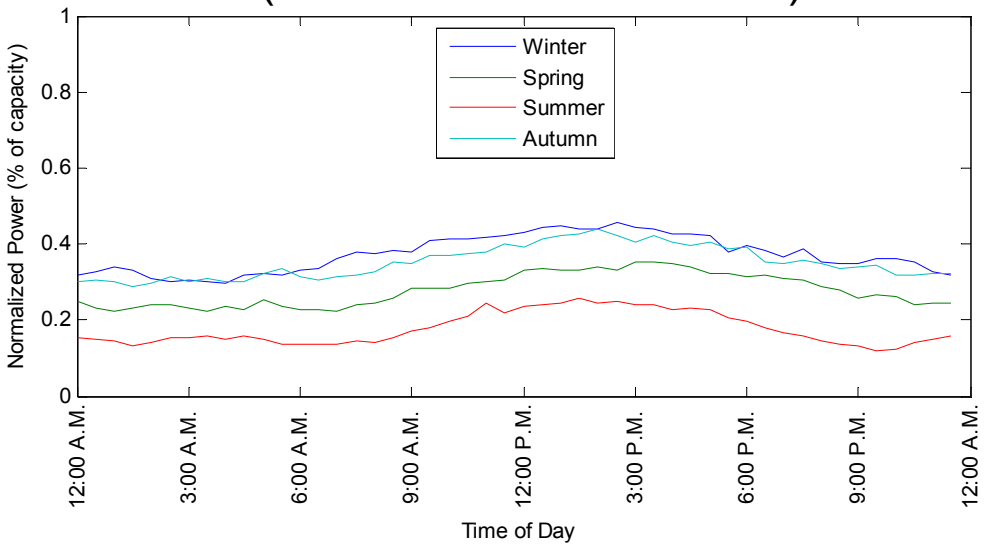
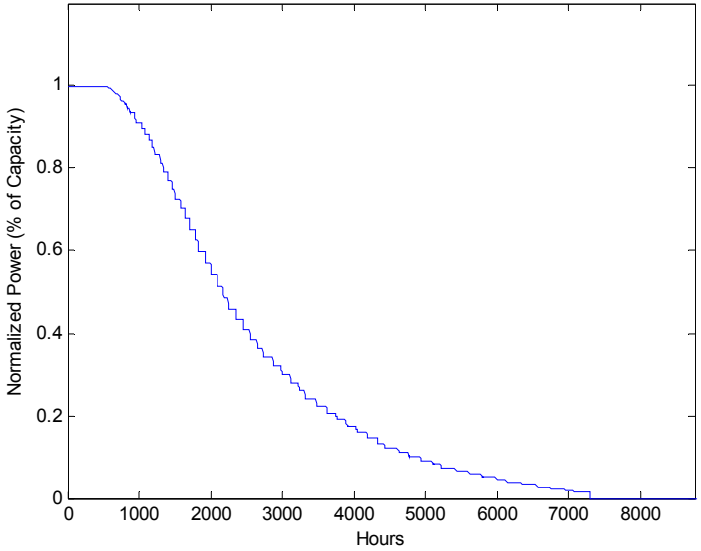
Flores Island Wind Power

Seasonal Average Daily Profiles
(modeled for E33 turbine)



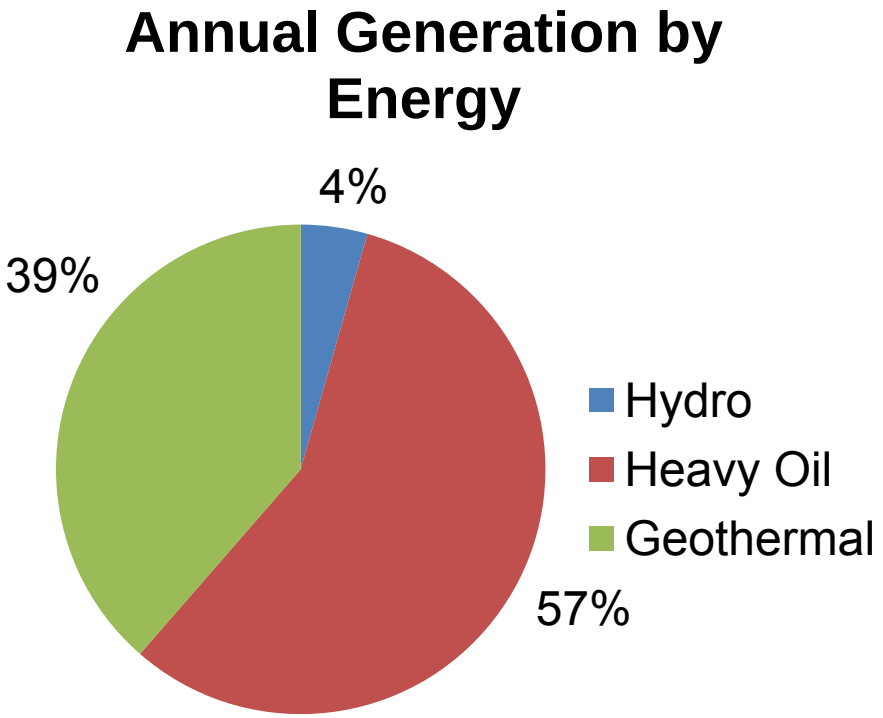
Annual Output Duration Curve
(modeled for E33 Turbine)



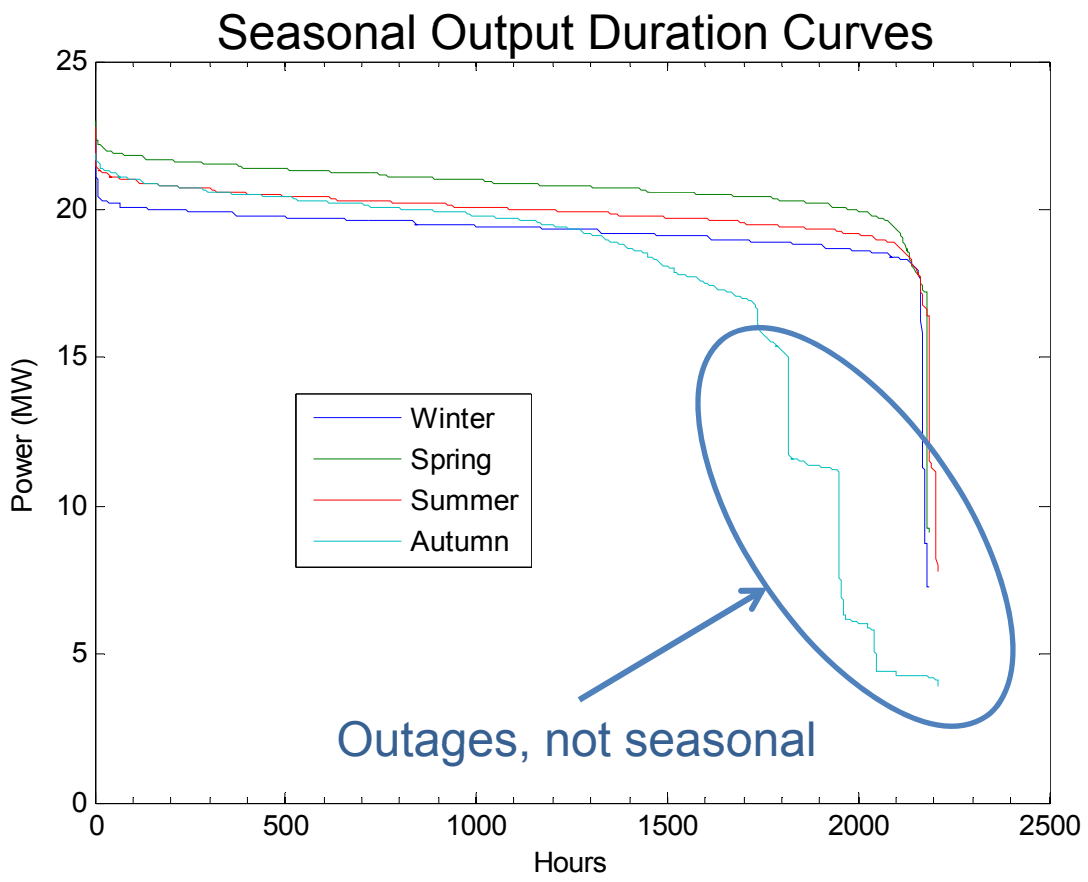
*Both normalized for Enercon E33 turbine
- More on Wind Data Later

São Miguel Island Generation

Power plant	Type	Pmin (MW)	Pmax (MW)
Caldeirão	Fuel Oil	3.848	7.5
		3.848	7.5
		3.848	7.5
		3.848	7.5
		8.41	18.165
		8.41	18.165
		8.41	18.165
		8.41	18.165
Agraçor	Biomass		0.4
			0.4
Túneis	Hydro		1.658
Tambores			0.094
Fábrica Nova			0.608
Canário			0.4
Ribeira Quente			0.8
Ribeira da Praia			0.8
Fajã Redonda			0.67
Pico Vermelho	Geothermal		13
Ribeira Grande			14.8



São Miguel Geothermal Power



Generator Ramp Rates

	Ramp Rate (%Pmax / min)
Diesel	100%
Hydro	5.1%
Fuel Oil (7.5MW)	27%
Fuel Oil (18MW)	17%
Wind	67%

- Hydro ramp rate derived from historical dispatch data
- Wind ramping up limited by wind available

Renewable Generation LCOE

Wind Power

Lifetime (yrs)	15
Expected Annual Production (MWh)	22,500
Installation Cost	€ 14,500,000
$/€	1.42
Interest Rate	5%
LCOE ($/kWh)	0.088

Geothermal Power

Lifetime (yrs)	50
Expected Annual Production (MWh)	83,000
Installation Cost	€ 30,000,000
$/€	1.42
Interest Rate	5%
LCOE ($/kWh)	$0.0281

Hydro Power

Lifetime (yrs)	50
Expected Annual Production (MWh)	5,120
Installation Cost	€ 5,700,000
$/€	1.42
Interest Rate	5%
LCOE ($/kWh)	0.087

Fossil Fuel Costs

- Considering Operational Cost Only
  - Heavy Oil - $0.185 per kWh (from MIT GI Study)
  - Diesel - $0.261 per kWh

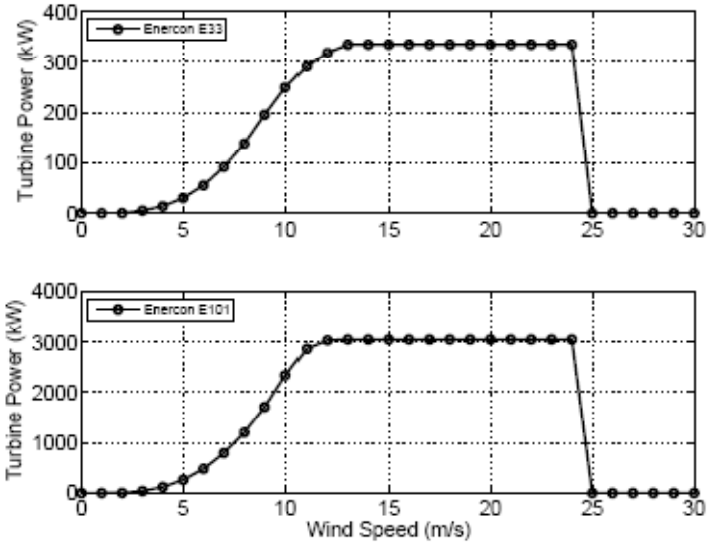
Diesel Marginal Cost Calculation

Diesel Market Price ($/l)	0.867
Annual Consumption (l)	1,807,879
Annual Energy Produced (kWh)	6,006,856
Constant Marginal Cost ($/kWh)	**0.261**

Wind Data

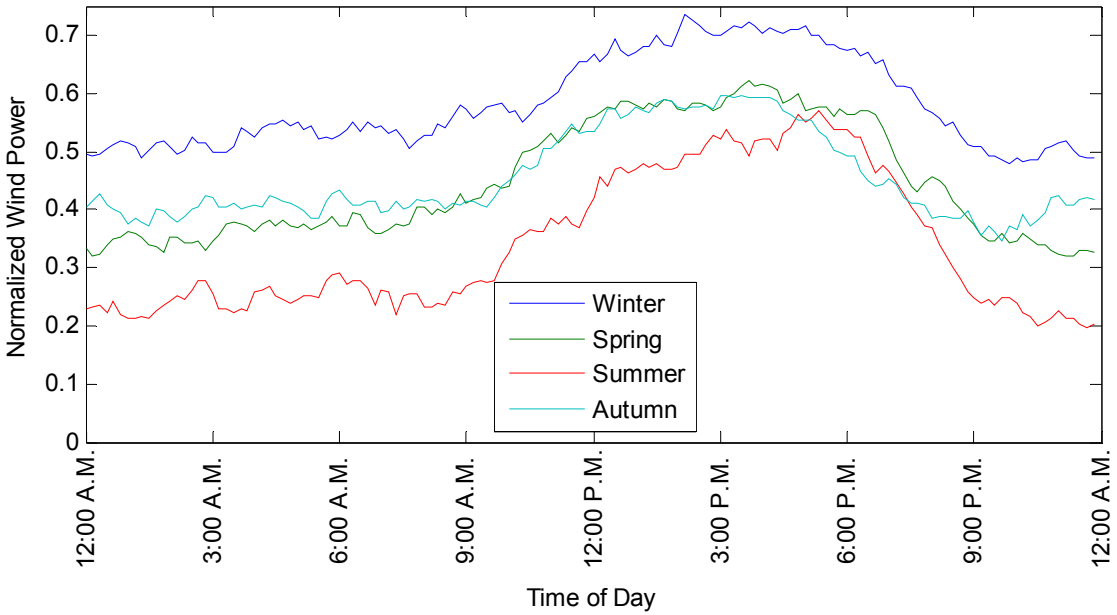
- 10 min avg Meteorological tower data
  - Measured at 6.8m
- Corrected for missing values
  - Linear interpolation
- Wind speed Height Correction
  - z_m – measurement height
  - z_h – turbine hub height
  - z_0 – surface roughness
- Speed to Power Conversion
  - from manufacturer's data sheets
  - Enercon E33 and E101 turbines
- Normalized (0 to 1)

$$U(z_h) = U(z_m) \frac{\ln\left(\frac{z_h}{z_0}\right)}{\ln\left(\frac{z_m}{z_0}\right)}$$

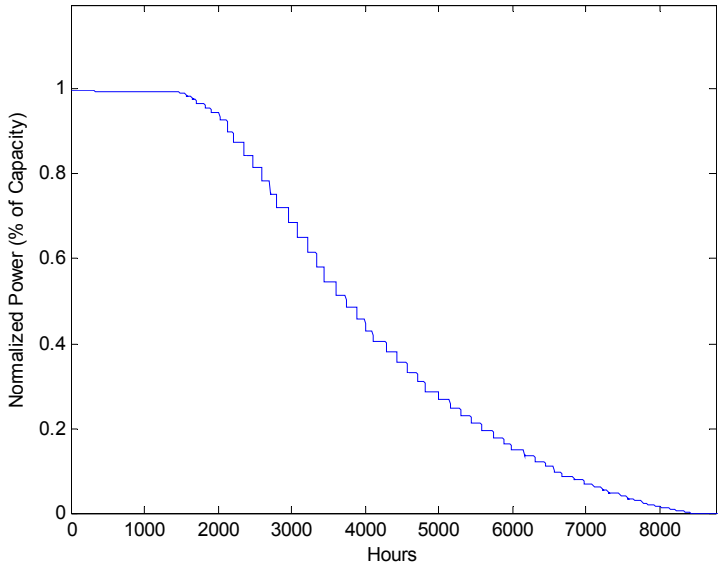


Potential Wind Power on São Miguel

Seasonal Average, Daily Profiles
(modeled for E101)



Output Duration Curve
(Modeled for E101)



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