PRODUCTION COST MODEL FOR PORTLAND GENERAL ELECTRIC GENERATING UNITS

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Overview

This independent project aims to produce a cost model for the power generating units of the Portland General Electric (PGE) power company, based in Oregon. The project uses publicly available data on hourly demand, power plant capacity, estimated forced outage rate, and estimated variable operations and maintenance costs to produce the estimated annual cost of energy generation for PGE's generating units, as well as a table of effective load calculations.

This document serves as an overview of the cost model, which has been primarily performed via a series of Excel spreadsheets. These sheets are available in the pge_cost_model_spreadsheet file, accessible via my GitHub project directory.

Sources

Data was obtained entirely from publicly available sources. As many of the necessary values for cost model calculation are privately held information, these values were estimated for the purposes of completing the project. All downloaded files can be found in the project repository.

USA Energy Information Administration (www.eia.gov)

- PGE 2023 hourly demand (MWh), sourced from the EIA's electricity API (available here), used to calculate expected annual demand.
- 2023 Cost & Performance Report (available here), used to estimate each plant's variable operations & maintenance costs.

Portland General Electric (portlandgeneral.com)

- PGE plant capacity totals, used to calculate plant capacity.

North American Electric Reliability Corporation (www.nerc.com)

- 2022 Generating Unit Statistical Brochure 2, used to estimate each plant's forced outage rate (FOR).

Iowa State University Engineering (home.engineering.iastate.edu)

- Production Cost Modeling Guide, used for cost modeling techniques.

Demand Analysis

To begin, we must first define a function of annual demand on the PGE grid. For the purposes of this project, historical demand data is used to estimate the next year's annual demand; in a more sophisticated model, forecasting functions may be used to obtain a more accurate estimate of demand. The hourly demand data spans from 12:00 AM, January 2023 to 11:59 PM, December 2023, for a total of 8760 hours, with measured demand in megawatt-hours for each hour.

Based on this data, we will calculate a histogram of demand, measuring the probability of a particular range of demand. For simplicity, bins of 100 MWh are used. We obtain the following histogram of demand, where the y-axis indicates the probability of a particular load falling within the given range.

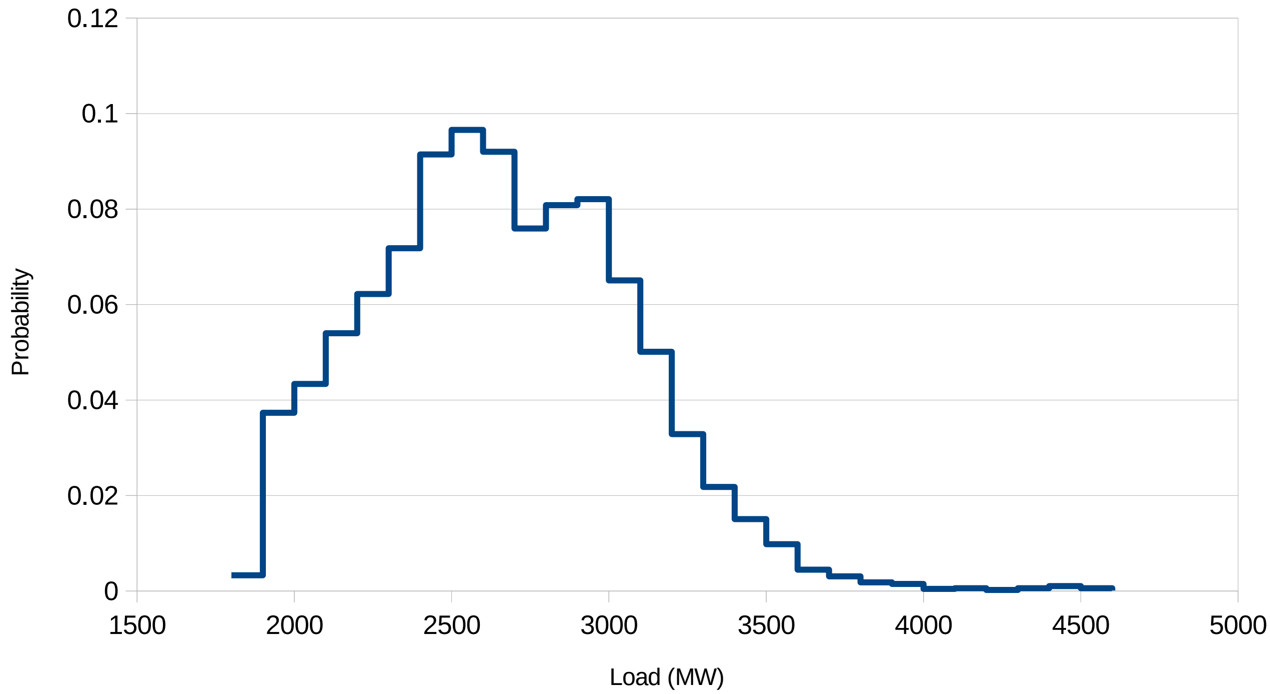

Figure 1: Histogram of demand probabilities

More useful to us is the CDF (cumulative distribution function) of the same set of probabilities. We specifically want to calculate the probability that a load will equal or exceed a given load, which will enable us to track the effective load in the next section. The CDF is given below as the probability that the load will equal or exceed the given load.

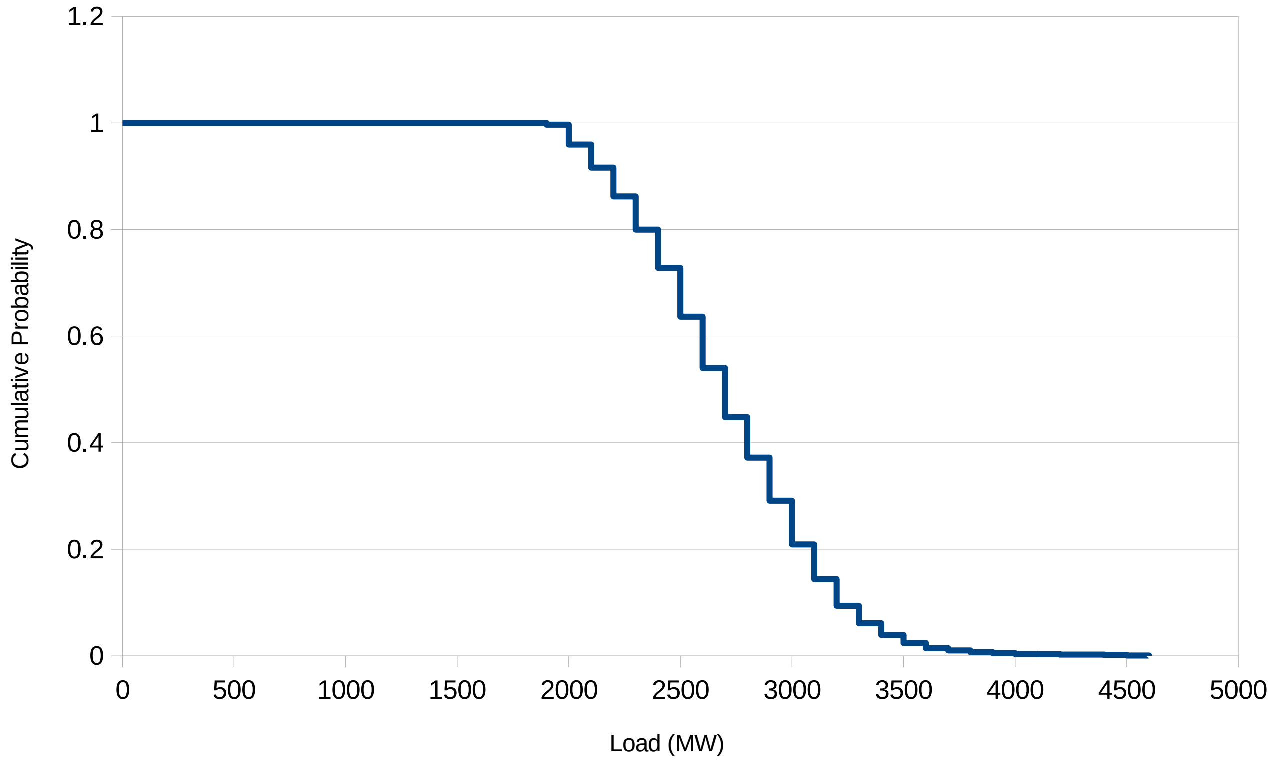

Figure 2: Cumulative distribution function of demand probabilities

Note that the above function shows the minimum load to be ~1800 MWh, while the maximum load reaches ~4600 MWh. This will inform our analysis of effective load, as PGE must supply at least 1800 MWh to successfully serve even the minimum demand.

Effective Load

The next step is to calculate effective load, which accounts for unreliability in power generation. To do this, we use the CDF above as the base load with no capacity, then convolve this random variable with a series of two-state random variables representing each generating unit in the system, with an outage representing an increase in effective load. This approach models a capacity outage as an increase in demand, rather than a decrease in capacity.

For example, the Biglow Canyon plant has a capacity of 450 MWh, and a forced outage rate (FOR) of 17.5%. We consider the Biglow Canyon plant as a two-state random variable, with an 82.5% probability of no increased load on the system (successful operation) and a 17.5% probability of a 450 MWh increase on the effective load. We then convolve this two-state random variable with the CDF of the base demand to determine the effective load CDF with the Biglow Canyon in operation. We repeat this calculation for each plant in PGE's fleet of generating units. (The convolution process is described in greater detail in Section 4.2 of the Iowa State University Production Cost Modeling guide.)

Note that loading order matters when calculating loss-of-load probabilities. We use a least-cost loading order for the purposes of this project, with priority given to higher capacity units. Convolving all units results in the effective load CDF below.

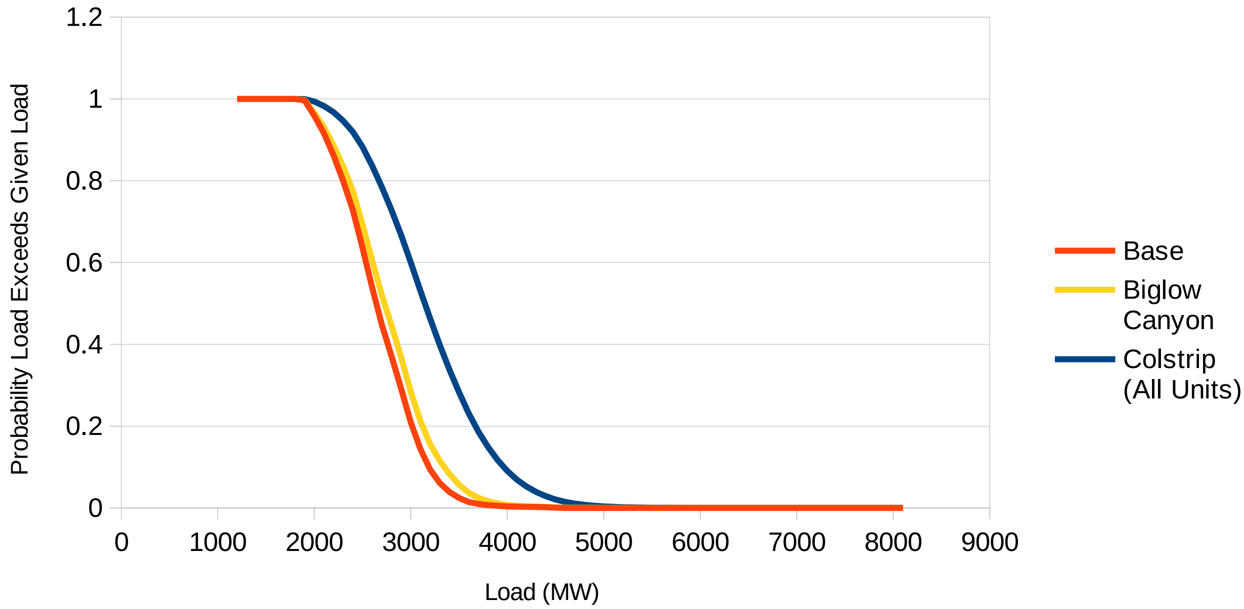

Figure 3: Effective load CDF with base load, Biglow Canyon convolved, and Colstrip (all units) convolved

We also obtain the following table of effective load functions, which shows the effective load function when each unit is added to the system. We can use this table to determine loss-of-load probability, which is the probability that the effective load will surpass the total capacity provided by the system. The loss-of-load probability for each effective load function is highlighted in yellow (the full table is available in the Excel file).

	Base	Biglow Canyon	Tucannon River	Wheatridge	Round Butte	Pelton	North Fork	Faraday	Oak Grove	River Mill	T.W. Sullivan	Beaver	Carty	Port Westward 1	Coyote Springs	Port Westward 2	Colstrip
Active	/	0.825	0.825	0.825	0.9464	0.9464	0.9464	0.9464	0.9464	0.8383	0.8383	0.8235	0.824	0.9227	0.927	0.927	0.9079
Outage	/	0.175	0.175	0.175	0.0536	0.0536	0.0536	0.0536	0.0536	0.1617	0.1617	0.1765	0.177	0.0773	0.073	0.073	0.0921
Capacity	/	450	267	100	187	57	56	46	43	25	18	511	436	393	257	214	296
Cost	/	0	0	0	1.57	1.57	1.57	1.57	1.57	1.57	1.57	2.1	2.1	2.1	2.1	2.1	5.06
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Load (MW)	**Fraction of time load exceeds given load**																
1200	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1300	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1400	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1500	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1600	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1700	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1800	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1900	0.997	0.99726883562	0.997746789384	0.9981411	0.998240738	0.9983	0.99842428	0.998509	0.99858867	0.9988169	0.9990081904	0.9992	0.999	0.999379393878	0.999424698125	0.9994666951618	0.999516
2000	0.959	0.96647260274	0.97233989726	0.9767861	0.978030368	0.9791	0.98014391	0.981124	0.98205557	0.984729	0.9870069894	0.9893	0.991	0.9918698694514	0.992463368981	0.9930135430458	0.993657
2100	0.916	0.93068493151	0.942815068493	0.94798191	0.950670446	0.9521	0.95358289	0.955007	0.95640644	0.9605539	0.9644630144	0.9707	0.976	0.977763403576	0.979386675115	0.9808914478316	0.982651
2200	0.862	0.88613869863	0.905586472603	0.91210148	0.915568573	0.9175	0.91930925	0.921146	0.92296123	0.9283693	0.9335735661	0.9453	0.955	0.9584349156931	0.961423862601	0.9641979235939	0.967446
2300	0.8	0.83481164384	0.857852311644	0.86620579	0.87058899	0.873	0.87538242	0.877737	0.88006365	0.8870002	0.8936895736	0.9125	0.928	0.9334262701646	0.937692652913	0.9416909151856	0.946418
2400	0.728	0.77499429224	0.80224015411	0.81197228	0.817339207	0.8202	0.82302382	0.82583	0.82861244	0.8369321	0.8450281101	0.8724	0.895	0.9022151490378	0.907730171619	0.9129610963743	0.919217
2500	0.637	0.69302511416	0.726819991438	0.74001852	0.746782158	0.7506	0.75429615	0.75798	0.76161673	0.7724499	0.7828767018	0.821	0.851	0.860400776189	0.867557268373	0.8744095297514	0.882679
2600	0.54	0.60575913242	0.645843321918	0.66001424	0.66815919	0.6724	0.6765644	0.680731	0.68487137	0.6972811	0.7094358994	0.7584	0.796	0.8081943871221	0.817336314584	0.8261223272822	0.836766
2700	0.448	0.52040239726	0.564955978881	0.57911126	0.587735893	0.592	0.5963521	0.600651	0.60494373	0.617868	0.6307091234	0.6896	0.735	0.7496757479982	0.760811124274	0.7715362147302	0.784561
2800	0.372	0.44688641553	0.489960687785	0.50308486	0.511496278	0.5156	0.51968118	0.523791	0.52791048	0.5403668	0.552898713	0.6201	0.672	0.6889337278223	0.701450822353	0.7135765929125	0.728389
2900	0.291	0.36764269406	0.409313070776	0.4234264	0.431771112	0.436	0.44030764	0.444562	0.44880872	0.4615995	0.4743361415	0.5484	0.606	0.6244956132478	0.637905623741	0.6510040641722	0.667132
3000	0.209	0.28392694064	0.325310145548	0.34001066	0.348751435	0.3532	0.35764168	0.362073	0.36649401	0.3798043	0.3930305782	0.4728	0.534	0.554492328791	0.568740718393	0.5827618580225	0.600148
3100	0.144	0.21334474886	0.254214540525	0.26665627	0.27505915	0.279	0.28298576	0.286987	0.29101189	0.3032173	0.3156014571	0.3981	0.462	0.4827856693643	0.497834477632	0.5126984707964	0.531199
3200	0.094	0.1558989726	0.192954123858	0.2036747	0.210982304	0.2144	0.21787897	0.221369	0.22488585	0.2355784	0.2465156428	0.3282	0.392	0.4136268863281	0.429020303393	0.4442689317786	0.463309
3300	0.061	0.11549086758	0.144967180365	0.1533649	0.159437313	0.1622	0.16499894	0.167833	0.17070281	0.1794642	0.1885378742	0.2666	0.329	0.3503537459935	0.365255862538	0.3801102570151	0.398774
3400	0.039	0.08335901826	0.106106521119	0.11290714	0.117772278	0.12	0.12226715	0.124558	0.12687716	0.1339638	0.1413211856	0.214	0.273	0.2931812667509	0.307022388142	0.3209516706745	0.338612
3500	0.024	0.05656392694	0.073947559932	0.07957538	0.083530496	0.0854	0.08722254	0.089101	0.09100141	0.0968025	0.1028114914	0.1684	0.222	0.2406342710496	0.253262731965	0.2660930346792	0.282503
3600	0.014	0.03707762557	0.050799942922	0.05485078	0.057962597	0.0593	0.0607284	0.062148	0.06359313	0.0680251	0.0726783676	0.1292	0.177	0.1933187557552	0.204782310043	0.2164968793747	0.231566
3700	0.01	0.0246347032	0.034911458333	0.03769194	0.039936895	0.0409	0.04189092	0.042901	0.04393229	0.0471115	0.0504931805	0.0973	0.138	0.1528039325788	0.163051477973	0.1735613544157	0.187136
3800	0.007	0.01633847032	0.023377925228	0.02539629	0.026975054	0.0277	0.02837911	0.029103	0.02984288	0.0321211	0.0345450702	0.072	0.106	0.1191928620052	0.128058084865	0.1371980241037	0.149069
3900	0.005	0.01101598174	0.015576769406	0.01694197	0.01805417	0.0185	0.0190221	0.019524	0.02003711	0.0216227	0.023320297	0.0525	0.081	0.0918926154405	0.099296723683	0.1069971714877	0.117082
4000	0.004	0.00715468037	0.010213684361	0.01115222	0.011915706	0.0122	0.01258174	0.012927	0.01328053	0.0143731	0.0155453331	0.0377	0.061	0.0697596706761	0.075821901795	0.0821896608561	0.090605

Figure 4: Effective load CDFs for each convolved unit

We can see in the above table that even with all units in operation, there is a 39.68% chance of the effective load exceeding 3300 MWh, the total capacity of all units. Even ignoring the chance of unit failure, there is still a 6.1% chance that the actual demand exceeds the total capacity of all units. In other words, out of 8760 annual hours, the PGE system would fail to produce adequate energy to serve demand for 534.36 hours, or a total of 22.27 days.

Cost Model

To determine the final annual cost model of PGE's generating units, we calculate the total annual load provided by each unit, in MWh, and multiply it by the operation and maintenance cost in dollars per MWh.

Annual load of a unit is calculated by determining the total number of hours of operation based on the unit's capacity and the probability of that unit being operational, including the chance of outage. We calculate the total annual load as:

capacity * percentage of hours active * (1 – forced outage rate) * 8760

For example, the Biglow Canyon plant, the first unit in the loading order, has a capacity of 450 MWh, which means it must be active 100% of the time to serve the minimum demand of 1800 MWh, and it has a forced outage rate of 17.5%. Thus, Biglow Canyon's annual load is calculated as 450*1*(1-.175)*8760 = 3,252,150 MWh. This is equivalent to the area under the base demand CDF over the range 0 to 450 MWh, multiplied by the rate of operation and the total annual hours.

For the other plants, we must consider previous plants to determine whether a unit will be active or not. For example, the Carty plant, 12th in the loading order, has a capacity of 436 MWh, so combined with previous plants, it covers the range of 1760 to 2196 MWh. In order to determine the Carty plant's operation hours, we must use the CDF of the previous plant in the loading order, the Beaver plant (11th), to determine the probability of the effective load being high enough to activate the Carty plant. This calculation is equivalent to the area under the demand CDF for the Beaver plant over the range 1760 to 2196 MWh, multiplied by the rate of operation and the total annual hours. This calculation, performed in Excel, results in an annual load of 3,097,657.054 MWh.

We perform this calculation for each plant in the loading order, from least to most cost, then multiply the observed annual load by the hourly operation and maintenance cost. In the end, we obtain a total annaul load of 22,680,153.036 MWh, and a total annual energy cost of $36,424,384.44. A table of individual unit results is shown below, alongside the combined total annual load and annual energy cost.

Location	Active	Outage	Capacity	Cost	Observed Annual Load (Mwh)	Annual Energy Costs
Biglow Canyon	0.825	0.175	450	0	3,252,150.000	$0.00
Tucannon River	0.825	0.175	267	0	1,929,609.000	$0.00
Wheatridge	0.825	0.175	100	0	722,700.000	$0.00
Round Butte	0.9464	0.0536	187	1.57	1,550,316.768	$2,433,997.33
Pelton	0.9464	0.0536	57	1.57	472,556.448	$741,913.62
North Fork	0.9464	0.0536	56	1.57	464,265.984	$728,897.59
Faraday	0.9464	0.0536	46	1.57	381,361.344	$598,737.31
Oak Grove	0.9464	0.0536	43	1.57	356,489.952	$559,689.22
River Mill	0.8383	0.1617	25	1.57	183,587.700	$288,232.69
T.W. Sullivan	0.8383	0.1617	18	1.57	132,183.144	$207,527.54
Beaver	0.8235	0.1765	511	2.1	3,686,282.460	$7,741,193.17
Carty	0.8235	0.1765	436	2.1	3,097,657.054	$6,505,079.81
Port Westward 1	0.9227	0.0773	393	2.1	2,828,312.556	$5,939,456.37
Coyote Springs	0.927	0.073	257	2.1	1,540,908.460	$3,235,907.77
Port Westward 2	0.927	0.073	214	2.1	1,043,924.033	$2,192,240.47
Colstrip	0.9079	0.0921	296	5.06	1,037,848.133	$5,251,511.55
				Total	22,680,153.036	$36,424,384.44

Figure 5: Observed annual load and annual energy costs

Limitations

This model has been highly simplified for the purposes of this project – in a professional environment, more sophisticated forecast data would likely be used to predict hourly demand, and an actual power company may commit their loading order vastly differently than a simple least-cost first model. Additionally, each plant has been considered a single unit for the purposes of this project – in reality, a plant might be divided into multiple generating units, especially if the plant uses multiple energy sources with different costs per MWh. Finally, publicly available data for PGE does not include forced outage rates or cost of operation and maintenance, so these values had to be estimated from nationally collected data.

All that said, as this project is primarily a demonstration of cost modeling techniques, real-world accuracy is not paramount. In the future I hope to have access to more sophisticated modeling techniques and more nuanced data upon which to perform them.