# APPENDIX I - PLANNING RESERVE MARGIN STUDY

## Introduction

The planning reserve margin (PRM), measured as a percentage of coincident system peak load, is a parameter used in resource planning to ensure there are adequate resources to meet forecasted load over time. PacifiCorp selects a PRM for use in its resource planning by studying the relationship between cost and reliability among ten different PRM levels, accounting for variability and uncertainty in load and generation resources.[1] Costs include capital and run-rate fixed costs for new resources required to achieve ten different PRM levels, ranging from 11 percent to 20 percent, along with system production costs (fuel and non-fuel variable operating costs, contract costs, and market purchases). In analyzing reliability, PacifiCorp performed a stochastic loss of load study using the Planning and Risk (PaR) production cost simulation model to calculate the following reliability metrics for each PRM level:

- Expected Unserved Energy (EUE): Measured in gigawatt-hours (GWh), EUE reports the expected (mean) amount of load that exceeds available resources over the course of a given year. EUE measures the magnitude of reliability events, but does not measure frequency or duration.
- Loss of Load Hours (LOLH): LOLH is a count of the expected (mean) number of hours in which load exceeds available resources over the course of a given year. A LOLH of 2.4 hours per year equates to one day in 10 years, a common reliability target in the industry. LOLH measurs the duration of reliability events, but does not measure frequency or magnitude.
- Loss of Load Events (LOLE): LOLE is a count of the expected (mean) number of reliability events over the course of a given year. A LOLE of 0.1 events per year equates to one event in 10 years, a common reliability target in the industry. LOLE measures the frequency of reliability events, but does not measure magnitude or duration.

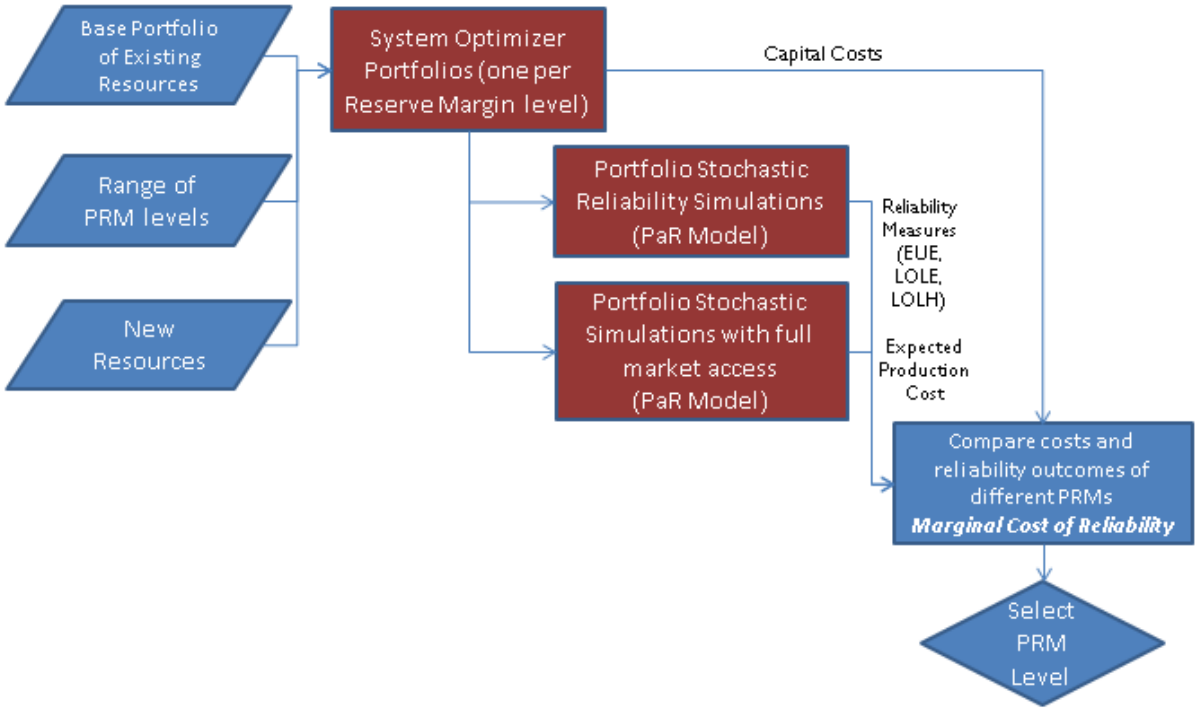
PacifiCorp's loss of load study results reflect its participation in the Northwest Power Pool (NWPP) reserve sharing agreement. This agreement allows a participant to receive energy from other participants within the first hour of a contingency event, defined as an event when there is an unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch, or other electrical element. PacifiCorp's participation in the NWPP reserve sharing agreement improves reliability at a given PRM level. Upon evaluating the relationship between cost and reliability in its PRM study, PacifiCorp will continue to use a 13 percent target PRM in its resource planning.

[1] Costs and reliability metrics are calculated for eleven different PRM levels, ranging from 10 percent to 20 percent. Comparative analysis among each PRM is performed for 10 different PRM levels by comparing the cost and reliability results from PRM levels ranging between 11 percent and 20 percent to those from the 10 percent PRM.

## Methodology

Figure I.1 shows the workflow used in PacifiCorp's PRM study. The four basic modeling steps in the workflow include: (1) using the System Optimizer (SO) model, produce resource portfolios among eleven different PRM levels ranging between 10 percent and 20 percent; (2) using the Planning and Risk model (PaR), produce reliability metrics for each resource portfolio; (3) using PaR, produce system stochastic variable production costs with full market access for each resource portfolio; (4) produce the marginal cost of reliabability using outcomes of different PRM levels, (5) select PRM level.

**Figure I.1 - Workflow for Planning Reserve Margin Study**




### Development of Resource Portfolios

The SO model is used to produce resource portoflios assuming PRM levels ranging between 10 percent and 20 percent. The SO model optimizes expansion resources over a 20-year planning horizon to meet peak load inclusive of the PRM applicable to each case. An improvement was made in the study to meet the PRM in both summer and winter. As the PRM level is increased from 10 percent to 20 percent, additional resources are added to the portfolio. Resource options used in this step of the workflow include demand side management (DSM), gas-fired combined cycle combustion turbines (CCCT), gas-fired simple cycle combustion turbines (SCCT), renewable resources and front office transactions (FOTs).

FOTs are considered as a resource expansion option in this phase of the workflow. FOTs are proxy resources used in the IRP portfolio development process that represent firm forward short-term market purchases for summer and winter on-peak delivery, which coincides with the time

of year and time of day in which PacifiCorp observes its coincident system peak load. These proxy resources are a reasonable representation of firm market purchases when performing comparative analysis of different resource portfolios to arrive at a preferred portfolio in the IRP.

Upfront capital and run-rate fixed costs from each portfolio are recorded and used later in the workflow where the relationship between cost and reliability is analyzed. Resources from each portfolio are used in the subsequent workflow steps where reliability metrics and production costs are produced in PaR.

## Development of Reliability Metrics

PaR is used to produce reliability metrics for each of the resource portfolios developed assuming PRM levels ranging between 10 percent and 20 percent. PaR is a production cost simulation model, configured to represent PacifiCorp's integrated system, that uses Monte Carlo random sampling of stochastic variables to produce a distribution of system operation. For this step in the workflow, reliability metrics are produced from a 500-iteration PaR simulation with Monte Carlo draws of stochastic variables that affect system reliability—load, hydro generation, and thermal unit outages. As discussed above, system balancing hourly purchases are enabled to capture the contribution of firm market purchases to system reliability. The PaR reliability studies are used to report instances where load exceeds available resources, including system balancing hourly purchases. Reported EUE measures the stochastic mean volume of instances where load exceeds available resources, and is mesasured in GWh. EUE measures the magnitude of reliability events. Reported LOLH is a count of the stochastic mean hours in which load exceeds available resources. LOLH measures the duration of reliability events. Reported LOLE is a count of the stochastic mean events in which load exceeds available resources. LOLE is a measure of the frequency of reliability events.

Each of the reliability metrics described above is adjusted to account for PacifiCorp's participation in the NWPP reserve sharing agreement, which allows a participant to receive energy from other participants within the first hour of a contingency event. The NWPP adjustments are made to EUE by reducing the stochastic mean volume of instances where load exceeds available resources for the first hour of a reliability event. For example, if the stochastic mean volume of EUE for a reliability event is 120 MWh, equal to 40 MWh in three consecutive hours, then the adjusted EUE is 80 MWh after removing the first hour of the event. Using this same example, LOLH would be adjusted from three to two hours, and LOLE would not be adjusted. The LOLE is only adjusted inasmuch as a given reliability event has a one hour duration.

For PaR, the contribution of firm market purchases are removed and instead include system balancing hourly purchases that cover the firm market purchases, limited by transmission and market depth limits, for the reliability metrics.

## Development of System Variable Production Costs

In addition to using PaR to develop reliability metrics, PaR is also used to produce system variable production operating costs for each of the resource portfolios developed assuming PRM levels ranging between 10 percent and 20 percent. For PaR's system variable production cost runs, its Monte Carlo sampling of stochastic variables is expanded to include natural gas and

wholesale market prices in addition to load, hydro generation, and thermal unit outages. At this step, the stochastic treatment of market prices is key given its influence on the economic dispatch of system resources, cost of system balancing purchases, and revenues from system balancing sales. In this step, full market access is included for the simulation. The stochastic mean of system variable costs is added to the upfront capital and run-rate fixed costs from each portfolio so that total portfolio costs are captured for each PRM level.

Marginal Cost of Reliability The marginal cost of reliability compares costs and reliabability outcomes across different PRM levels for 2020 through 2030. The use of a 10-year test period was an improvement to that of earlier IRPs which used a one-year test period. The marginal cost of reliability for each PRM, vis-a-vis that of the 10-percent PRM, is calculated as the difference in total production costs divided by the change in EUE. Correspondingly, for a 10 year period, the average marginal cost of reliability is the 10-year nominal levelized cost of yearly marginal reliability costs. The average ten-year marginal cost of reliability is calculated for all PRM levels ranging between 11 percent and 20 percent.

## Selection of PRM Level

Using the marginal cost of reliability analysis, the PRM level is selected for use in the 2017 IRP.

# Results

## Resource Portfolios

Table I.1 shows new resources added to the portfolio for the summer at PRM levels ranging between 10 and 20 percent. Each portfolio includes high load hour (HLH) front office transactions (FOTs) ranging from 550 to 1,136 MWs and flat FOTs of 176 MW in all PRMs. A 454 MW CCCT is added for the 19 percent and 20 percent PRM studies. DSM resource additions range between 374 MW and 431 MW. An improvement, to prior IRPs, was the inclusion of DSM Class 1 to the resource selection. As the PRM increases, system capacity is largely met with FOTs. Because new CCCT resources are added in blocks indicative of a typical plant size (i.e. the model cannot add a 2 MW CCCT plant), the addition of new DSM resources does not always follow an increase in the PRM.

**Table I.1 - Expansion Resource Additions by PRM for Summer**

| PRM (%) | Summer | | | | | | |
|---|---|---|---|---|---|---|---|
| | DSM Capacity at System Peak | DSM Class 1 | FOT | FOT Flat | SCCT | CCCT | Total |
| 10 | 380 | 0 | 550 | 176 | 0 | 0 | 1,107 |
| 11 | 374 | 0 | 651 | 176 | 0 | 0 | 1,201 |
| 12 | 380 | 0 | 738 | 176 | 0 | 0 | 1,294 |
| 13 | 384 | 0 | 828 | 176 | 0 | 0 | 1,388 |
| 14 | 394 | 0 | 912 | 175 | 0 | 0 | 1,481 |
| 15 | 400 | 0 | 1,000 | 175 | 0 | 0 | 1,575 |
| 16 | 382 | 0 | 1,112 | 176 | 0 | 0 | 1,670 |
| 17 | 425 | 25 | 1,134 | 174 | 0 | 0 | 1,759 |
| 18 | 431 | 113 | 1,136 | 172 | 0 | 0 | 1,852 |
| 19 | 396 | 0 | 982 | 175 | 0 | 454 | 2,007 |
| 20 | 380 | 0 | 1,093 | 176 | 0 | 454 | 2,103 |

Table I.2 shows new resources added to the portfolio for the winter at PRM levels ranging between 10 percent and 20 percent. The winter resource rating are difference from summer due to temperative variations and contribution to system peak.

**Table I.2 - Expansion Resource Additions by PRM for Winter**

| PRM (%) | Winter | | | | | | |
|---|---|---|---|---|---|---|---|
| | DSM Capacity at System Peak | DSM Class 1 | FOT | FOT Flat | SCCT | CCCT | Total |
| 10 | 240 | 0 | 26 | 176 | 0 | 0 | 442 |
| 11 | 237 | 0 | 34 | 176 | 0 | 0 | 447 |
| 12 | 240 | 0 | 41 | 176 | 0 | 0 | 456 |
| 13 | 243 | 0 | 48 | 176 | 0 | 0 | 467 |
| 14 | 250 | 0 | 55 | 175 | 0 | 0 | 480 |
| 15 | 253 | 0 | 70 | 175 | 0 | 0 | 497 |
| 16 | 241 | 0 | 86 | 176 | 0 | 0 | 502 |
| 17 | 259 | 25 | 101 | 174 | 0 | 0 | 559 |
| 18 | 266 | 113 | 93 | 172 | 0 | 0 | 643 |
| 19 | 248 | 0 | 133 | 175 | 0 | 454 | 1,010 |
| 20 | 239 | 0 | 149 | 176 | 0 | 454 | 1,018 |

## Reliability Metrics

Table I.3 shows EUE, LOLH, and LOLE reliability results before and after adjusting these reliability metrics for PacifiCorp's participation in the NWPP reserve sharing agreement. Each of the reliability metrics generally improve as the PRM increases and after accounting for benefits associated with PacifiCorp's participation in the NWPP reserve sharing agreement. After accounting for its participation in the NWPP reserve sharing agreement, all PRM levels meet a one day in ten year planning criteria (LOLH at or below 2.4), and PRM levels of between 19 and 20 percent meet a one event in ten year planning criteria (LOLE at or above 0.1).

**Table I.3 - Expected Reliability Metrics by PRM**

| PRM (%) | Before NWPP Adjustment | | | After NWPP Adjustment | | |
|---|---|---|---|---|---|---|
| | Simulated Energy Not Served (GWh) | LOLH (<2.4 target year) (Hour) | Loss of Load Episodes | EUE (GWh) | LOLH (Hour) | Modeled Loss of Load Episodes |
| 10 | 79 | 0.94 | 0.69 | 21 | 0.25 | 0.15 |
| 11 | 80 | 0.93 | 0.68 | 21 | 0.25 | 0.15 |
| 12 | 79 | 0.94 | 0.69 | 21 | 0.25 | 0.15 |
| 13 | 78 | 0.92 | 0.68 | 20 | 0.24 | 0.15 |
| 14 | 76 | 0.90 | 0.66 | 20 | 0.24 | 0.15 |
| 15 | 75 | 0.90 | 0.66 | 20 | 0.24 | 0.15 |
| 16 | 78 | 0.94 | 0.69 | 21 | 0.25 | 0.15 |
| 17 | 72 | 0.92 | 0.68 | 19 | 0.24 | 0.15 |
| 18 | 71 | 0.91 | 0.68 | 18 | 0.23 | 0.14 |
| 19 | 33 | 0.78 | 0.60 | 8 | 0.18 | 0.10 |
| 20 | 34 | 0.76 | 0.58 | 8 | 0.19 | 0.10 |

The reliability metrics do not montonically improve with each incremental increase in the PRM. This is influenced by the physical location of new resources within PacifiCorp's system at varying PRM levels and the ability of these resources to serve load in all load pockets when Monte Carlo sampling is applied to load, hydro generation, and thermal unit outages. Considering that the reliability metrics are measuring very small magnitudes of change among the different PRM levels, the PaR outputs are fit to a logarithmic function to report the overall trend in reliability improvements as the PRM level increases. Table I.4 shows the fitted EUE LOLH, and LOLE results. Figure I.2, Figure I.3 and Figure I.4 show a plot of the fitted trend for EUE, LOLH, and LOLE, respectively, after accounting for PacifiCorp's participation in the NWPP reserve sharing agreement.

**Table I.4 - Fitted Reliability Metrics by PRM**

| PRM (%) | Before NWPP Adjustment | | | After NWPP Adjustment | | |
|---|---|---|---|---|---|---|
| | EUE (GWh) | LOLH (<2.4 target year) (Hour) | Modeled Loss of Load Episodes | EUE (GWh) | LOLH (Hour) | Modeled Loss of Load Episodes |
| 10 | 91 | 0.97 | 0.71 | 24 | 0.26 | 0.16 |
| 11 | 81 | 0.94 | 0.69 | 22 | 0.25 | 0.15 |
| 12 | 76 | 0.92 | 0.68 | 20 | 0.24 | 0.15 |
| 13 | 72 | 0.90 | 0.67 | 19 | 0.23 | 0.14 |
| 14 | 68 | 0.89 | 0.66 | 18 | 0.23 | 0.14 |
| 15 | 66 | 0.88 | 0.66 | 17 | 0.23 | 0.14 |
| 16 | 64 | 0.87 | 0.65 | 16 | 0.22 | 0.14 |
| 17 | 62 | 0.87 | 0.65 | 16 | 0.22 | 0.13 |
| 18 | 60 | 0.86 | 0.65 | 15 | 0.22 | 0.13 |
| 19 | 58 | 0.86 | 0.64 | 15 | 0.22 | 0.13 |
| 20 | 57 | 0.85 | 0.64 | 14 | 0.21 | 0.13 |

**Figure I.2 - Expected and Fitted Relationship of EUE to PRM**

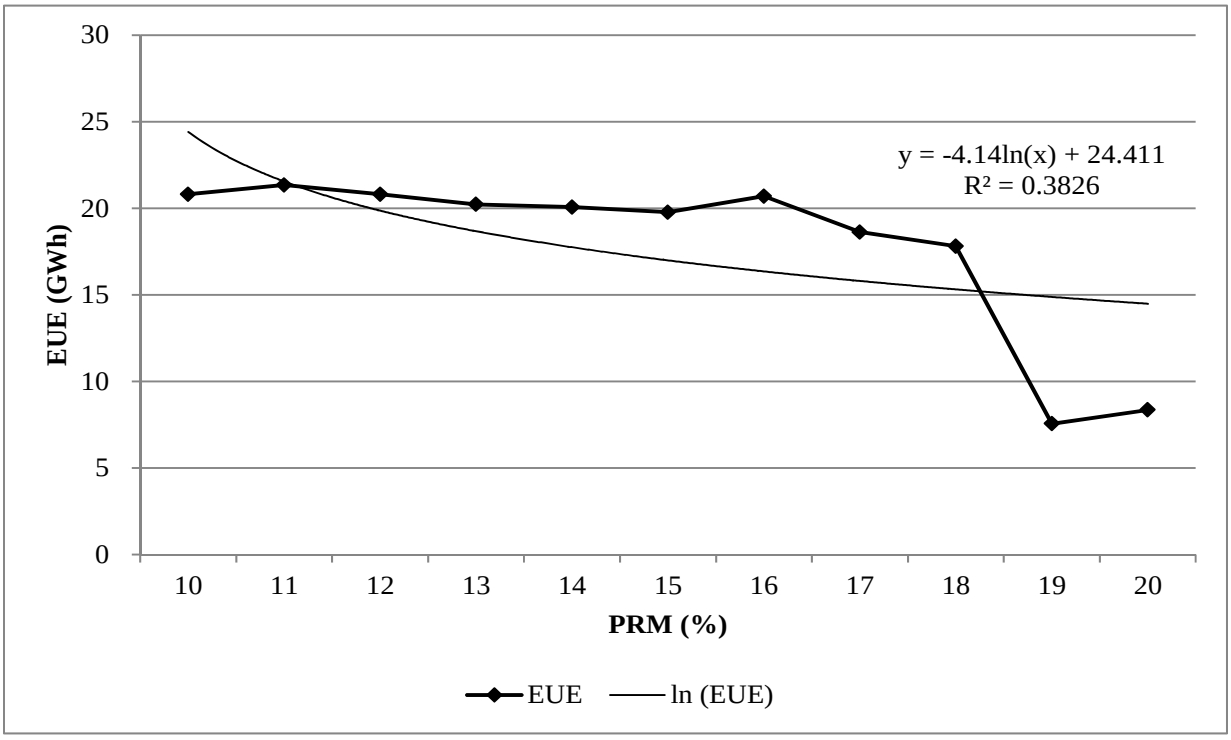



**Figure I.3 - Expected and Fitted Relationship of LOLH to PRM**

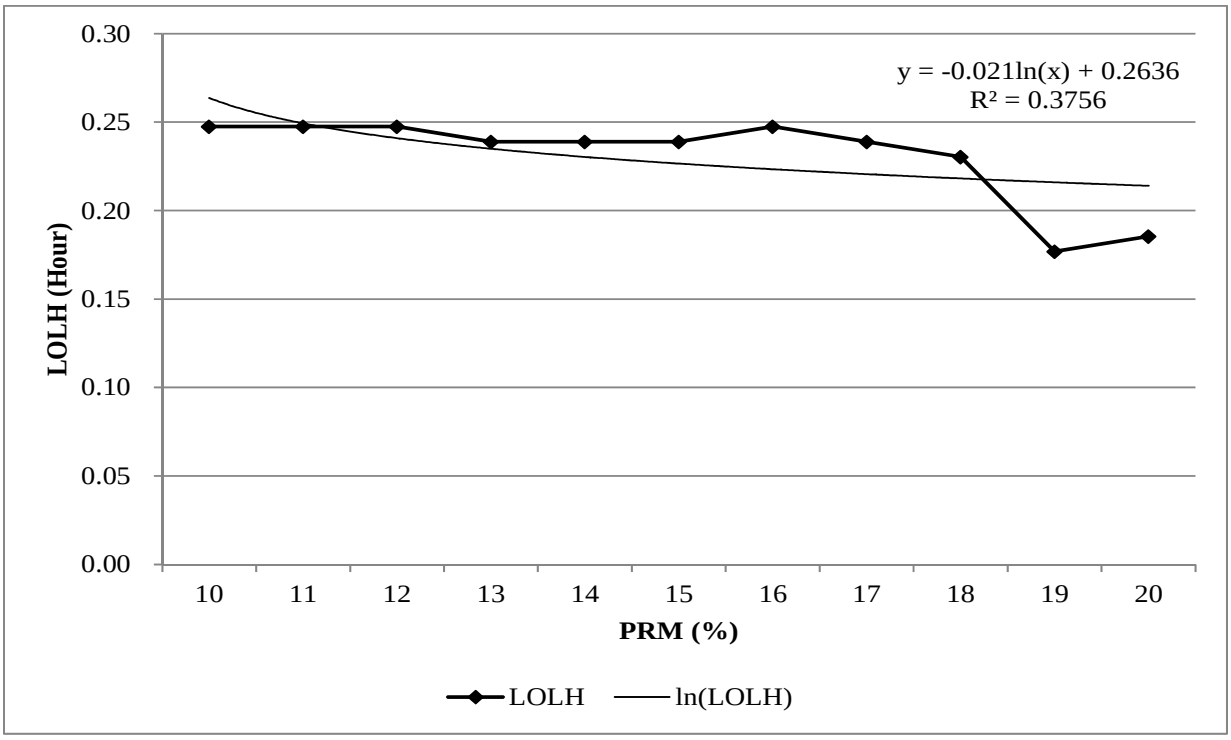
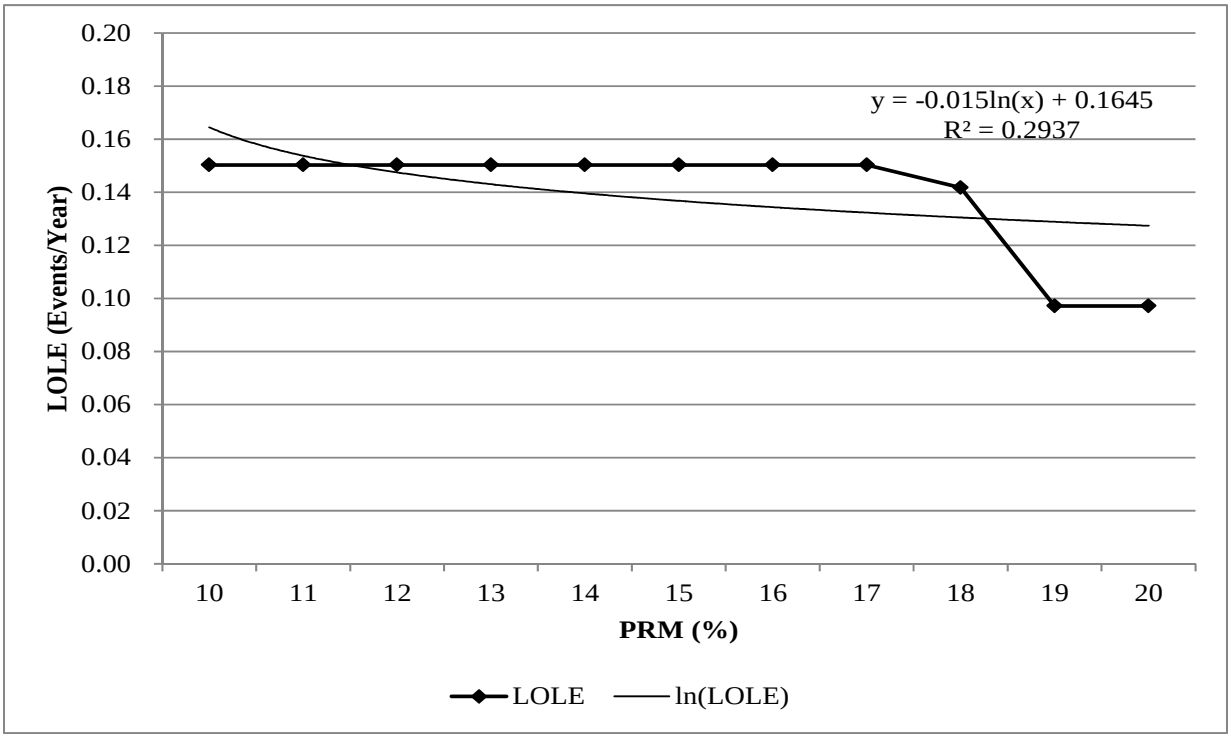


**Figure I.4 - Simulated Relationship of Loss of Load Episode to PRM**




## System Costs

For the 2020 reference year, Table I.5 shows the stochastic mean of system variable production costs and the upfront capital and run-rate fixed costs, including the cost of new DSM resources, for each portfolio developed at PRM levels ranging between 10 percent and 20 percent. The fixed costs associated with these new resource additions drive total costs higher as PRM levels increase. DSM run-rate costs vary depending on resource additions for DSM Class 1 and new resources where a CCCT was added in 19 percent and 20 percent.

**Table I.5 – System Variable, Up-front Capital, and Run-rate Fixed Costs by PRM**

| PRM (%) | System Production Costs ($m) | Class 2 DSM ($m) | Class 1 DSM ($m) | Existing Resource Fixed Costs ($m) | New Resource Fixed Cost ($m) | Total Costs ($m) |
|---|---|---|---|---|---|---|
| 10 | 10,969 | 437 | 0 | 6,093 | 183 | $17,681 |
| 11 | 11,003 | 404 | 0 | 6,093 | 197 | $17,698 |
| 12 | 10,966 | 437 | 2 | 6,093 | 203 | $17,701 |
| 13 | 10,958 | 463 | 9 | 6,093 | 193 | $17,715 |
| 14 | 10,906 | 514 | 12 | 6,093 | 198 | $17,723 |
| 15 | 10,892 | 553 | 28 | 6,093 | 181 | $17,747 |
| 16 | 10,923 | 440 | 2 | 6,093 | 382 | $17,840 |
| 17 | 10,882 | 522 | 18 | 6,093 | 354 | $17,869 |
| 18 | 10,865 | 535 | 63 | 6,093 | 371 | $17,927 |
| 19 | 10,835 | 527 | 26 | 6,093 | 581 | $18,061 |
| 20 | 10,870 | 429 | 7 | 6,093 | 745 | $18,144 |

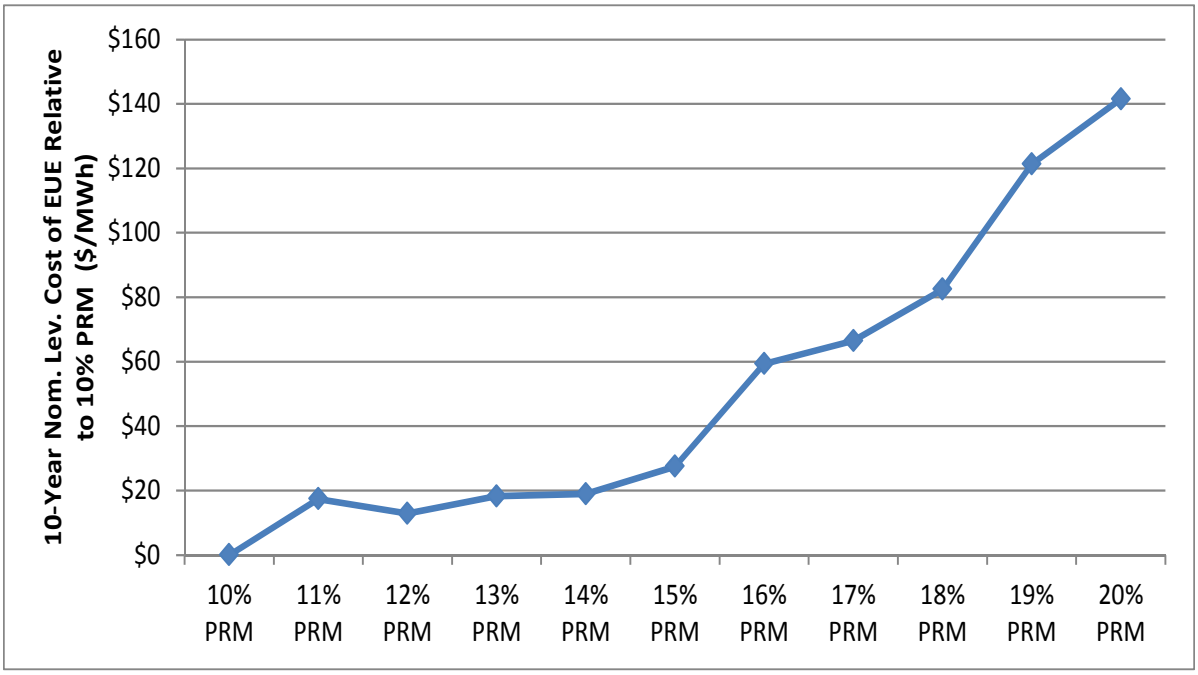
## Incremental Cost of Reliability

Table I.6 shows the incremental cost of reliability, stated as the 10-year nominal levelized cost of EUE relative to 10 percent PRM, at PRM levels ranging between 11 percent and 20 percent. Figure I.5 depicts this same information graphically. The incremental cost of reliability rises modestly at the 14 percent to 15 percent PRM, then rises dramatically as PRM levels increase from 16 percent to 20 percent.

**Table I.6 - 10-year nominal levelized cost of EUE relative to 10 percent PRM**

| PRM | Reduction in EUE Reliability from 10% PRM (GWh) | Reduction in Total Cost from 10% PRM ($ Million) | $/MWh |
|---|---|---|---|
| 10 | - | - | $0 |
| 11 | 930 | 16 | $17 |
| 12 | 1,475 | 19 | $13 |
| 13 | 1,861 | 34 | $18 |
| 14 | 2,160 | 41 | $19 |
| 15 | 2,405 | 66 | $27 |
| 16 | 2,612 | 155 | $59 |
| 17 | 2,791 | 185 | $66 |
| 18 | 2,949 | 243 | $82 |
| 19 | 3,091 | 375 | $121 |
| 20 | 3,219 | 455 | $141 |

**Figure I.5 - Incremental Cost of Reliability by PRM**




## Conclusion

PacifiCorp will continue to use a 13 percent target PRM in its resource planning after evaluating the relationship between cost and reliability in the PRM study. A PRM below 13 percent would not sufficiently cover the need to carry short-term operating reserve needs (contingency and regulating margin) and longer-term uncertainties such as extended outages and changes in customer load.[2] A PRM above 15 percent improves reliability above a one event in ten year planning level, though with a 300 percent to 700 percent increase in the incremental cost per megawatt-hour of reduced EUE when compared to a 13 percent PRM. With these considerations, the selected 13 percent PRM level ensures PacifiCorp can reliably meet customer loads while maintaining operating reserves, with a planning criteria that meets one day in 10 year planning targets, at the lowest reasonable cost.

[2] PacifiCorp must hold approximately six percent of its resources in reserve to meet contingency reserve requirements and an estimated additional 4.5 percent to 5.5 percent of its resources in reserve, depending upon system conditions at the time of peak load, as regulating margin. This sums to 10.5 percent to 11.5 percent of operating reserves before even considering longer-term uncertainties such as extended outages (transmission or generation) and customer load growth.