CHAPTER 10: OPERATING AND PLANNING RESERVES

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KEY FINDINGS

The Northwest Power Act defines reserves as “the electric power needed to avert particular planning or operating shortages for the benefit of firm power customers of the Administrator… (A) from resources or (B) from rights to interrupt, curtail, or otherwise withdraw, as provided by specific contract provisions, portions of the electric power supplied to customers.” To protect against planning shortages, the Council has developed an Adequacy Reserve Margin (ARM) that serves as a resource acquisition guide for future energy and capacity needs. To protect against operating shortages, the Council includes contingency reserve requirements and within-hour balancing reserve requirements in its resource simulation and planning models.

The adequacy reserve margin specifies the amount of “extra”[1] resource needed, above the forecast weather-normalized load, to cover future uncertainties, such as temperature variations and resource outages. A separate ARM is calculated for energy needs and for capacity needs. The ARM is defined as the difference between total rate-based resource capability and weather-normalized load, divided by load, for a power supply that just meets the Council’s adequacy standard.[2] Thus, in theory, future power supplies that meet the ARM thresholds should comply with the Council’s adequacy standard.

Contingency reserves refer to actions that can be taken to maintain system balance during the unplanned loss of a large generator or transmission line. The Northwest Power Pool sets these reserve requirements for the Northwest to 3 percent of load plus 3 percent of generation or to the magnitude of the single largest system component failure, whichever is larger.[3] At least half of these reserves must be supplied by unloaded generators that are synchronized with the power supply (i.e. spinning reserves).

Within-hour balancing reserves are provided by resources with sufficiently fast ramp rates to meet the second-to-second and minute-to-minute variations between load and generation left over after scheduled operations. Because of the rapid and sizeable development of wind generation in the Northwest, balancing reserve requirements have grown substantially. The bulk of these reserves are carried by the region’s hydroelectric system, which has led to a reduction in hydroelectric peaking capability and an increase in its minimum off-peak generation. The Council only includes the balancing reserves for the Bonneville Power Administration’s balancing area in its analyses.

[1] When including only rate-based resources and critical-period hydro in the ARM calculation, it is possible that the planning target turns out to be negative, that is, the power supply can be deficit and still be adequate.
[2] The Council deems a power supply to be adequate if its loss of load probability is no more than 5 percent.
[3] Northwest Power Pool, “Reserve Sharing Program Documentation,” May 1, 2015, Attachment A, page 37, http://www.nwpp.org/documents/RSGC/NWPP-Reserve-Sharing-Doc-April-17-2015-RSG-Approved-Effective-May-1-2015.pdf

BACKGROUND

The fundamental objective of power system operations is to continuously match supply of power from electric generators to customers' load at all times. This involves proper planning to ensure that the power supply has sufficient energy, capacity and balancing capability to cover the monthly, daily, hourly and moment-to-moment variations in load and generation). Until recently, load serving entities in the Northwest focused more on energy needs because of the large capacity of the region's hydroelectric system. In other words, the system had sufficient machine capability to cover hourly peaks (capacity) and short-term variations in load (balancing) but did not have enough storage behind reservoirs to generate at high levels for extended periods of time (energy).

In more recent years, changes in the seasonal shape of Northwest load, increasing constraints placed on the operation of the hydroelectric system, and rapidly increasing amounts of variable generation resources (i.e. wind) have made system capacity and balancing needs higher priorities.

In this chapter, details are provided for the types of ancillary services and reserves that the power system must provide in order to continuously match generation to load. The term "ancillary services" usually refers to operations that a power supply manager takes to keep the system stable and reliable. These services include actions to maintain proper frequency and voltage across the entire system. They also include generator operations (i.e. ramp up and ramp down) to match the variability in load and, in today's world, to offset the variability of wind (and other variable generating supplies). The power system must also have sufficient surplus generating capability (or load management operations) to offset the loss of a major system component.

This chapter focuses on two aspects of ancillary services that are critical in the development of the 7th Power Plan, namely operating reserves and planning reserves. Those terms are defined more clearly below. Chapter 16 and Appendix K of this plan provide a more detailed discussion of how the region assesses its need for operating and planning reserves and how it can best provide for that need.

ANCILLARY SERVICES

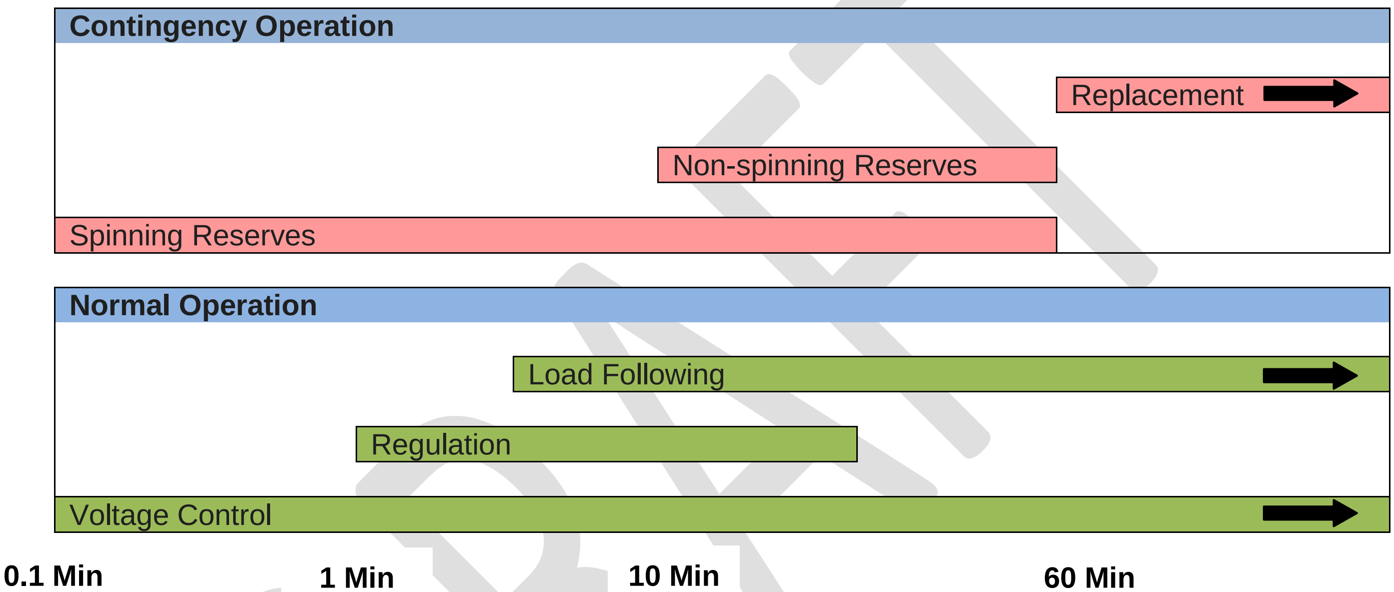
Ancillary services related to electric power are actions taken by system operators to ensure that power is delivered in a reliable manner without diminished quality. The United States Federal Energy Regulatory Commission (FERC) defines ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system." In general, ancillary services provide for:

- Frequency and voltage control
- Load following capability
- Outage protection

Frequency and voltage control maintain the stability and security of the transmission system and provide a consistent delivery of electricity (e.g. no brownouts). Load following capabilities are actions taken to insure that variations in load are matched exactly by generation at all times, ranging from seconds to minutes, hours, days and weeks. Outage protection operations are actions taken to instantly replace the loss of a generator or bulk transmission line. Table 10-1 provides a more detailed summary of ancillary services.

In general, ancillary services can be broken down into actions that can be taken during normal operations and those needed during emergency situations. Figure 10 - 1 below summarizes the types of actions that are typically taken during normal and emergency conditions and when those actions are commonly taken.

Figure 10 - 1: Response Time for Ancillary Services*



* Adapted from Kirby, Brendan, "Ancillary Services: Technical and Commercial Insights," July 2007, page 8, Prepared for WÄRTSILÄ (a Finnish corporation which manufactures and services power sources and other equipment in the marine and energy markets).

Table 10 - 1: Summary of Key Ancillary Services*

Service	Service Description		
	Response Speed	*Duration*	*Cycle Time*
Normal Conditions			
Regulating Reserve	Online resources, on automatic generation control, that can respond rapidly to system-operator requests for up and down movements; used to track the minute-to-minute fluctuations in system load and to correct for unintended fluctuations in generator output to comply with Control Performance Standards (CPSs) 1 and 2 of the North American Electric Reliability Council (NERC 2006)		
	~1 min	*Minutes*	*Minutes*
Load Following or Fast Energy Markets	Similar to regulation but slower. Bridges between the regulation service and the hourly energy markets.		
	~10 minutes	*10 min to hours*	*10 min to hours*
Contingency Conditions			
Spinning Reserve	Online generation, synchronized to the grid, that can increase output immediately in response to a major generator or transmission outage and can reach full output within 10 min to comply with NERC's Disturbance Control Standard (DCS)		
	Seconds to <10 min	*10 to 120 min*	*Hours to Days*
Non-Spinning Reserve	Same as spinning reserve, but need not respond immediately; resources can be offline but still must be capable of reaching full output within the required 10 min		
	<10 min	*10 to 120 min*	*Hours to Days*
Replacement or Supplemental Reserve	Same as supplemental reserve, but with a 30-60 min response time; used to restore spinning and non-spinning reserves to their pre-contingency status		
	<30 min	*2 hours*	*Hours to Days*
Other Services			
Voltage Control	The injection or absorption of reactive power to maintain transmission-system voltages within required ranges		
	Seconds	*Seconds*	*Continuous*
Black Start	Generation, in the correct location, that is able to start itself without support from the grid and which has sufficient real and reactive capability and control to be useful in energizing pieces of the transmission system and starting additional generators.		
	Minutes	*Hours*	*Months to Years*

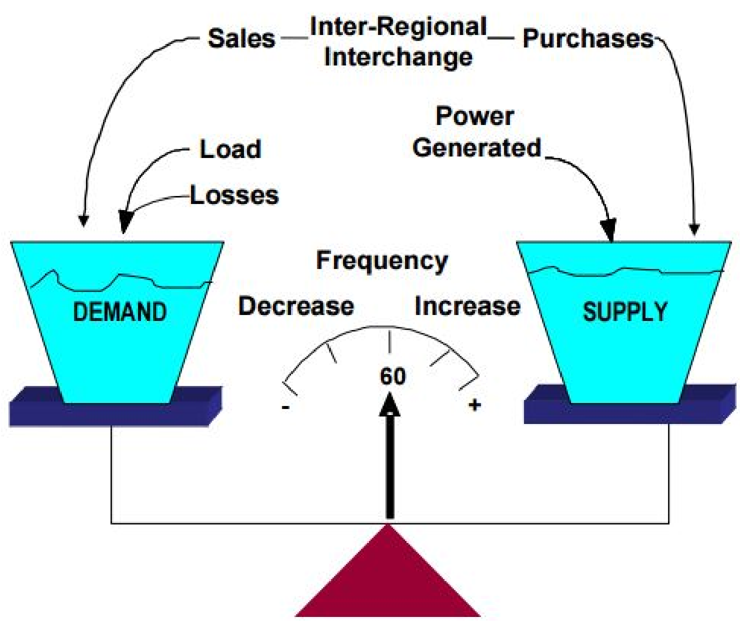
* Kirby, Brendan, "Ancillary Services: Technical and Commercial Insights," July 2007, page 9, Prepared for WÄRTSILÄ (a Finnish corporation which manufactures and services power sources and other equipment in the marine and energy markets).

Frequency and Voltage Control

The normal frequency of alternating current in the United States is 60 cycles per second. The normal voltage for residential and commercial use is 120 volts. While the frequency of electric current stays the same across all phases of the power system, from generation through end use, the voltage varies. Historically, electric power has been generated at large generating facilities and is then transported to users via high voltage transmission lines. The bulk electricity transmission grid often runs at 500,000 volts and is then transformed to lower voltage lines (230,000 and lower) before reaching the local distribution system that delivers the final power to users at 120 volts.

Frequency control refers to the capability of ensuring that grid frequency stays within a specific range of 60 cycles per second. Frequency will increase or decrease when mismatches between electricity generation and load occur. It decreases when load exceeds generation and increases when generation exceeds load. Large frequency deviations result in equipment damage and potential power system failure.

Figure 10 - 2: Illustration of Frequency Control*



*Source: “BALANCING AND FREQUENCY CONTROL,” A Technical Document Prepared by the NERC Resources Subcommittee, January 26, 2011, page 7.

Balancing authorities are electrical subareas within the region that are the responsible entities to maintain load-interchange-generation balance and support interconnection frequency in real time. Each balancing authority must balance its own load and resources and keep track of imports and exports, all while its own load and variable resource generation is continuously changing. Balancing authorities use a variety of techniques to balance their own generation and load and to keep the frequency of the system stable. Further, they are responsible for minimizing fluctuations in frequency between balancing authorities as power flows from one area to another.

Between balancing authorities, frequency is controlled by maintaining a stable net interchange with neighboring areas. The basic test of success for this is called the Area Control Error (ACE). ACE is a measurement, calculated every four seconds, based on the imbalance between load and generation within a balancing area, taking into account previously planned imports and exports and the frequency of the interconnection. The North American Electric Reliability Corporation (NERC) and Western Electricity Coordinating Council (WECC) reliability standards govern the amount of allowable deviation of the balancing authority's ACE over various intervals, although the basic premise is that ACE should be approximately zero. The ACE is maintained through a combination of automatic and operator actions. The automatic part is done through a computer-controlled system called Automatic Generation Control (AGC), which monitors the frequency of the system and correspondingly adjusts participating generators' output (within seconds) to bring the frequency back in line.

Voltage control refers to ensuring that the system voltage, for every phase of electricity delivery, is kept within a specific range of its targeted value. High voltage variations can destroy equipment by breaking down insulation. Periods of low voltage can make motors stall and overheat equipment. In extreme cases, a voltage loss can cause a blackout when a local drop in voltage cascades throughout a region.

In technical terms, voltage is controlled by injecting or absorbing *reactive power* by means of *synchronous or static* compensation. Every alternating-current (AC) power system has both real and reactive power. In an AC system, current varies (at 60 cycles per second in North America) as does the voltage. When the current and voltage oscillations get out of phase, the voltage can drag behind or race ahead of the current (i.e. get out of phase). This effectively lowers or increases the net voltage of the system. To compensate for this, electrical components that provide reactive power, such as capacitors, are added to the system.

In its planning process, the Council assumes that frequency and voltage control actions will be provided by the appropriate parties and, therefore, does not include these actions in its simulation and planning models.

Load Following Capabilities

Reserves to cover load following activities have two major purposes; 1) to cover unexpected variation in loads due to temperature or other factors and 2) to cover unexpected changes in generation from variable resources (i.e. wind).

Regulation and Scheduling

Regulation is the use of on-line generation equipped with Automatic Generation Control (AGC) which can change output quickly (megawatts per minute) to track the moment-to-moment fluctuations in customer loads and to correct for unintended fluctuations in generation. Regulation helps to maintain interconnection frequency, manage differences between actual and scheduled power flows between balancing areas, and match generation to load within a balancing area. Load following is the use of on-line generation, storage, or load equipment to track the intra- and inter-hour changes in customer loads.

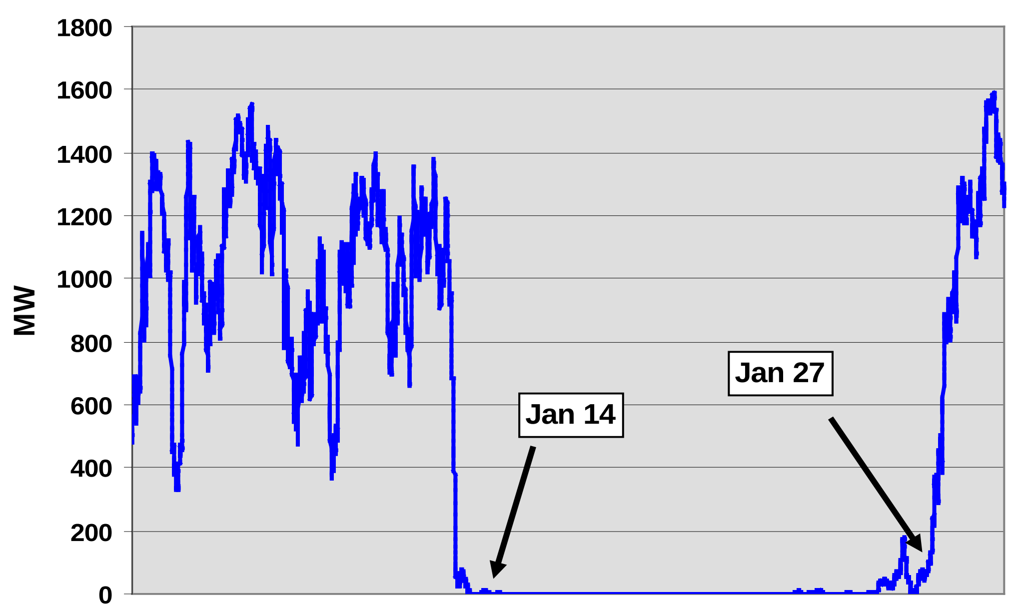
Scheduling is the before-the-fact assignment of generation and transmission resources to meet anticipated loads. Scheduling can encompass different time periods: a week ahead (e.g., a utility will schedule its units on Thursday for each hour of the following week), a day ahead, and before each hour. Scheduling of generation occurs for flows out of a balancing area, flows into a balancing area, and flows through a balancing area.

The Council does not include any regulation or scheduling operations in its planning process because they are not relevant to developing long-term resource acquisition strategies.

Balancing Reserves

Balancing reserves are provided by resources with sufficiently fast ramp rates to meet the second-to-second and minute-to-minute variations between load and generation left over after providing regulation and scheduled operations. Before the sharply increasing development of wind generation, balancing reserves were maintained mostly to cover short-term variations in load. After the development of wind, these reserves also covered short-term variance in the expected variable energy resource generation. Balancing reserves not only provide additional generating capability when loads unexpectedly increase (or wind/solar unexpectedly decrease) but also provide the ability to cut back generation when load suddenly drops or when wind/solar generation unexpectedly increases. Figure 10 - 3 below illustrates the variation in wind generation. In this particular case, wind stopped generating for almost a two-week period.

Figure 10 - 3: Bonneville Wind Generation (January 5 to 29, 2009)



Balancing reserves that provide additional capability are referred to as incremental (INC) reserves. Those that back off generation (or add more load) are referred to as decremental (DEC) reserves. The shortest time step in the Council's resource adequacy model (GENESYS) is one hour. Therefore, it cannot assess the need for or the sufficiency of balancing reserves. That need must be determined by other means.[4] Currently the Council only includes the Bonneville Power Administration requirements of 900 megawatts of incremental reserve and 1,100 megawatts of decremental reserve in its analyses. More detail regarding the assessment and cost-effective implementation of these reserves is provided in Chapter 16 and in Appendix K.

In the Council's model, balancing reserves are assumed to be provided by the hydroelectric system. This has the effect of reducing the regional hydroelectric peaking capability and of increasing its minimum off-peak period generation.

Example of Load Following Operations

An example of basic load following operations is described below, based on five-minute interval data from the Bonneville Power Administration balancing area for January of 2008. This was taken from Chapter 12 of the Council's 6th Power Plan and provides a good example of load following operations.

Figure 10 - 4 illustrates a typical weekly load pattern, with a sharp daily up ramps in the morning as people get up, turn on electric heat, turn on lights, take showers, and as businesses begin the day. It also shows the Bonneville balancing area wind generation from the same period, highlighting the irregular pattern typical of wind generation. The data from this week will be used in several subsequent graphs, focusing on shorter time intervals to illustrate particular issues.

Focusing on a single day, January 7, 2008, Figure 10 - 5 highlights a single operating hour, from 6:00 a.m. to 7:00 a.m.

[4] Assessing the need for within-hour balancing reserves requires an analysis of sub-hourly (preferably minute to minute) resource dispatch and load. Balancing reserves carried by the hydroelectric system are incorporated as constraints in the Council's TRAPEZOIDAL model, which assesses hydroelectric peaking capability.

Figure 10 - 4: Bonneville Load and Wind Patterns (January 1 to 7, 2008)

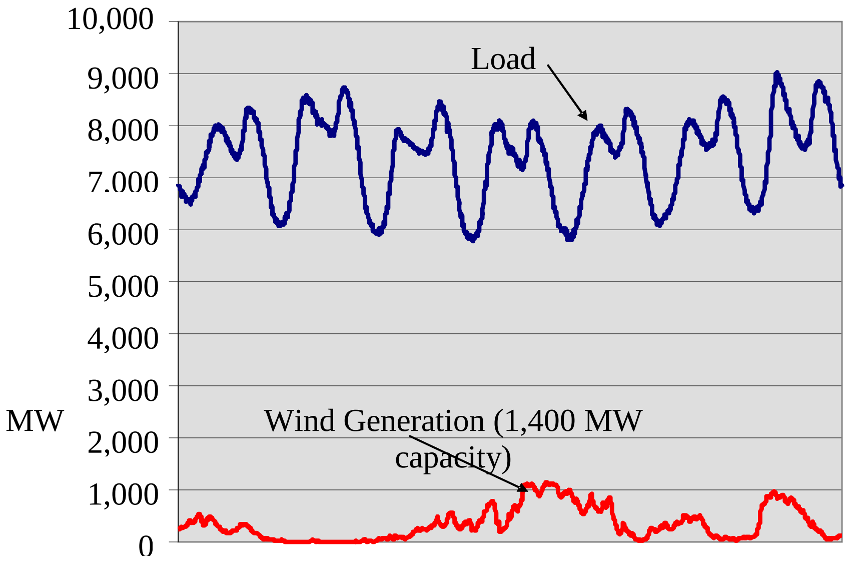
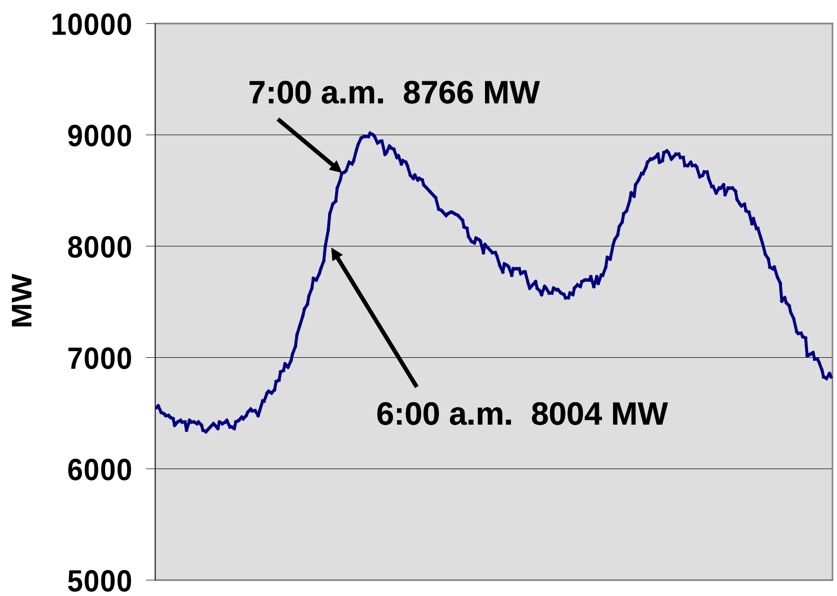


Figure 10 - 5: Daily Load Curve - Bonneville January 7, 2008 Midnight to Midnight

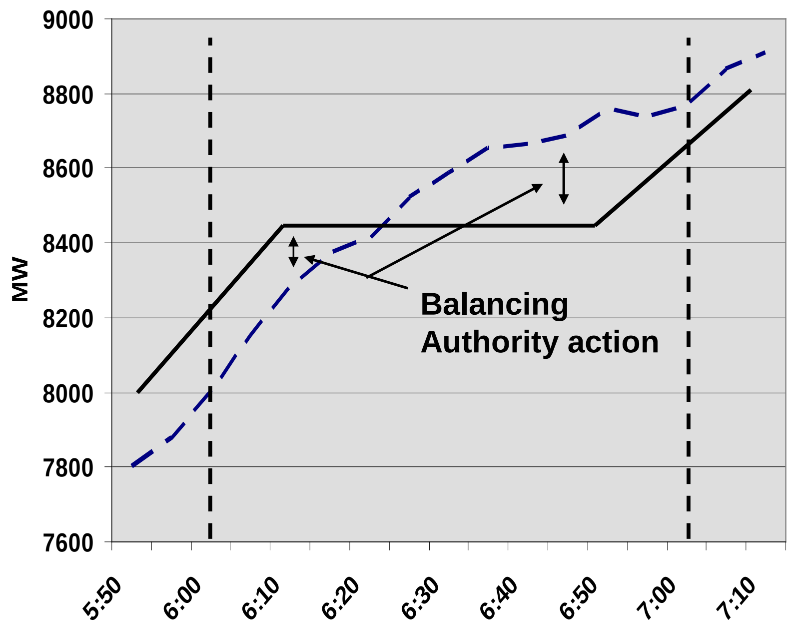


A balancing authority has to deal with a load ramp of, for example, 762 megawatts over the course of an hour, using the generation under its control in its own balancing area. At the same time, it must deal with any imports or exports that have their own time pattern for adjustment. Scheduling between balancing authorities in WECC is generally done in one-hour increments, with the schedules ramping in across the hour, from 10 minutes before the hour to 10 minutes after the hour.

Figure 10 - 6 focuses on the 6:00 a.m. to 7:00 a.m. load from the previous graph, while adding a hypothetical net schedule of generation to meet the average hourly load by any of its providers, including purchases from and sales to the market. The balancing authority must address the differences (both positive and negative) between the total scheduled generation and the net load in the balancing area by operating the generation under its control either up or down to match the load instantaneously, and to manage its ACE to acceptable levels. The graph points to the differences between scheduled generation and actual load that requires balancing authority action.

There are NERC and WECC reliability standards that govern how balancing authority action can be taken. In addition to contingency reserves, which must be available in case of a sudden forced outage, the standards require regulation reserves, which is generation connected to the balancing authority's AGC system. The standards do not require any specific megawatt or percentage level of regulation reserves. Rather, they require that the balancing authority hold a sufficient amount so that its ACE can be controlled within the required limits. How the balancing authority meets the requirements highlighted in Figure 10 - 6 involves some discretion.

Figure 10 - 6: Example Hourly Scheduling*



*Solid line shows scheduled generation and dashed line shows actual load.

Most balancing authorities prefer to break the requirement into two parts: one meeting the pure regulation requirement, allowing AGC generation to respond every four seconds; the other adjusting generation output over a longer period, typically 10 minutes. The pure regulation requirement is illustrated by Figure 10 - 7, which shows a hypothetical, random pattern at four-second intervals (which is the kind of pattern the load actually exhibits) on top of a five-minute trend. This is the load that the generation on AGC actually follows. Figure 10 - 8 illustrates one pattern of breaking that requirement up, separating the regulation requirement for generation on AGC from the remaining requirement, usually called load-following or balancing.[5]

Figure 10 - 7: Example Load at Four-Second Intervals Over Five Minutes

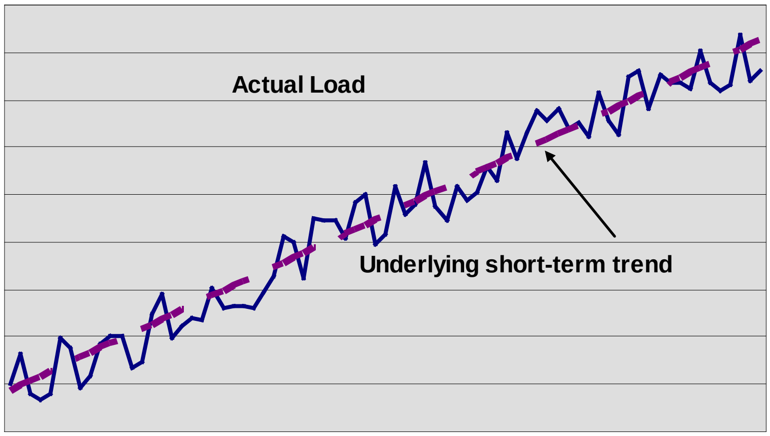
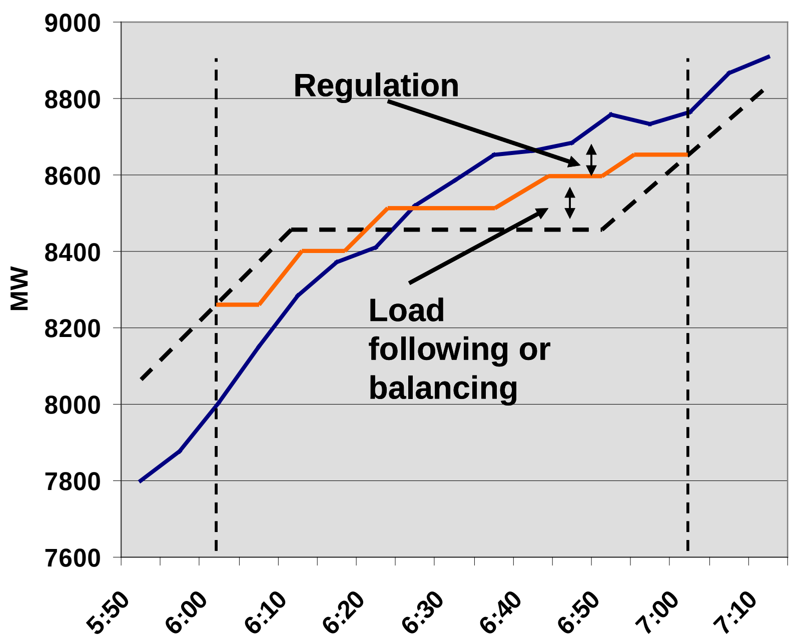


Figure 10 - 8: Illustration of Hourly Scheduling with Load Following*



*Dashed line shows scheduled generation, solid blue line shows actual load and orange line in between separates the AGC regulation from load following actions.

[5] When the only remaining requirement is the variation in load, load-following is the most common term. When the requirement includes the effect of variable generation, like wind, the term balancing is often used instead.

Balancing authorities plan for regulation and balancing services before the need for them arises. They ensure that enough scheduled generation is on AGC to provide moment-to-moment regulation services. They also plan to operate some generators at levels lower than they otherwise would in order to have the ability to increase generation and provide incremental load-following. Conversely, they may also need to operate some generators at levels higher than they otherwise would in order to have the ability to decrease generation and provide decremental load following.

The Council only includes within-hour balancing reserves in its long-term planning process. These are reserves that allow the power system to match generation to load (both up and down) during sub-hourly periods. In particular, these reserves cover the variation in sub-hourly loads and in wind and solar generation. Currently, the Council's analysis only considers within-hour balancing reserves of the Bonneville Power Administration balancing area, which are 900 megawatts of incremental (increasing) reserves and 1,100 megawatts of decremental (decreasing) reserves. Chapter 16 and Appendix K describe how the Council is planning to assess the regional need for balancing reserves and how to best provide for them.

Outage Protection

FERC defines operating reserves (in Order No. 888) as "extra generation available to serve load in case there is an unplanned event such as loss of generation." The term "operating reserves," however, is not a standard term but generally means an amount of surplus generating capability that can be dispatched immediately or in a very short time in the event of a system failure. These reserves, more commonly referred to as contingency reserves, are required to include both spinning and standing (non-spinning) reserves.

The Council and other power industry entities define operating reserves in a more general way, to include not only contingency reserves but also reserves to cover load following operations, that is, the ability to cover unexpected variations (up or down) in load and in generation from variable energy resources (i.e. wind, solar, run-of-river hydro). A discussion of load following reserves was presented above. Contingency reserves are typically used for short-term and lower magnitude outage protection. Utilities also have measures to cover more severe outages and system blackouts.

Contingency Reserves

Contingency reserves refer to actions that can be taken to maintain system balance during the unplanned loss of a large generator or transmission line. Contingency reserves in the Northwest are set by the Northwest Power Pool (NWPP), a reserve-sharing subarea within the Western Electricity Coordinating Council (WECC), which itself is a subgroup of the North American Electric Reliability Corporation (NERC). The NWPP requires utilities to carry contingency reserves equal to 3 percent of load plus 3 percent of generation <u>or</u> equal to the magnitude of the single largest system component failure, whichever is larger.[6] At least half of these reserves must be supplied by spinning reserves and the rest can be provided by standing reserves.

Spinning reserves are provided by an unloaded or partially-loaded generation source, which is synchronized to the power system and is instantly ready to serve additional load. Standing reserves are provided by generation not connected to the system but capable of serving load within a short period of time (10 minutes). In practice, many utilities lower costs by sharing reserves.

Contingency reserves can also be provided via agreements with customers to cut back a portion of their load under certain conditions. Load that can be cut automatically or in a very short time can be used as a spinning reserve. Load that takes longer to switch off provides standing reserves. Chapter 14 on demand response describes the Council's assessment of the regional potential for deploying such customer agreements to provide peaking capacity reserves.

The Council's hourly resource simulation model (GENESYS) keeps track of any hour in which contingency reserves cannot be maintained. Currently, a failure to maintain contingency reserves is treated as a curtailment. Fortunately, given the large capacity of the hydroelectric system, it is very rare to see a failure to maintain contingency reserves.

Black Start Measures

Black start measures provide sufficient generating capability to restart the power system or an islanded region of a power system in the event of a major blackout. The Council's power plan does not include an assessment of sufficiency for regional (aggregate) black start generation. Typically, individual utilities have their own strategies for providing backup generation (and other actions) to offset system failures. When the situation gets worse and more than one utility is involved, the Northwest Power Pool assesses the situation and generally initiates a conference call among affected balancing authorities.

Nonetheless, it is important for planners to understand the need for black start capability. Brendan Kirby summarizes the characteristics of black start generators in his 2007 report entitled "Ancillary Services: Technical and Commercial Insights,"

> *"Black start generators must be capable of starting themselves quickly without an external electricity source. They must have sufficient real and reactive power capability to be able to energize transmission lines and restart other generators. They must have sufficient ramping and control capability to remain stable as real and reactive loads change. Typically black start generators are at least tens of MW in capacity. They must also have relatively low minimum load capability and a broad operating range. They must be appropriately located in the power system to be useful in restarting other generators and in re-synchronizing the interconnection. They must be both able to control frequency and voltage and*

[6] http://www.nwpp.org/documents/RSGC/NWPP-Reserve-Sharing-Doc-April-17-2015-RSG-Approved-Effective-May-1-2015.pdf

> *also be tolerant of off-nominal frequency and voltage. System frequency and voltage can fluctuate dramatically, especially in the early stages of system restoration. They must also have good communications with the system operations control center to facilitate a coordinated restart. Some regions require an on-site fuel supply."*

The Council assumes that individual utilities and load-serving entities will develop their own black start measures. These measures are not relevant to developing a long-term resource acquisition strategy.

PLANNING RESERVES

The Planning Reserve Margin (PRM) is the estimated amount of new generation capacity needed to meet expected future load over a planning horizon. Usually coupled with probabilistic analyses, PRMs have been an industry standard used for decades as a target for future resource acquisition. The PRM is generally defined as the difference in deliverable generation and weather-normalized load, divided by load. Deliverable resources include existing resources, resources that are expected to be completed and operational and net firm transactions. Based on experience, for bulk power systems that are not energy-constrained, the planning reserve margin is the difference between available capacity and peak load, normalized by peak load, in units of percent. For example, a 20 percent planning reserve margin would imply that planned system capacity should exceed expected load by 20 percent. Building a power supply that meets the PRM requirement is expected to maintain reliable operation while meeting unforeseen increases in future load (e.g. extreme weather) and unexpected outages of existing capacity. Further, from a planning perspective, planning reserve margin trends indicate whether capacity additions are keeping up with load growth.

Planning reserve margins are generally capacity-only based metrics. Therefore, PRMs do not provide an accurate assessment of performance in energy or fuel limited systems (e.g., hydro capacity with limited storage). That is why the Council developed the Adequacy Reserve Margin (ARM) metric, which establishes minimum reserves needed for future capacity and energy needs. In other words, the Council develops an adequacy reserve margin for energy needs and a separate adequacy reserve margin for capacity needs.

The ARM is defined as the difference between total rate-based resource capability and weather-normalized load, divided by the load, for a power supply that just meets the Council's adequacy standard. Thus, in theory, future power supplies that meet the ARM targets should comply with the Council's adequacy standard of a loss of load probability not greater than 5 percent. The ARMs are then used in the Council's Regional Portfolio Model to develop a resource acquisition strategy that complies with the Council's adequacy standard while simultaneously accounting for the energy/fuel limitations of some resources and the associated available capacity to the system. More detail on how the ARMs are used to develop the Council's resource strategy is provided in Chapter 15.