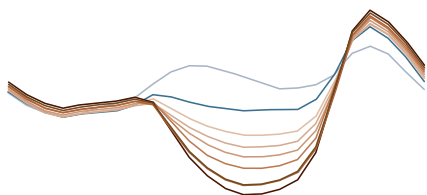


FAST FACTS

What the duck curve tells us about managing a green grid

The electric grid and the requirements to manage it are changing. Renewable resources increasingly satisfy the state's electricity

demand. Existing and emerging technology enables consumer control of electricity consumption. These factors lead to different operating conditions that require flexible resource capabilities to ensure green grid reliability. The ISO created future scenarios of net load curves to illustrate these changing conditions. Net load is the difference between forecasted load and expected electricity production from variable generation resources. In certain times of the year, these curves produce a "belly" appearance in the mid-afternoon that quickly ramps up to produce an "arch" similar to the neck of a duck—hence the industry moniker of "The Duck Chart".

Energy and environmental goals drive change

In California, energy and environmental policy initiatives are driving electric grid changes. Key initiatives include the following:

- 33 percent of retail electricity from renewable power by 2020;
- greenhouse gas emissions reduction goal to 1990 levels by 2020;
- regulations in the next 4-9 years requiring power plants that use coastal water for cooling to either repower, retrofit or retire;
- policies to increase distributed generation; and
- an executive order for 1.5 million zero emission vehicles by 2025.

New operating conditions emerge

The ISO performed detailed analysis for every day of the year from 2012 to 2020 to understand changing grid conditions. The analysis shows how real-time electricity net demand changes as policy initiatives are realized. In particular, several conditions emerge that will require specific resource operational capabilities. The conditions include the following:

- **short, steep ramps** – when the ISO must bring on or shut down generation resources to meet an increasing or decreasing electricity demand quickly, over a short period of time;
- **overgeneration risk** – when more electricity is supplied than is needed to satisfy real-time electricity requirements; and
- **decreased frequency response** – when less resources are operating and available to automatically adjust electricity production to maintain grid reliability.

Green grid reliability requires flexible resource capabilities

To reliably operate in these conditions, the ISO requires flexible resources defined by their operating capabilities. These characteristics include the ability to perform the following functions:

- sustain upward or downward ramp;
- respond for a defined period of time;
- change ramp directions quickly;
- store energy or modify use;
- react quickly and meet expected operating levels;
- start with short notice from a zero or low-electricity operating level;
- start and stop multiple times per day; and
- accurately forecast operating capability.

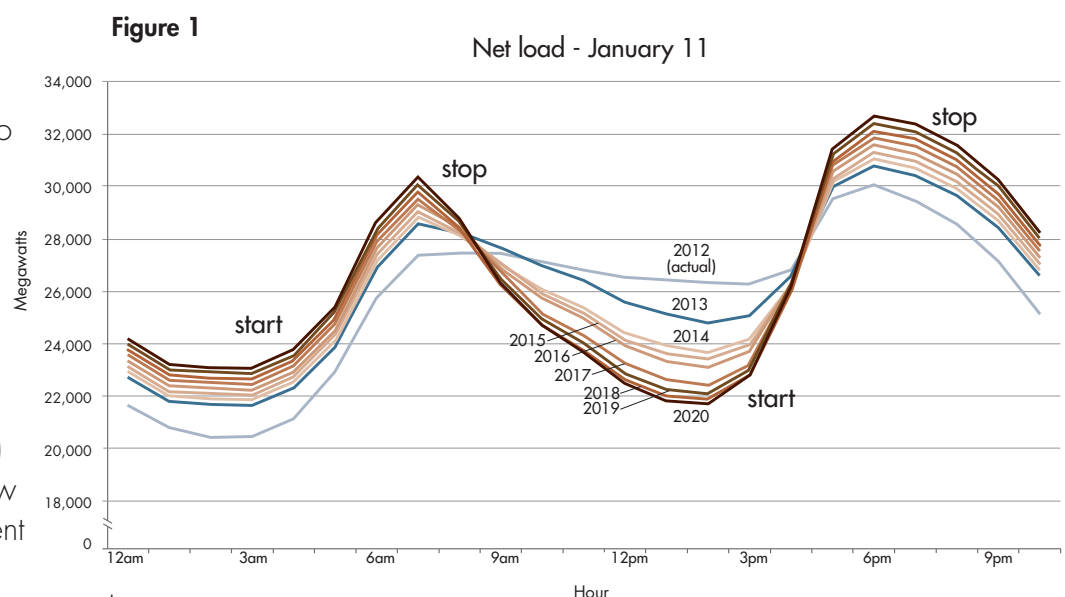
Reliability requires balancing supply and demand

The net load curves represent the variable portion that ISO must meet in real time. To maintain reliability the ISO must continuously match the demand for electricity with supply on a second-by-second basis. Historically, the ISO directed conventional, controllable power plant units to move up or down with the instantaneous or variable demand. With the growing penetration of renewables on the grid, there are higher levels of non-controllable, variable generation resources. Because of that, the ISO must direct controllable resources to match both variable demand and variable supply. The net load curves best illustrate this variability. The net load is calculated by taking the forecasted load and subtracting the forecasted electricity production from variable generation resources, wind and solar. These curves capture the forecast variability. The daily net load curves capture one aspect of forecasted variability. There will also be variability intra-hour and day-to-day that must be managed. The ISO created curves for every day of the year from 2012 to 2020 to illustrate how the net load following need varies with changing grid conditions.

Ramping flexibility

The ISO needs a resource mix that can react quickly to adjust electricity production to meet the sharp changes in electricity net demand.

Figure 1 shows a net load curve for the January 11 study day for years 2012 through 2020. This curve shows the megawatt (MW) amounts the ISO must follow on the y axis over the different hours of the day shown on the x axis. Four distinct ramp periods emerge.



The first ramp of 8,000 MW in the upward direction (duck's tail) occurs in the morning starting around 4:00 a.m. as people get up and go about their daily routine. The second, in the downward direction, occurs after the sun comes up around 7:00 a.m. when on-line conventional generation is replaced by supply from solar generation resources (producing the belly of the duck). As the sun sets starting around 4:00 p.m., and solar generation ends, the ISO must dispatch resources that can meet the third and most significant daily ramp (the arch of the duck's neck). Immediately following this steep 11,000 MW ramp up, as demand on the system decreases into the evening hours, the ISO must reduce or shut down that generation to meet the final downward ramp.

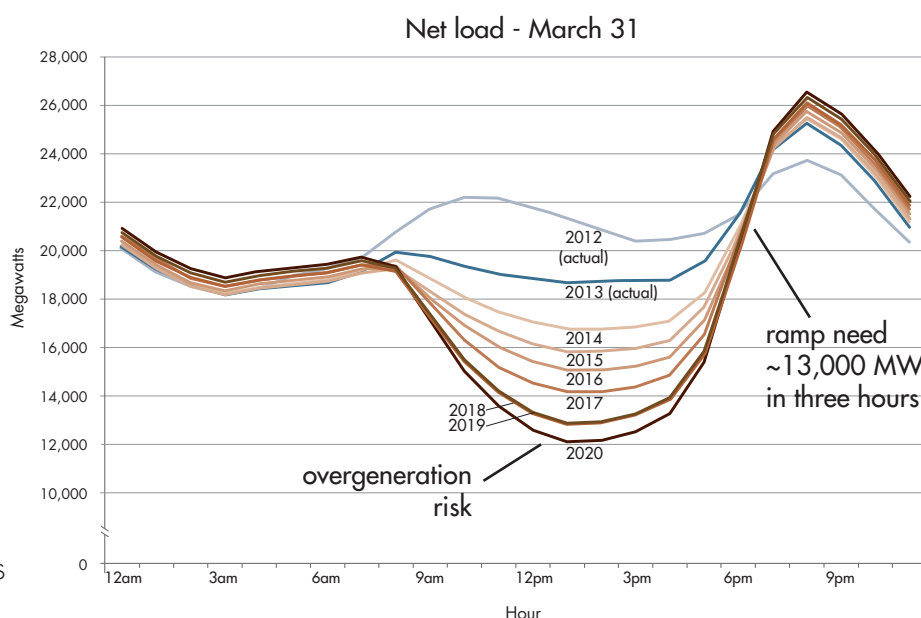
Flexible resources needed

To ensure reliability under changing grid conditions, the ISO needs resources with ramping flexibility and the ability to start and stop multiple times per day. To ensure supply and demand match at all times, controllable resources will need the flexibility to change output levels and start and stop as dictated by real-time grid conditions. Grid ramping conditions will vary through the year. The net load curve or duck chart in **Figure 2** illustrates the steepening ramps expected during the spring. The duck chart shows the system requirement to supply an additional 13,000 MW, all within approximately three hours, to replace the electricity lost by solar power as the sun sets.

Overgeneration mitigation

Overgeneration happens when more electricity is supplied than is needed to satisfy real-time electricity requirements. The ISO experiences overgeneration in two main operating conditions. The first occurs as the ISO prepares to meet the upcoming upward ramps that occur in the morning and in the late afternoon. The existing fleet includes many long-start resources that need time to come on line before they can support upcoming ramps. Therefore, they must produce at some minimum power output levels in times when this electricity is not needed. The second occurs when output from any non-dispatchable/must-take resource further increases supply in times of low electricity need, typically in the nighttime hours. Historically, this condition was most likely to occur in the early morning hours when low demand combines with electricity and generation brought on line to prepare for the morning ramp. The duck curve in **Figure 2** shows that overgeneration is expected to occur during the middle of the day as well.

Figure 2: The duck curve shows steep ramping needs and overgeneration risk



Because the ISO must continuously balance supply and demand, steps must be taken to mitigate over generation risk. These steps include increasing exports, expanding resource capabilities, and requiring renewable generation curtailment. The ability to export power depends on the needs of neighboring entities and balancing agreements. The available resources must evolve to include capabilities to start and stop multiple times per day and start with short notice from a zero or low electricity operating levels. The resource mix would also benefit from resources with energy storage capabilities and demand side response capabilities to help meet real-time system conditions.

Reliable grids have automated frequency response

System frequency measures the extent to which supply and demand are in balance. To ensure reliability, system frequency must be managed in a very tight band around 60 hertz. When an unexpected event occurs that disrupts the supply-demand balance, such as a loss of a generator or transmission line, frequency is impacted. These events do not allow time for manual response and balance is maintained through automated equipment. Conventional generation resources include frequency-sensing equipment, or governors, that automatically adjust electricity output within seconds in response to frequency to correct out-of-balance conditions.

Part of the renewable integration analysis conducted by the ISO uncovered concerns about frequency response capabilities due to the displacement of conventional generators on the system. The 2020 33% studies show that in times of low load and high renewable generation, as much as 60% of the energy production would come from renewable generators that displace conventional generation and frequency response capability. Under these operating conditions, the grid may not be able to prevent frequency decline following the loss of a large conventional generator or transmission asset. This situation arises because renewable generators are not currently required to include automated frequency response capability and are operated at full output (they can not increase power). Without this automated capability, the system becomes increasingly exposed to blackouts when generation or transmission outages occur.

Policy needed for flexible resources

To reliably manage the green grid, the ISO needs flexible resources with the right operational characteristics in the right location. The ISO is actively engaged in policy efforts to build awareness of the new grid needs. Working with the industry and policymakers, the ISO is collaborating on rules and new market mechanisms that support and encourage the development of flexible resources to ensure a reliable future grid.