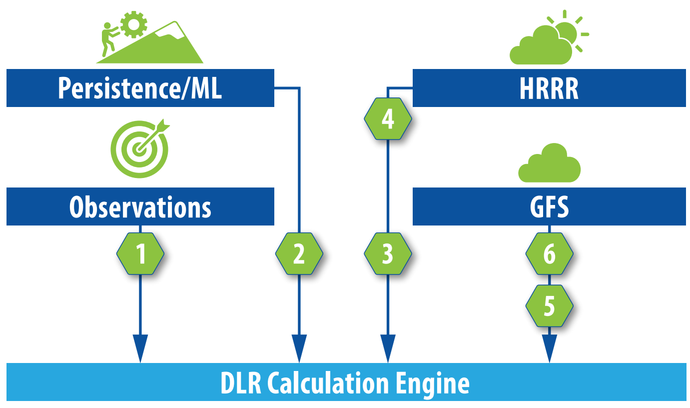
Changes in weather forecasts impacts transmission line capacity at different time horizons.

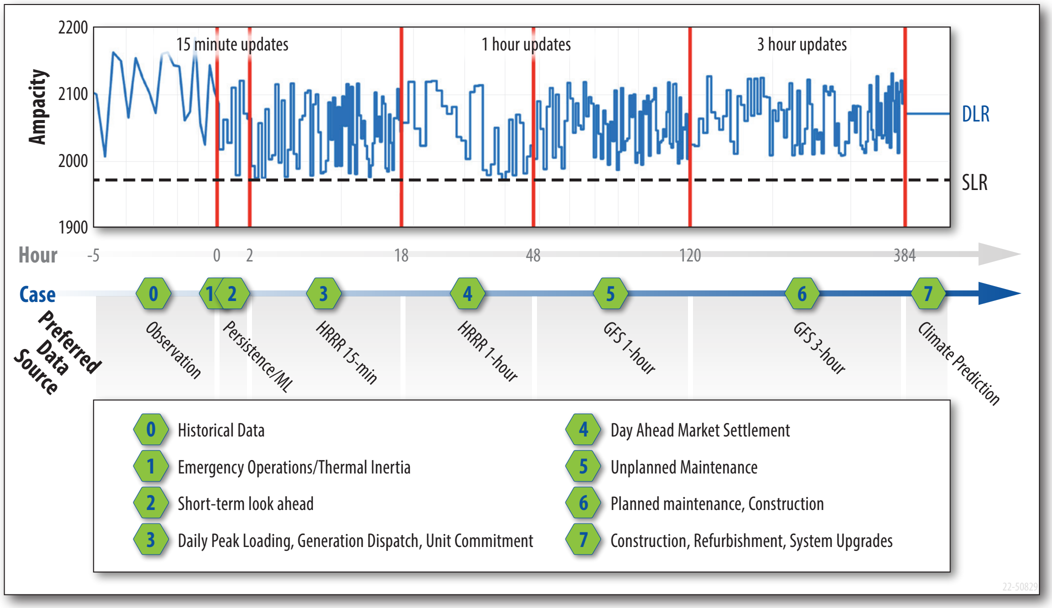
Dynamic Line Rating Forecast Time Frames

As dynamic line ratings (DLR) are used to support different use cases, the preferred data source varies according to the forecast horizon. The below guidance is one possibility to utilize weather forecasting. Note that the time-periods of forecasts and spatial resolution may be subject to change as National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) periodically upgrades its forecast models and data servers. Moreover, advances in analytics may justify combining data sources for more reliable DLR forecasts. The list below gives a time period (t) followed by possible guidance for data in that interval.

0. **t < 0**
   The historical profile of the conductor. Determined by gathering historical weather data from NOAA or other sources.
1. **t = 0**
   The current state of the conductor based on observed weather data, DLR calculations, or direct measurement devices of the conductor itself.
2. **0 < t < 2 hours**
   If no previous data is already available, the short-term timeframe would rely on persistence assumptions for the weather data. If a significant amount of weather data for the region has been gathered, short-term forecasts could be constructed using a machine learning method. The weather forecast models starting from "now" take a



Representation of the framework recommended to collect data sources needed for DLR.



A Timeline of Forecasting Use Cases. The plot compares DLR at different time horizons to the constant static line rating (SLR).

little under 2 hours to both run and post data to the NOAA Operational Model Archive and Distribution System (NOMADS) server (https://nomads.ncep.noaa.gov/), so for the short-term period of up to 2 hours, a previous set of forecast data would have to be used if available.

3. **2 hours < t < 18 hours**
   For the short-term period up to 18 hours ahead, the recommendation is to utilize the High-Resolution Rapid Refresh (HRRR) model with 15-minute resolution in the United States. This model is updated on an hourly basis. This model utilizes 3 km grid spacing. Other regional models could be used for this time period.
4. **18 hours < t < 48 hours**
   For the short-term period from 18 to 48 hours ahead, the recommendation is to utilize the HRRR model with 1-hour resolution in the United States. This model utilizes 3 km grid spacing. The longer timeframe HRRR model is only generated once every 6 hours. Other regional models could be used for this time period.
5. **2 days < t < 5 days**
   For the time period from 2 to 5 days ahead, the recommendation is to use the Global Forecast System (GFS) model with 1-hour resolution. The GFS model is updated once every 6 hours. This model uses 13 km grid spacing. Other global models such as the European model (ECMWF) could also be used for this period.
6. **5 days < t < 16 days**
   For the time period from 5 to 16 days ahead, the recommendation is to use the GFS model with 3-hour resolution. The GFS model is updated once every 6 hours. This model uses 13 km grid spacing. The European model (ECMWF) could also be used for this period.
7. **16 days < t**
   Beyond 16 days, there are no reliable forecast models, but climate prediction models could be utilized. These models cannot be used for direct calculations of DLR, as they only provide predictions over a monthly period based on if seasonal conditions are expected to be below, at, or above average values.

USE CASE DESCRIPTIONS

Power system use cases across the United States vary based on market and region, but potential operational use cases are captured below.

0. **Historical Data**
   Tracking asset health of the line or for future planning purposes.
1. **Emergency Operations/ Thermal Inertia**
   Based on local conditions, this rating can be assumed constant for the next 15 minutes, or emergency ratings can be deployed for 15 minutes. Emergency ratings are often used in system contingency situations.
2. **Short-term look ahead**
   As system operators and automated energy management system

(EMS) algorithms work through daily fluctuations and forecast errors, the short-term look ahead can inform reserve deployments or other system dispatch decisions.

3. **Daily Peak Loading, Generation Dispatch, Unit Commitment**
   Decisions made multiple hours in advance of the dispatch hour can have large impacts on system reliability. These decisions can be informed by DLR.
4. **Day-Ahead Market Settlement**
   In power system markets, there is often a day-ahead mechanism, which matches willing buyers and sellers, subject to network security and other constraints. DLR can inform the system constraints used to validate network security.
5. **Unplanned Maintenance**
   Power equipment sometimes needs unplanned maintenance. That maintenance can either force the generation offline rapidly or the maintenance can wait a few days without further harm to the system equipment. By including DLR in the unplanned maintenance coordination, the system operator can improve the system reliability while operating in a deteriorated state.
6. **Planned Maintenance, Long-term Generation Scheduling**
   The dispatch schedule may be adjusted for generators in need of planned maintenance, or long-term generation may be scheduled based on DLR and variable energy resource forecasts. Long-term generation decisions may include dispatch of long-duration energy storage or units with long warm up times.
7. **Construction, Refurbishment, System Upgrades**
   The utility system is always undergoing improvements as assets age or system requirements shift. Long-term planning for such upgrades can include considerations for climatological impacts. For instance, a predicted cooler than average month could be used for scheduling major outages, but little else can be done with the data.

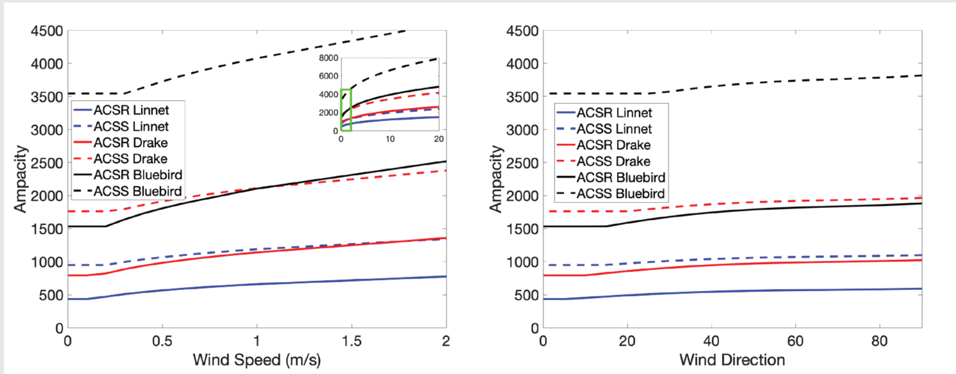
WEATHER FORECAST USE CASES

Electric utilities already use some form of forecasting on a day-to-day basis for dispatching. Each day, the loads at each substation at the extremities of the transmission system are forecasted forward on an hourly basis for the next 24 to 48 hours. The forecasts are achieved using various trending and machine learning techniques looking at historical load readings. The forecasted hourly loads are imported into an economic dispatch tool, a software that is designed to optimize the prices of electricity across the power system of interest based on the cost for each generator. The power system of interest may be an individual utility or a wider energy market.

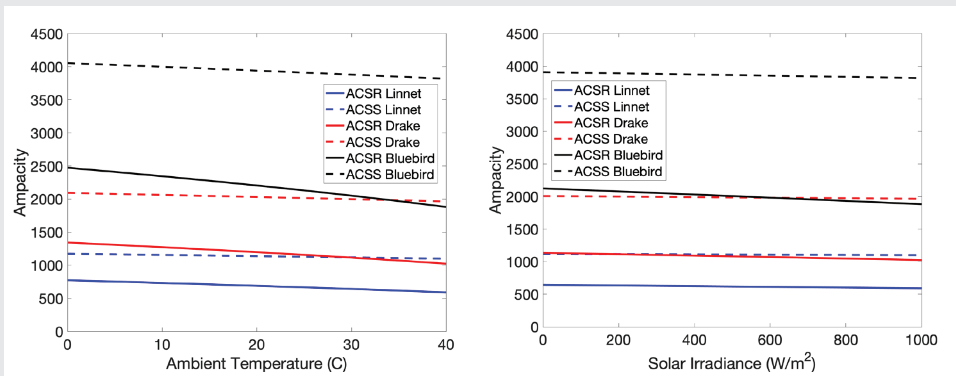
The economic dispatch tool is run for every hour of the load forecast to schedule each generator on the system in such a way as to minimize electricity prices across the power system for the next 24 to 48 hours. There are times when load demands at particular locations in the system and available generation at other locations within the system lead to high usage of particular transmission lines. This can sometimes cause transmission lines to reach their capacity limit and force other lines to be used which may leverage more expensive generation. If the restrictive line had more capacity available (via DLR), then cheaper generation could be used to serve the load. DLR relies heavily on weather conditions and forecasts. Understanding the different time horizons is critical to efficiently using DLR for power system operations.

Other Weather Data: The National Blend of Models (NBM) has been utilized by FERC for demonstration of ambient adjusted ratings (AAR), which covers 1-hour time steps from 0-36 hours, 3-hour time steps from 36-192 hours, and 6-hour time steps from 192-240 hours at 2.5 km resolution. This model is calibrated over a blend of NWS and non-NWS sources for its predictions. It contains variables necessary for DLR, but has not yet been tested for its use at INL. NOAA maintains several sets of archived data on an AWS server (https://registry.opendata.aws/collab/noaa/).

When examining the sensitivity to weather variables, the wind speed by far has the largest impact on the DLR ampacity, and solar irradiance has the smallest impact. The impact for wind direction and temperature is similar over the entire range, but the temperature is likely to have much smaller variations on an hourly basis. Due to this the error between the forecasted wind and observation wind is the most important variable, the error varies widely by region.



The sensitivity to all four variables increases for larger conductor diameters (Linnet → Drake → Bluebird shown in blue/red/black), and for higher temperature conductors (ACSR → ACSS shown in solid/dashed).



While utilities may be hesitant to use forecasts due to uncertainty, it is noted that several other organizations regularly use forecasts for safety-related concerns. The Federal Aviation Administration (FAA) works with NOAA and the NWS to coordinate collection of weather data through airport observations at METeorological Aerodrome Reports (METARs) deployed at airports. The FAA relies of NWS forecasts for 24 hours to provide terminal aerodrome forecasts across 700 airports throughout the United States. The FAA will utilize this information for flight planning and possible airport delays. The conditions they rely on from the forecasts include: ceiling and visibility, precipitation, wind speeds, turbulence and icing. Weather advisories based on changing forecast conditions can also be used to advise en-route aircraft of potentially hazardous weather.

The NWS also works with the state Departments of Transportation (DOTs) to mitigate the impacts of hazardous weather conditions that can negatively impact surface transportation. The NWS collaborates with DOTs for forecast conditions that can impact roadways such as snowfall, rainfall, flooding, timing and uncertainty of those events, as well as non-routine situations such as smoke from wildfires. The DOTs utilize this information for proper planning, deployment of resources, treatment of roadways, and necessary road close operations.

FOR MORE INFORMATION

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