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When intermittent power production serves transient loads

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ABSTRACT

Renewable power generation exhibits notorious intermittence. The power load varies daily and also seasonally. The topic of renewable generation, storage and grid interfacing is complex in that it brings into one setting many diverse interests and technologies. Our long-term goal is to help define ways to profitably increase renewable generation. In this paper, we focus on normal day for a grid operator, PJM, (Pennsylvania, New Jersey and Maryland). The variability of wind and (and assumed) solar outputs require a certain capability for load following or storage. Using dynamic modelling, we estimate the variability of the wind output and we simulate a projected solar penetration of 3% of new capacity. To save for eventual use every unit of energy thus generated, a storage system must have the capability to levelize the supply of renewable power. The capacity requirements for storage and generation of such a system are mapped out in 1 min intervals, and are used to define the capacities and ramp rates for a hypothetical pumped storage plant. Knowledge of weather patterns may be helpful to plan dispatch and storage of renewable energy. The results of a brief excursion into the difficult topic of weather patterns are recorded here too.

1. Introduction: the problem

To be useful, a power source must be controllable. This is so, because the daily electrical power load for any location is constantly changing. Consider for instance Fig. 1, which shows the average electric load for the PJM grid for weekdays and weekend days [1]. The wind power input [2] into the grid is also shown for two consecutive days, on the vertical scale on the ordinate axis on the right side. The load profile varies with the hour of the day. Power grid operators such as PJM purchase generating power on a daily basis for the upcoming day. The bidding process by power generators specifies the hour of the day in which power generating capacity will be available. As demand unfolds the next day, different power assets retained by successful bidding are brought into line at specified times. Unplanned adjustments of capacity, if necessary, tend to be costly. The generation technologies that can respond within minutes to load changes can command premium prices, especially during the summer in locations where air conditioning loads define the peak yearly loads.

The bulk of the load is met with what is called “baseload generation”, which is typically coal or nuclear based. When small load variations are present, “load following” power plants (hydro, steam or gas turbines) are brought into line, sequencing the higher efficiencies first. “Peak hours”, when the load varies rapidly, are met with gas turbines or hydro. Unexpected increases are met with “spinning reserves”. These reserves are ready to come on line within minutes. They can take several forms, such as a fired up coal plant and small steam turbine that is running at low capacity and in steady thermal regime. The turbine and generator can be loaded by increasing excitation and steam flow. Another type, generally regarded as more flexible, is the gas turbine: again, increasing the air, fuel and excitation can be done within seconds if the gas turbine is at temperature and synchronized, and only within minutes from a cold start. The third technology available is hydropower. Some Francis runners can be “motored” to spin in an air cavity, that can be flooded to produce power within seconds of demand. Grid operators meet demand with baseline, intermediate and peak hours’ power generation, as shown in Fig. 2. Small, continuous load variations arising from small mismatches between load and supply require AGC (automatic generation control systems) that regulate the power production of mostly hydro or gas turbine units. The current wind generation in the PJM area is small, and its fluctuations, not different in principle than those of the load, are automatically handled via AGC. When AGC calls on fossil fuel technology, the benefits of renewable energy storage are lost.

The technologies that supply variable power tend to be expensive per unit of capacity. Gas turbines and hydro, as mentioned before, offer the capability of meeting peak loads and AGC. Small

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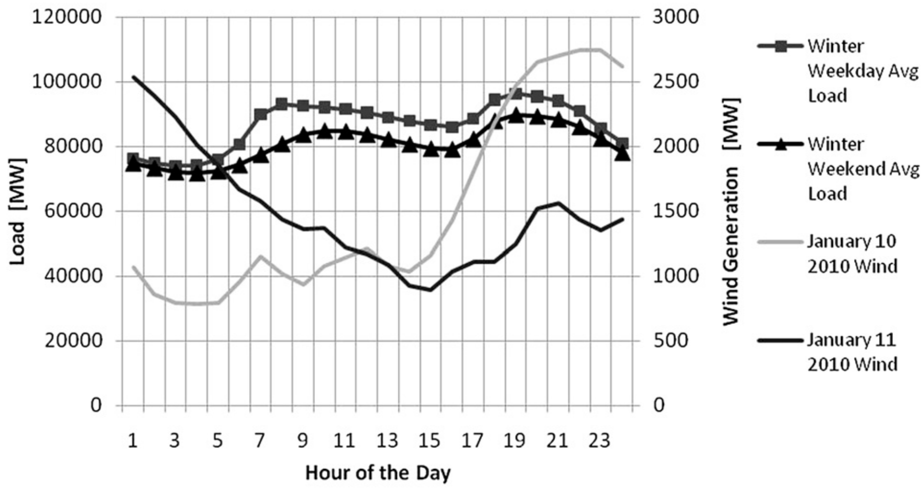

Fig. 1. Load and wind generation profile for the PJM service area, winter.

variations on the load may require continuous adjustment, as well as coordination with large industrial users. Both technologies are well suited to meet short-term changes in the load, which renders them quite unique with regards to the grid.

In contrast, wind and solar power are not that easily regulated, because their supply is largely random, although weather correlations may allow some degree of predictability. Their intermittency is more conditioned by weather, season and time of day than any other technology. The random nature of the problem can be best appraised via Fig. 3, where we display the wind and solar power production for a partly cloudy day. This summer day is selected because the renewable supply decreases as the load increases, although we do not consider the load for the purposes of the present study. Under ideal summer conditions, six 20 MW solar farms would peak at 120 MW of generation.

The renewable supply profiles are uncorrelated or not strongly correlated among themselves as discussed in the last section of this report. The load has variability of its own, as already discussed with reference to Fig. 1. Therein lies the problem: at least in some days, it is impossible to fit the renewable production into any of the categories of Fig. 2. The problem is compounded as we gaze into the future. Many states have enacted targets for renewable energy production meeting 20–30% demand. In the PJM area, comprising a wide geographical area extending from parts of Ohio in the West to Maryland in the East, with an island in Chicago, over 50% of the proposed additional generation capacity in the next 20 yrs could be renewable, Fig. 4.

This is a lofty goal, but we have some doubts about its realization. We seek with our tools to delineate ways to operate pumped hydro storage to maximize utilization of renewable energy. In this paper, we describe different ways whereby the existing (small) PJM renewable capacity could be levelized using PS.

2. Capacity and capacity value

Storage must erase, if only partially, the intermittency of renewables. Because of this intermittence, Independent Grid Operators (IGOs) have adopted rules whereby a capacity value is assigned to renewable and other forms of generation. Each plant has an installed capacity, but this is not the same as its capacity value.

The energy produced during the summer window by the resource (June 1st to August 31st, 4p.m. to 7 p.m.) is a measure of its availability [4]. The energy that could be produced if the resource were available all of the times of the summer window at full capacity is naturally a much larger value. The ratio of the energy produced to the energy that could have been produced is the capacity value. For PJM, wind gets about 13% capacity value, whereas solar, more abundant in the summer, gets about 38% [4]. By comparison, the capacity value of thermal plants ranges from 70 to 90% [5], and that of some nuclear power plants can exceed 90%, although they may be coupled to PS in some locations. Increasing the capacity value of renewable energy would result in its increased

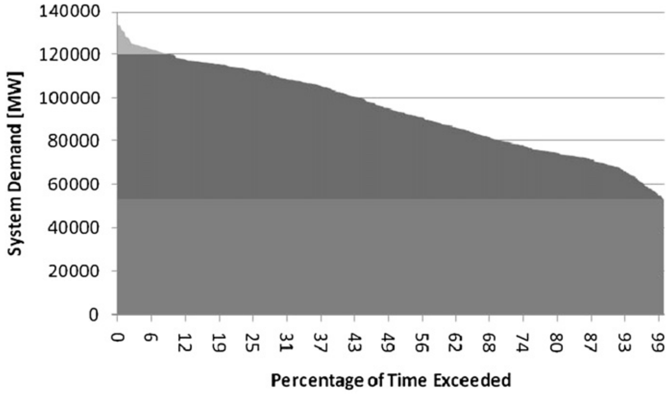

Fig. 2. Schematic of demand and of demand hours.

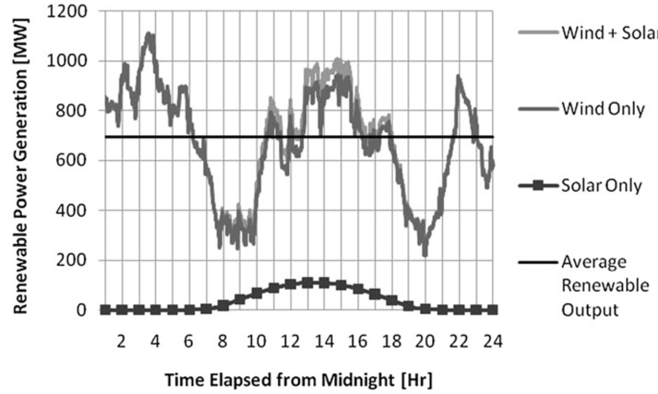

Fig. 3. Wind and simulated solar penetration for the PJM service area, winter.