Understanding the Texas Power Outage from Load and Generation Data

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Introduction

I decided to write this document after I came across an Opinion article written by The Editorial Board of the Wall Street Journal on Feb 16. Even though I was motivated to write the document by the article in the Wall Street Journal (WSJ), most of the document is dedicated to providing information to people who are not as familiar with the energy industry as I am, so that they can understand the events that occurred during the cold spell in February 2021 and led to rolling blackouts.

I start by explaining some general characteristics of the wind generated power in Texas. Then I discuss the behavior of the load and generation in ERCOT along with its relationship to the dropping temperatures through the cold spell that started around Feb 10 and left millions of Texans without power and water. Finally, I comment on the information and opinions provided in the following excerpt from the Wall Street Journal (WSJ) article.

"The problem is Texas's overreliance on wind power that has left the grid more vulnerable to bad weather. Half of wind turbines froze last week, causing wind's share of electricity to plunge to 8% from 42%. Power prices in the wholesale market spiked, and grid regulators on Friday warned of rolling blackouts. Natural gas and coal generators ramped up to cover the supply gap but couldn't meet the surging demand for electricity—which half of households rely on for heating—even as many families powered up their gas furnaces. Then some gas wells and pipelines froze.

In short, there wasn't sufficient baseload power from coal and nuclear to support the grid. Baseload power is needed to stabilize grid frequency amid changes in demand and supply. When there's not enough baseload power, the grid gets unbalanced and power sources can fail. The more the grid relies on intermittent renewables like wind and solar, the more baseload power is needed to back them up.
TO READ THE FULL STORY"

The above excerpt from the article seems to convey a message that the power problems in Texas in February can be traced back quite simply to two sources - 1) wind generation and 2) not enough baseload generation. I examine the validity of this view and present my analysis as part of the comments at the end of the article.

I have attempted to understand what happened during the worst few days of the cold spell by looking at the public information available on the ERCOT website and that provided by NOAA. The opinions presented in this document are entirely mine. I have not talked to any ERCOT or any electricity company employees to acquire the information presented in this document.

The Crisis

The temperatures in Texas started dropping precipitously during the second week of February 2021 and continued dropping until they plummeted to historically low levels on the night of Feb 15 and morning of Feb 16. The ERCOT system load rose to 70 GW on the evening of Feb 14, an unprecedented level for the winter. The temperatures were still falling and load was trending up, but ERCOT could not bring additional generation online. To avert a disaster involving a collapse of the grid, ERCOT started shedding load (rolling blackouts). The weather kept getting colder hitting the lowest temperatures a day after the load shedding started. The effect on Texas was devastating. The reason of the shortfall in accessible generation was malfunctioning of generators and fuel supply systems due to cold weather.

Units of Load, Power and Energy measurement

I will start by talking about the units used to measure power and energy. The basic unit used to measure power consumed by an electrical load or produced by a generator is "watt", which is 1/746 of a horsepower. The power consumed by a load is usually referred to simply as "load". The load and generation commonly encountered are thousands of times a watt. So the commonly used units are KW (thousand watts), MW (million watts), and GW (billion watts). The unit for measuring energy, which is also referred to as "usage" and "electricity", used over a specified time interval, or energy generated over a specified time interval, is kilowatt-hour (KWH), megawatt-hour (MWH) , gigawatt-hour (GWH) or terawatt hours (TWH). KWH is the energy consumed/ generated by a load/generator with power of 1KW over a period of 1 hour. Similarly MWH, GWH and TWH are energy consumed/generated by a power of 1 MW, 1 GW, 1 TW (trillion watts) over one hour. A 1MW generator, which is a generator with a power output of 1MW, running for 10 hours, produces 10MWH of energy. A 5MW generator running for 2 hours also produces 10MWH of energy.

The Grid

Transmission System - Electrical wires in the ERCOT region that transmit electricity over large distances, often hundreds of miles. The transmission uses very high voltage (69 KV to 765 KV) because the losses due to heat in transmission are smaller at higher voltage. Doubling the voltage reduces losses to quarter of the original value.

Distribution System - Electrical wires and step-down transformers that take electricity from the transmission lines to the consumer at a final voltage of 220V or 110V.

Grid - The whole interconnected system consisting of transmission and distribution systems, electrical load and generators. Because the grid is interconnected, something happening in one part of the grid affects the whole grid. The system is very complex and it is not easy to predict what a change at one point in the grid, for example, addition of a generator or load, will do to the system. Complex computer algorithms are used to predict the effects of a change. ERCOT is perhaps simpler than other regions, because it is isolated from the rest of the national grid.

To appreciate the responsibility of the grid operator (ERCOT) when the load is getting close to the total generation capacity, one has to consider what happens when the grid operator loses control of the grid. It is easier to predict the effects of small isolated changes in a complex system when it is stable. If one can lower the grid requirement in a controlled manner so that the system is stable at all times, one maintains predictability and control of the grid. The nightmare scenario for the grid operator would be some unforeseen overloading of a transmission line causing it to trip. That causes the current in the remaining transmission lines to change, some of which might overload and trip. There would be a cascading effect until a large part of the grid or the whole grid comes down like it happened in the Eastern Interconnect in 2003. Once the cascade starts, the collapse is instantaneous for all practical purposes. Then the process of restarting is painful. Most power plants need external power to start. So one has to start with the plants that have a “black start capability”, which is the capability to start without external power, and then continue with the process of restoring the grid.

When the load rises close to the unsafe limit, the operator starts turning off chunks of load, like the load from a section of a city. One cannot prevent the consumers from increasing their power consumption as it gets colder or hotter. The operator has to forecast the load requirements of the various sections of the city and decide which sections should be cut off at various times during the period of power shortage.

Independent System Operator (ISO) -The organization responsible for making sure the grid works reliably. It sets rules and standards for entities using, owning, maintaining or servicing various parts of the grid. ERCOT is the ISO that is responsible for the Texas grid.

ERCOT Wind Generation Characteristics

Wind energy constitutes a significant portion of the generation portfolio in ERCOT, and is growing every year. The nameplate capacity of wind generation in ERCOT is about 25,000 MW. Nameplate capacity of a wind generator is the maximum power it can generate which happens when the wind speed is above a certain threshold. Usually the wind speed is lower than this threshold. In 2020, wind generation supplied 8.5 million MWH, which is approximately a quarter of the total energy usage of ERCOT. Power generated by wind can vary over a wide range from one hour to the next and from day to day for the same hour of day. Figure 1 shows the range of generated power for each of the 15-minute intervals of a day over the 31 days of January 2021.

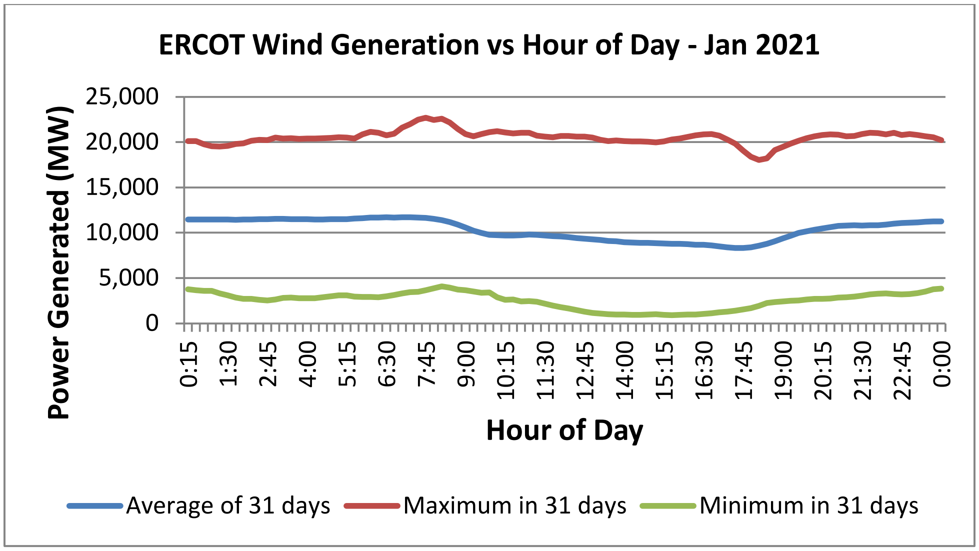

Figure 1. Variation of wind generated power from day to day.

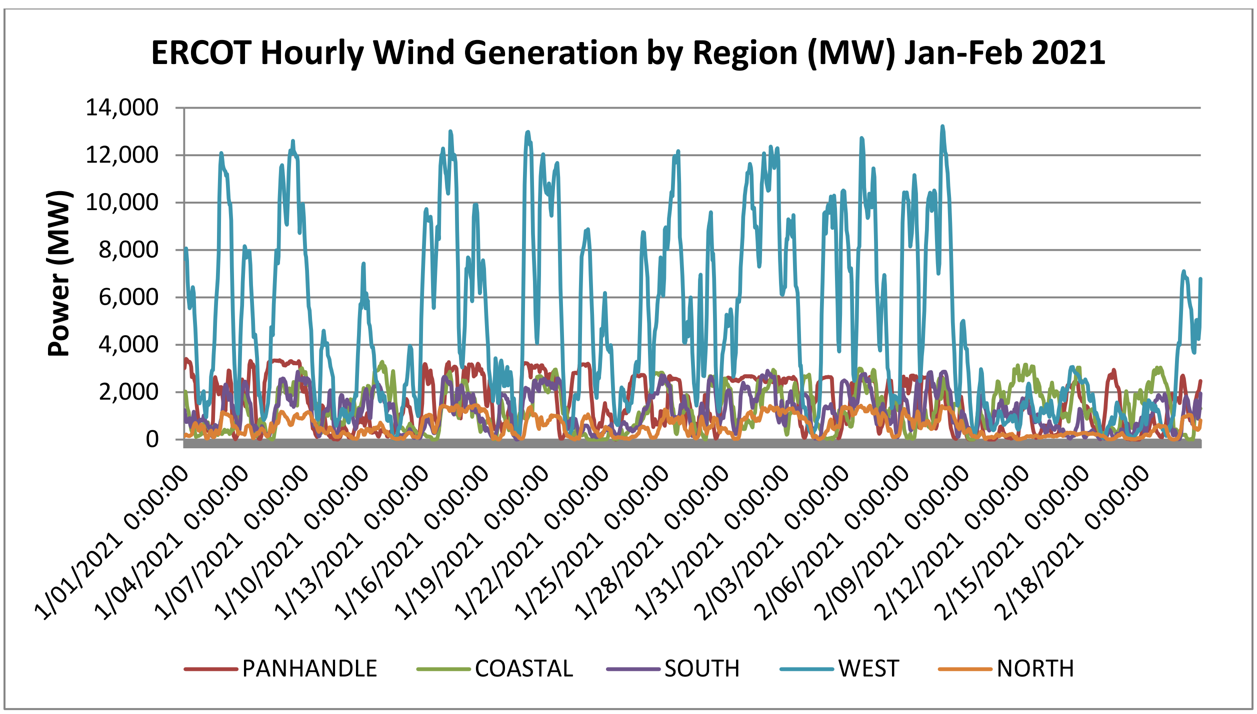

Figure 2. Wind power generated in the various regions of Texas.

Most of the wind power in Texas is generated in West Texas. Hourly variation of the wind generated power in the various regions of Texas is shown in figure 2. As we see from the hourly variation, the power one can bank on being there in any given hour in the future is very small compared to the nameplate capacity and the average power expected in that hour. When planning for the generation required for reliability, the ISO takes this into consideration. It follows that if one loses half the power expected from wind, it should not cripple the system because the ISO should have enough power from dispatchable sources to fill in the shortfall.

Generation Mix in ERCOT

The ERCOT hourly system load during 2020 varied between 27 GW and 74 GW. The minimum hourly load during a calendar month in 2020 was close to 30 GW during most months and a little higher during the summer months (see figure 3). In the absence of renewable generation, the least expensive solution to satisfy the load would involve producing 27 GW from generators that can run continuously with a constant output of 27 GW without stopping or starting. These generators are not required to have the ability to ramp up or down quickly. They are referred to as baseload generators. Traditionally nuclear plants and coal plants have served as baseload generators because of low fuel costs. They take a long time to ramp up or down to the desired output. A coal plant might take half a day while a nuclear plant might take more than a day. The reason to use them is that the operating costs per MWH are low. However, since the production of shale gas ramped up 10 years ago, natural gas prices have been low and the highly efficient combined cycle natural gas plants have seen increased use as baseload plants. Compared to a coal plant they produce very little pollution and half the carbon dioxide production compared to a coal plant for the same power output. They have the advantage of a much shorter ramp-up or ramp-down time over coal and nuclear plants.

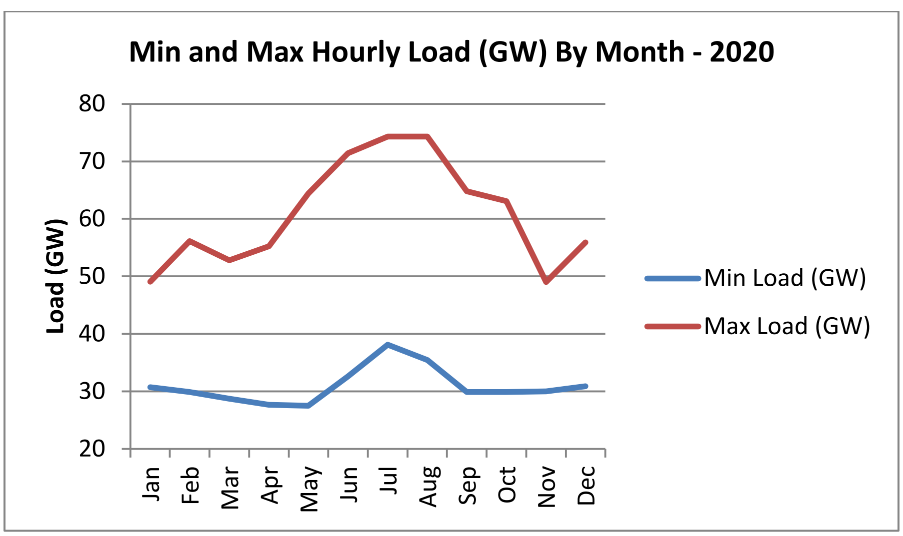

Figure 3. ERCOT Hourly load range by month in 2020

Throwing renewable energy in the mix means that the power required to be produced by the dispatchable generation, like the coal and gas generation, needs to vary not only because the load changes but also because the renewable production changes with the wind speed or sunlight. Therefore, a smaller part of the generation is used as baseload generation. ERCOT has approximately 5GW of nuclear generation capacity, and about two and a half times as much of coal generation capacity. The coal capacity is more suitable for baseload operation than for use requiring varying output. The nuclear plants can be used only as baseload and is used year round. In the summer another 10GW of coal capacity can be used for baseload operation. The rest of the fossil fuel generation requires varying degrees of ramping and starting and stopping. Natural gas plants are more suitable for that operation.

Reliability of the Grid

Since the wind generation has been named frequently in the past week as the culprit for the power fiasco, let us address the question "does the wind generation compromise the reliability of the grid". I would say the answer is no. Variability of the generation does not translate to unreliability. Reliability of the system is affected when components of the grid do not perform as expected. Variability of wind generation due to wind speed is expected and should not affect reliability. On the other hand, a variation due to unexpected equipment malfunction would compromise reliability. How seriously it affects the ability of the operator to acquire the required amount of generation, depends upon how large the effect is compared to the uncertainty due to the usual variability from wind speed. Noting that the wind generation forecasts even one hour ahead can have a 15%-20% uncertainty (standard deviation), a 50% reduction in the output is significant but probable enough that the operator would be prepared for it.

In contrast to the wind generation, we expect to be able to control the output of the nuclear, coal and natural gas generation. If we assume we have enough of it to supply the load, and then a part of it underperforms to an extent that we did not allow for, the ISO might have to resort to load shedding. During the cold spell in February both, the wind generation and the "controllable" generation, underperformed to an extent that was unforeseen. The malfunction of the generators as well the fuel supply system contributed to the underperformance. The reduction in output due to malfunction of the wind turbines was not as significant as the reduction in the output of the other generation. This is because we have observed the reduced levels in the past due to low wind speed and we allow for the possibility that the wind generation will go to those low levels again in the future. We conclude this section by stating that equipment malfunction in the generation system and fuel supply system led to the load shedding in Texas in February.

Timeline of events

I will now attempt to recreate the timeline of the events during the cold spell from the generation and load data that ERCOT provided on its website. The graphs in figure 4 show the hourly variation of load, generation and air temperatures during February 2021. The horizontal axis shows the time starting Feb 1 morning. The scale for the temperatures is on the right side of the graph and that for the generation and load is on the left side. The thick green and turquoise lines show the temperature in Abilene and Houston respectively. Most of the wind generators are west of Abilene, some of them close and most of the others up to two hundred miles southwest. Most of the energy consumption is near Houston and Dallas. The thin black line shows the actual ERCOT system load. The thin red line shows the load value that was forecasted, a day earlier, for the hour shown on the horizontal axis. The purple line near the bottom shows the wind generated power.

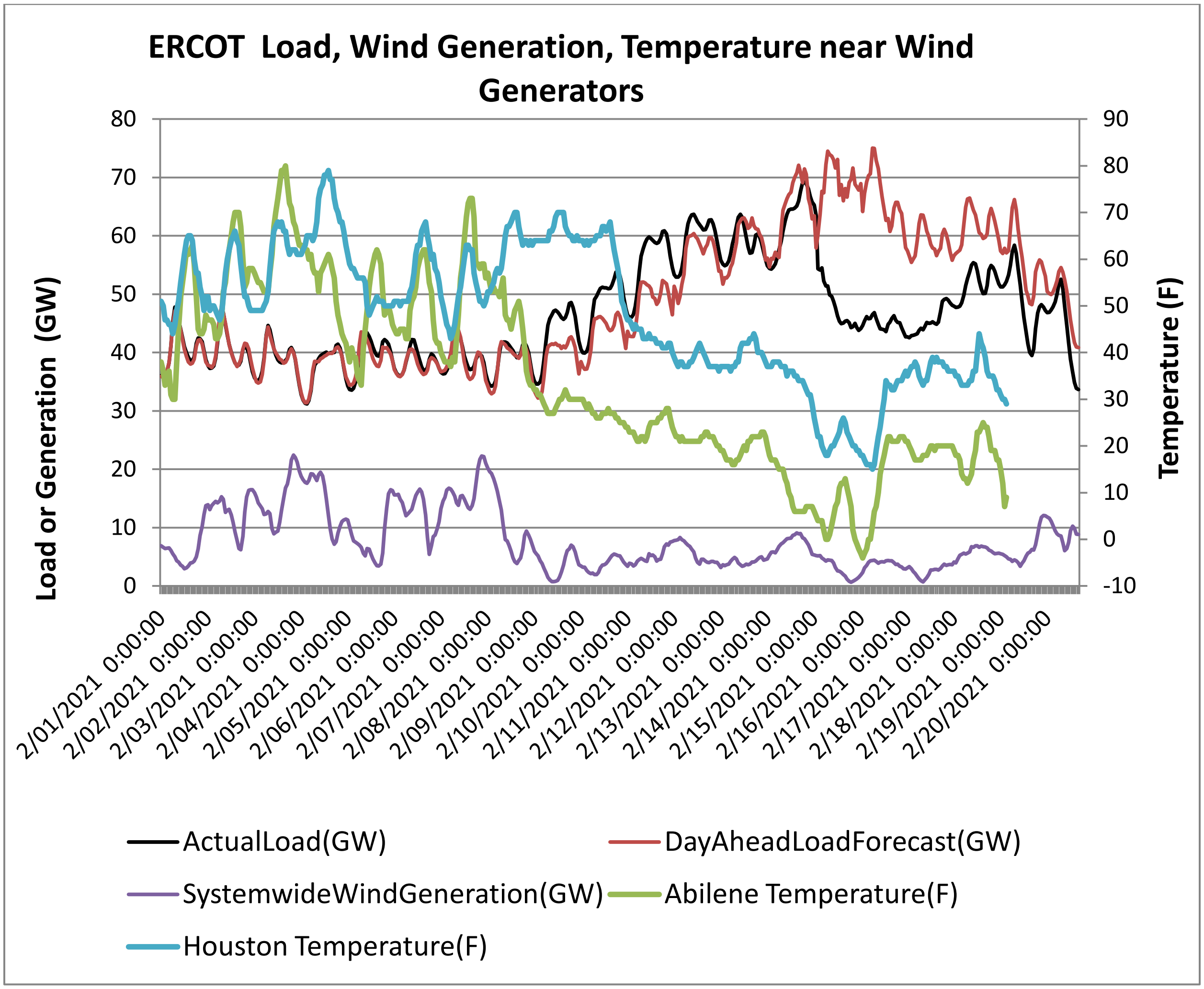

Figure 4. Evolution of load, wind generation and air temperatures in Feb 2021

We see reasonably warm temperatures in both Houston and Abilene until the end of Feb 8. Then the temperature in Abilene starts dropping and quickly falls below freezing. The wind generation output (purple line) also drops around that time. The system load (black line) starts rising and goes above the day-ahead load forecast (red line). It is not clear why the load forecast underestimated the load. The load forecast being off might have contributed to the problems of inadequate generation. The load forecast catches up with the actual load on Feb 13 morning after being low for a few days. Then on the night of Feb 14 Houston temperatures plummet below freezing. The system load is still rising at that time and is forecasted to continue rising to about 75 GW. That is when the load shedding starts as can be seen from the black line (actual load) falling way below forecast. From the separation of the black and the red curve it seems we were 30 GW short on generation at the coldest time. If additional generation was not available, but the power plants that were operating, kept running, one would expect that the load would not have to be cut to levels much below the pre load-shedding levels. The actual load of 45 GW when the load shedding was underway indicates that some of the plants that were running might have been turned off, perhaps because of problems with the gas supply.

Comments on Wall Street Journal Article

1) Look at the following sentence in the WSJ article -*"Half of wind turbines froze last week, causing wind's share of electricity to plunge to 8% from 42%."*

It looks like the wind production dropped from an average of 10 GW to 5 GW. So it is plausible that half of the wind turbines froze. But the average wind production before the cold spell was approximately 10 GW and the load was 40 GW. Since Texas was not importing or exporting much, I would think the generation was equal to load, which is 40 GW. So the wind share of the electricity was 25% and not 42%. The full sentence is hard to make sense of. Half of the wind turbines froze causing the share of electricity drop to less than one fifth. Do the authors mean that each of the turbines that froze generated 4.5 times the power on average than each of the ones that did not freeze? If one looks at the graphs in figure 4, one notices that the wind output did drop to half when it got cold and the share of the wind-generated power dropped to close to 8%. The share dropped to a value close to 8%, because the load increased to almost 70GW from 40GW and that load increase was not caused by half of the wind turbines freezing. To conclude, a) wind's share of electricity did not plunge to 8% from 42% , but dropped to 8% from 25% and b) of that drop the drop from 25% to 16% was due to wind turbines freezing.

The sentence in the WSJ article can be corrected by changing it from

"Half of wind turbines froze last week, causing wind's share of electricity to plunge to 8% from 42%."

To the following - Half of wind turbines froze last week. The load almost doubled from causes unrelated to the freezing of the turbines. The combined effect of the freezing of the turbines and the increase in load was that the wind's share of electricity plunged to 8% from 25%.

2) WSJ writes: *"The problem is Texas's overreliance on wind power that has left the grid more vulnerable to bad weather. Half of wind turbines froze last week, causing wind's share of electricity to plunge to 8% from 42%. Power prices in the wholesale market spiked and grid regulators on Friday warned of rolling blackouts."*

This section conveys the message that failure of the turbines was immediately followed by and caused the prices to spike. It does mention the increase in load later in the paragraph, but does not connect it to price spikes. Even after reading the whole paragraph, we see that the message from WSJ is that the freezing of the wind turbines caused the price spikes.

I have the following issue with this message. The wind generation had already dropped before early morning on Feb 9. The prices did not start spiking noticeably until late morning on Feb 11 (see figure 5). The load had been increasing and had reached 50 GW by this time from the earlier stable level of about 40 GW. The price spikes grew taller as the load continued to increase. The load reached a level of approximately 70GW before the load-shedding started. The prices rose to the maximum allowed value of $9000/MWH. It seems like the price increase was driven more by the load rather than the wind generation. It is not surprising because the reduction in wind generation was 5 GW, and the load increase before the rolling blackouts started was 30 GW. We conclude that there is no basis for ascribing the price spikes to the 5 GW loss of wind generation – price spikes that occurred 2 to 4 days after the loss of wind generation, days during which the load had increased by multiples of 5GW.

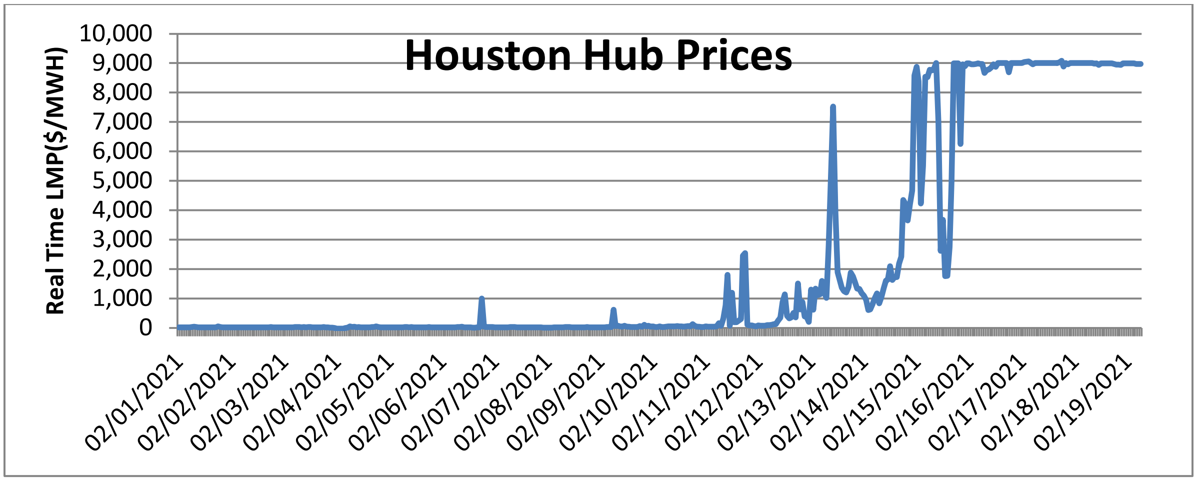

Figure 5. Real-time locational marginal prices at the Houston hub in Feb 2021

3) Now let us address the last part of the paragraph.

"In short, there wasn't sufficient baseload power from coal and nuclear to support the grid. Baseload power is needed to stabilize grid frequency amid changes in demand and supply. When there's not enough baseload power, the grid gets unbalanced and power sources can fail. The more the grid relies on intermittent renewables like wind and solar, the more baseload power is needed to back them up."

"In short" makes it sound like it is clear from, or is summarizing, information given in the last paragraph or earlier in this paragraph. I do not see anything that warrants the conclusion, or summarizes to the statement "*there wasn't sufficient baseload power from coal and nuclear to support the grid".* So, I will proceed to evaluate this section about baseload power as standalone piece of information.

Power from dispatchable (controllable) resources like nuclear, coal and natural gas is needed for the grid to function reliably. Baseload plants run flat out and do not have the ability to ramp up and down quickly. While the non-baseload generation can substitute for a baseload plant, a traditional baseload plant like a nuclear plant cannot do the job of the plant that has the capability of ramping up and down quickly. There is no argument to support the assertion that baseload power is needed rather than just dispatchable power. The only part of the sentence from WSJ, *"In short, there wasn't sufficient baseload power from coal and nuclear to support the grid",* which has any basis is "*There wasn't sufficient power".*

Again the "Baseload power" should be replaced with *"Dispatchable power" in the sentence "*Baseload Power *is needed to stabilize grid frequency amid changes in demand and supply."*

4) Now we address the statement *"The more the grid relies on intermittent renewables like wind and solar, the more baseload power is needed to back them up."* I assume "baseload power" means "baseload generation capacity". In fact, as more renewable generation capacity is added, the amount of dispatchable capacity needed does not change much. However, the component of baseload capacity in

the total generating capacity gets smaller because the dispatchable generation output is required to vary more. This is contrary to the statement in the WSJ article.

5) WSJ article states *"When there's not enough baseload power, the grid gets unbalanced and power sources can fail."*

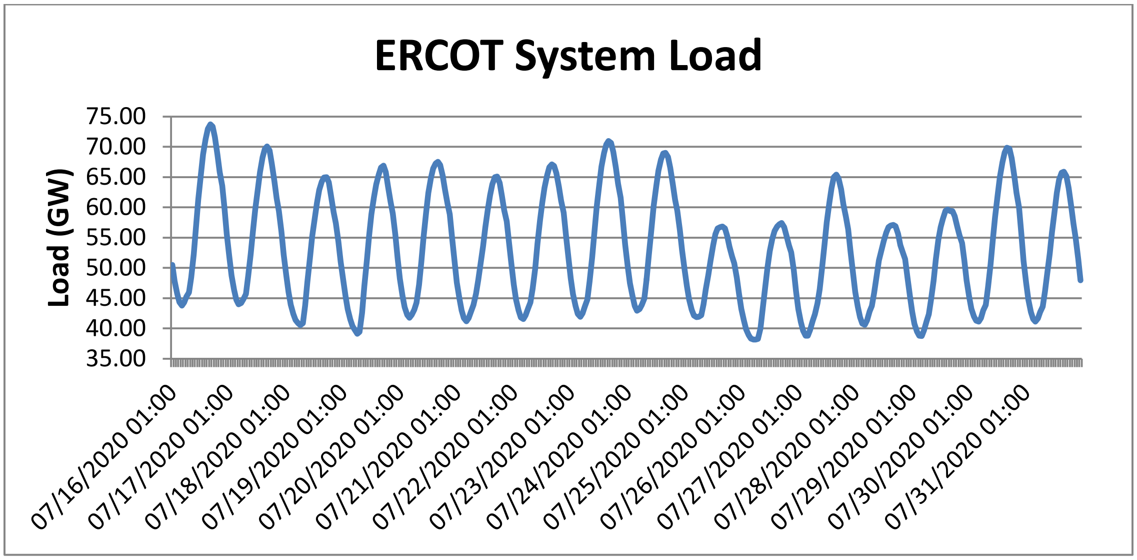

Figure 6. Hourly ERCOT system load in July 2020

If there is insufficient dispatchable power, the grid will fail (I don't see why the power sources will fail). However, there is no requirement for any minimum portion of the dispatchable power to be baseload, unless we are uncomfortable with the variation of the dispatchable power that is supplied. If we are, we have a big problem. Figure 6 shows the ERCOT load over a 15-day period in the summer of 2020. We see that, even if there were no renewable generation, we would have to deal with a generation requirement that can vary by a factor of two within a 10-hour period. It so happens that we do have ramping generation and know how to deal with it. Even getting rid of all of the baseload generation will not cause the grid to be unreliable.

Nailing down what caused the outage

It is important to conduct an examination in order to understand how a crisis came about so that it can be prevented from recurring if those of the circumstances associated with the crisis that are beyond our control, or we do not want to control, are encountered again in the future. In the recent outage, the factor that we cannot control is the weather. We can control the electrical load, but that might require changes we do not want to make. Assuming we do not want to change our energy consumption, the part that we can control, and which was one of the factors in the outage, is the generation and transmission. There are an infinite number of solutions involving transmission and generation which would satisfy our load requirements, each with its own set of pros and cons. A requirement of any acceptable solution is that the chances of the kind of crisis that we saw in February recurring are close to zero. Once a solution is accepted, we have to make sure the assumptions that we made about the factors that we control as well as about the range of variation of the factors we do not control, remain valid after the implementation of the solution. If we have wind generation, the generated power in any 15 minute interval falls more in the category of factors that we cannot control, like the weather. If dispatchable generation is part of the solution, we usually assume that it will be available, with near certainty, when needed with close to complete certainty. Any surprise related to the availability of the generation can lead to a crisis, and indeed, if the underperformance (underperformance beyond the stated allowance) did coincide with the occurrence of crisis, it can be reasonably labeled as "the cause" or "a cause" of the crisis, depending on what else failed to a comparable or larger extent.

Now, I would like the reader to consider the following statements, which are supported by the data on load and generation

a) Had the wind generation malfunctioned to the extent it did, and the dispatchable generation performed as expected, we would not have had the outage.
b) If the dispatchable generation (including the fuel supply system) malfunctioned to the extent it did, and wind generation did not malfunction, we would still have had the outage.

In the light of the discussion in the last paragraph, it would be reasonable to conclude that the cause of the outage was unexpected underperformance of the dispatachable generation in very cold weather. Nuclear, coal and gas generation are all classified as dispatchable.

What to do in the future

Having concluded that the outage occurred because equipment did not perform when the weather was very cold, what should be done differently to avert an outage in the future? It depends on why it underperformed. I consider the following possibilities.

1) The malfunction of the generating equipment occurred because the planners were unaware that the equipment fails at low temperatures. In this case we should get a better understanding of the equipment before deciding it is ready for use.

The planners were aware that the generation would fail at low temperatures but they decided that the probability of such low temperatures was so low that we did not have to worry about what happens at those temperatures. I looked at historical temperatures at the two biggest load centers, Houston and Dallas. Most of the load and dispatchable generation is located close to these. Houston has seen low Feb 2021-like temperatures several times in the past 50 years. Dallas has experienced sub-zero temperatures like this February only three times in the past 100 years. Although cold temperatures like these are unlikely in any give year, even in case of

Dallas the probability of the extreme low temperatures in any given year is at the level of 3%, and higher for Houston. That means if we treat these extreme events as highly improbable, ignore them, and decide not to winterize our equipment, then in a period of 23 years, we have a 50% probability of having an outage crisis like the last one. Having seen the damage from the last crisis, it is clear that the strategy which involves accepting a 3% chance of the crisis happening in any given year, and depends on not getting unlucky year after year for decades, is not an acceptable strategy. A simple step towards avoiding future crisis is to make sure that the equipment works reliably at the lowest and the highest temperatures seen since the temperatures being recorded, which is a little more than a hundred years for most cities.