

Big, Fast and Flexible: Grid Operations for Efficient Variable Renewable Integration

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Webinar Panelists

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Stephanie Bechler Hello everyone, I'm Stephanie Bechler with the National Renewable Energy Laboratory, and welcome to today's webinar, which is hosted by the Clean Energy Solutions Center in partnership with the U.S. Agency for International Development and NREL. Today's webinar is focused on grid operations for efficient variable renewable integration.

One important note of mention before we begin the presentation is that the Clean Energy Solutions Center does not endorse or recommend specific products or services. Information provided in this webinar is featured in the Solutions Center resource library as one of many best practices resources reviewed and selected by technical experts.

Before we begin, I'll go over some of the webinar's features. For audio, you have two options. You may either listen through your computer or over the telephone. If you choose to listen to the computer, please hit the mic and speakers option in the audio pane. Doing so will eliminate the possibility of feedback and echo. If you choose to dial in by phone, please select the telephone option in the box on the right hand side. It will display the telephone number and audio pin you should use to dial in.

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for audio recording they will be posted to the Solutions Center training page within a few weeks, and also added to the [Solutions Center YouTube channel](#) where you can find other informative webinars, as well as video interviews with thought leaders on clean energy policy topics.

Today's webinar agenda is centered around the presentation from our guest panelist, Michael Milligan. Michael has been kind enough to join us to discuss three different pathways, along with implementation considerations and, give examples for each for enhancing the size and speed of grid operations for efficient variable renewable integration.

Before Michael's presentation, I will provide a short overview of the Clean Energy Solutions Center Initiative. And then, following the presentation we will have a question and answer session moderated by Jennifer Leisch of USAID where Michael will address questions submitted by the audience. Then we'll conclude with closing remarks and a brief survey.

This guide provides a bit of background in terms of the how the Solutions Center came to be. The Solutions Center is one of 13 initiatives of the Clean Energy Ministerial that was launched in April of 2011. It is primarily led by Australia, the United States, Sweden, and other CEM partners. Outcomes of this initiative includes support of developing countries and emerging economies through enhancement of resources on policies relating to energy access, no cost expert policy assistance, and peer-to-peer learning and training tools such as the webinar you are attending today.

The Solutions Center has four primary goals. First, it serves as a clearinghouse of all clean energy policy resources. It also serves to share best practices, data, and analysis tools specific to clean energy policies and programs. The Solutions Center delivers dynamic services that enable expert assistance, learning, and peer-to-peer sharing of experiences. And finally, the Center fosters dialog on emerging policy issues and innovation around the globe.

Our primary audience is energy policymakers and analysts from government, technical organizations in all countries, but we also start to engage with private sector, NGOs, and civil society.

A marquee feature of The Solutions Center is the no-cost expert policy assistance program known as Ask an Expert. The Ask an Expert program has established a broad team of over 30 experts from around the globe who are available to provide remote policy advice and analysis to all countries at no cost. For example, in the area of grid integration and off grid solutions, we are very pleased to have Hugo Lucas of Factor CO2 serving as one of our experts.

If you have a need for policy assistance in grid integration or off grid solutions, or any other clean energy sector, we encourage you to use this valuable service. Again, the assistance is provided free of charge. If you have a question for our experts, please submit it through our simple online form at

cleanenergysolutions.org/expert. And we also invite you to spread the word about the service to those in your networks and organization.

Now I'd like to provide a brief introduction for today's panelist. Michael Milligan came to the National Renewable Energy Laboratory's National Wind Technology Center in 1992, and he is now with the Transmission and Grid Integration Group at NREL. His research focuses on large-scale integration of wind and solar energy on the bulk power system, on which he has authored or coauthored more than 200 journal articles, conference papers, technical reports and book chapters.

Moderating our question and answer today is Jennifer Leisch. Jennifer is a Climate Change Mitigation Specialist in the USAID Office of Global Climate Change, where she supports the U.S. Enhancing Capacity for Low Emission Development Strategies program.

And with those introductions, I would like to welcome Michael to the webinar.

Michael Milligan

Great. Thank you very much, Stephanie. And thank you all for joining us on this webinar. We have several things that we'd like to talk about, and so I'll kind of run through a couple of overview slides here before we get started.

The main focus of this webinar is to take a look at two different aspects of power system operation that can help with the efficient integration of renewable energy. The VRE, variable renewable energy, we typically are talking about wind and solar energy, both sources that clearly are driven by the weather. And we want to take a look at how the speed of operations, in particular, the economic dispatch function, and the size of the electrical balancing region can help with the efficient integration of variable renewable energy.

We recognize that around the world, all power systems have many things in common and yet, they also have many differences. So we want to take a look at how would it be possible to achieve these two objectives of large electrical footprints and fast dispatch in different context. Some countries are either moving toward the market or have markets in the bulk system, others have various forms of regulated or even state-owned utilities, and, of course, there are systems that have a combination of all those things. So we recognize those differences, but we want to take a look at different approaches that could be applicable in different institutional context. And then we'll talk about some other actions that can help improve grid operations.

So the next slide shows kind of a brief outline of what we're going to be looking at. We're going to spend a few minutes talking about basic power system operation and what that means for variable renewable integration. We'll then take a look at the concept of flexibility and how flexibility can help with the efficient integration.

And, as I mentioned, we're going to be focusing on the size of the balancing area and the speed of the economic dispatch as—that's our focus today, but

there are certainly many other things that you can do to increase flexibility in the power system.

And then we'll take a look at alternative approaches to coordination among balancing regions. And then finally, we'll take a look at some possible pathways that you can think about to achieve both a large balancing region and fast dispatch.

I want to also point out that we're going to give a couple of examples. We realize that there are many different pathways, and we hope that some of these suggestions will simulate you in the context of your country that might be useful.

So, our first topic is to take a quick look at power system operation and integration. The power system, regardless of where it's located and how it's operated, there's some basic physics that have to be—we have to recognize and are going to take over for us if we—so, we want to operate the power system in an economical fashion. We would like to approach some sort of least cost solution to balancing the system, and we also want to balance the system in such a way that it's reliable so that we're providing electricity to our customers whether they're residential, or commercial, or whatever else they might be.

And to do all of this we need to make sure that the system is balanced pretty much all the time.

And so what that means is supply must equal demand. There is the possibility that there's a slight difference between them, and if that happens, you can see in this diagram on the right, we have a sort of a stylized transmission tower that looks like a balancing weight in effect. And in this particular example, we have electricity generation over here on the right, which is a little bit less than demand on the left, and so that sort of pulls the scale, if you will. And in this example, we see the system is deviating from the nominal frequency. In this case, the nominal frequency is 60 Hz. In many parts of the world, the nominal frequency is 50 Hz. It doesn't matter for our purposes whether 50 or 60 Hz is the operating frequency of your system, but the point is we need to make sure that the generation and the demand are balanced. And slight imbalances will have an impact on frequency. If we have a large impact on frequency, that can trigger all sorts of loads from automatically disconnecting to avoid damage, and things like that. So we want to make sure that the frequency is pretty close to nominal. And to do that, the system must be balanced at all times.

Who's responsible for maintaining that balance? The names change depending upon where you are located. I'll use the term a balancing authority, sometimes called the balancing area authority. And this is the entity that is responsible for making sure that the demand and the supply are balanced. The map that you see here is from the western part of the United States. We thought this would be a nice example, because there are many balancing areas in the western part of the United States, and you can see each one of them here in color.

This is a very stylized picture. It doesn't really show anything about the transmission system. It also does not show how some of these areas are connected. For example, you see this large green area in the middle, PACE, which is Pacific Corp., on the eastern side of their system, and this green on the left hand side is another part of Pacific Corp. There is some transmission that connects the two, but in effect that functions as a single balancing region even though geographically it's a little bit spread out.

But the point is that each of these regions that you see in color is responsible for making sure that supply is equal to demand in its own region. And, of course, we need to also take into account any flows in between regions, interchange, or transactions. So, you might have, for example, there's a WACM, the Western Area Power Administration, Missouri River—you don't need to remember that name—but they might be selling some hydro energy to Pacific Corp. But when they balance the system, they take into account the fact that there's a scheduled either inflow or outflow of energy.

To help maintain the balance of the system, some areas have what we call ancillary services. These may be provided by a market, or they may be provided in another fashion. But these are services that can help the grid remain in balance.

And then finally, we have reserves. A reserve is essentially either generation, or it could be a demand response resource that's not fully loaded, and can therefore respond to imbalance situations. So, for example, if you find that demand is going up, and you have a unit that you can move up, or, maybe a better example would be you have a unit that disconnects offline, you have a reserve, which is an unloaded capability of the unit that can be brought up to replace the unit that trips offline. And there are many other types of reserves, but the point is that we do have a suite of other tools. We generally call them ancillary services, and those services can be used to help balance the system.

After all, it's really—what we're trying to do is to deliver energy to the customers, but in order to do that, we need to maintain voltage and frequency. We need to make sure that supply is equal to demand at all times.

This next slide is an example, kind of a stylized picture of how things might be operating in a given system. Now this particular example uses a five-minute economic dispatch. And a little bit later on this morning, I'll be talking about an energy imbalance market, or an energy imbalance service, which operates on a five-minute time step. And so, you can think of this example as being an example of an energy imbalance market, but there are other mechanisms you can use to achieve this.

But let's go through a couple of time horizons of power system operation. And again, this may not be exactly what you have in your country, but I suspect that you'll have something at least similar to what we have in this diagram.

The first process we generally call unit commitment or scheduling, and this process is often done one day in advance, because we have large thermal

units, like, for example, coal plants that must be started up a day or so in advance of when they need to be used. And so what that means is that on a Monday, for example, we need to make a decision of which of those plants we need to have available in case we need them on Tuesday. And so that process of deciding which plants we need and starting them up is called unit commitment.

When we do—I'm going to skip a little bit here. The economic dispatch, or the dispatch, is the process of moving one or more generators to a new output level to match demand. And we can do that—some people do it every hour, some people do it every five minutes. But before we dispatch the units, we need to have some information about where do we think demand is going to be in the next dispatch period. And that's where the concept of gate closure comes in.

Gate closure means I'm going to take all the recent, and the most recent data that I can, what is the demand, what are the generators doing, where do I think demand is going to be in the next five minute period, or the next hour, and then I make a decision in terms of how to dispatch the system for that next time period. Gate closing is that time where I take all the available information and use that to decide what the next dispatch point is.

So down at the bottom of this particular slide you see kind of an example timeline. And again, this particular timeline assumes that we are doing a dispatch every five minutes. And I want to sort of talk through how this might work. So over here on the left you see the gray box, the day-ahead unit commitment, and the timeline shows that at 12 p.m. Again, that's not a requirement, but many power systems will do the day ahead commitment by noon the day before the period in question. So we tie down which units we're going to have available.

And then in this example, we're going to be looking at the dispatch period that begins at 10:15 in the morning. So you can see that's more or less in the middle of the timeline, but before that happens, we need some other activities to occur.

So, the first one in this example is the gate closure, which happens at 10:05 on Tuesday. So, let's talk, for a second talk about what's happening at 10:05. We have a bunch of generators that are online. We made the decision in terms of which ones to put online yesterday by noon, Monday, in this case. And what we do now at 10:05 is we take a system snapshot. We say, "What is the demand? What is the wind doing? What is the solar doing? What are all the generator's doing, and where do we think the system is going to be ten minutes from now?"

And so we have a very short-term forecast, basically a ten minute forecast. And, at that point, what happens is we start our computer in calculating the economic dispatch that would be consistent with our short-term forecast of where the system is going to be at 10:15. And so you can see this red arrow, we have actually several activities going on here. The calculation of the new

economic dispatch, and that calculation is determining which output level and which unit will be attaining that output level starting at 10:15.

So we do those calculations, then we need to send the data to the specific generators so that they know where to position themselves. And then we allow some time, usually five minutes or so, for the generators to move to their new set point, to their new dispatch point. And so by 10:15 we have calculated, communicated, and dispatched all the units to their new set points.

So this is the process. In this example again, we've got ten minutes between the system snapshot and the actual dispatch point. All systems are a little bit different, but if you're running a five-minute dispatch, it's likely that you would have something similar to this.

Well, so that's the basic process, but time keeps going on. And so this next slide shows how these multiple dispatch periods will overlap. And I'm not going to go through this in a lot of detail, but I do want to point out that with our gate closure at time T1 that we talked about in this red box, we had that ten-minute period right in through here where we calculate, communicate, and move the units. But notice after we've done the calculation and communication, we start a brand new process that overlaps. At 10:10, we take another system snapshot. We do another round of calculation, communication, and movement, so that you see at 10:20, we can do a new dispatch.

And so this is a fairly complicated process. There's a lot of overlapping activities, but what this allows us to do is to take the latest and greatest system snapshot, calculate dispatch so that at the next five-minute period we can move our units to that next dispatch point.

So, again, this is an example of five minutes. Your system may be different. Some areas might do this every 15 minutes. Some areas might do this every hour. But the process, I think, is roughly similar across different systems.

That was a lot. So let's talk a little bit about grid integration. Wind and solar energy, of course, are driven by wind speed for wind, energy, and solar irradiation, the light, sunlight. And so they vary from day to day, hour to hour, minute to minute. Even if we knew exactly how much wind and how much solar power I'm going to get in a different time period, a given day, the output of those resources would still be variable. And because of that variability, I would need to operate my power system a little bit differently than I would if I had no wind or no solar energy.

But we don't know exactly how much wind and solar we're going to get at different time periods. And so, what we do is we do forecasts of wind and solar. Those forecasts are pretty good, but they're not always as good as we might like them to be, so that means that we need to allow for some uncertainty when we think about how much wind and solar energy we're going to be getting.

Uncertainty is not new. We've been dealing with uncertainty in demand for many, many decades, but the uncertainty is a little bit of a different flavor with wind and solar. Variability is also not new. We've been dealing with variability for many, many years, decades even, when we operate the power system. And that's why most power systems have built in methods to deal both with variability and also with uncertainty.

So, for example, when we do the day ahead unit commitment that we looked at a minute ago, we have some sort of a forecast for tomorrow. We know that that forecast or demand, it's probably pretty good, but we never know exactly when a cold front or a warm front might move through the region, which might change demand significantly. And at the same time, we do a forecast for wind and solar. But again, the variability and the uncertainty are two attributes of the power system we've been living with forever, but now we have a new source of variability and a new source of uncertainty with wind and solar.

So grid integration is essentially the process or the practice of recognizing the variability and uncertainty from wind and solar and trying to set up the power systems so that we can run it as efficiently as we possibly can, given the variability and uncertainty that we're going to be adding from wind and solar. And because of this additional variability and uncertainty, we need additional flexibility in the power system so that we can manage events that we didn't foresee very accurately.

This next slide we covered in a prior webinar, and you'll find it along with an explanation on the grid website, so I'm not going to go through it in detail, but I do want to point out as kind of a refresher some of the reasons why we need some flexibility. This graph shows demand by itself in the yellow. It shows wind energy in green and the orange is the net demand. So this net demand is what the remaining generators in the power system have to supply if we take full use of all the wind's energy.

So this net demand, you compare it to the demand by itself, orange versus yellow, you can see that the peaks are shorter. You can see, for example right here, I hope you can see my cursor here, in the no wind case we have a ramp, and you can see it goes from around 10,000 megawatts up to maybe a little bit less than 12,000 megawatts. But if we have a lot of wind, the wind allows us to turn down the thermal generation, but we have a ramp that goes from somewhere around 7,000 megawatts, or even a little bit less than that, all the way up to just over 10,000 megawatts.

So we have steeper ramps. That means that our conventional generation has to be more nimble. It has to move faster and further than it did in the no wind case. And we also have several situations where we have lower turndown. In other words, at nighttime we have a lot of wind right here on the diagram, and you can easily compare in the no wind case we could turn down our generation or thermal fleet to around 10,000 megawatts. But now with all this wind that we have, we really would need to turn down our thermal fleet to something a little bit less than 8,000 megawatts. So I need the ability of turning down my thermal fleet lower than I used to have to turn them down.

And so these are some examples of flexibility. The graph that you see here does not really cover the uncertainty aspect, but it does point out that even if we knew with perfect certainty what the wind energy is going to do, we still have to operate the power system differently, and we need additional flexibility. We need to be able to ramp our generation faster, and we need to be able to turn down the generation lower.

So this flexibility means that we have sufficient resources to do all these things, ramping and turning down lower than we used to.

This next chart you've also seen in another webinar, and I won't talk through this today, but this does show many, many options for increasing the flexibility on the power system. We're going to focus only on a couple of these that you can see on the left hand side highlighted in red. We want to take a look at what happens, what's the impact of expanding the size of the balancing area. And we also want to take a look at what happens if we can move to sub-hourly scheduling and dispatch.

And, as our example, I'm going to focus quite a bit on five-minute economic dispatch, because that's what many regions have moved to, because they've found that it's more efficient than longer time periods like an hour, or even more efficient than 15 minutes. So we want to take a look at these two in some depth today.

I also want to point out that the flexibility that we're talking about has two aspects. One is the physical flexibility. What is my power plant physically capable of doing? And that actually may be something I could change by doing some retrofits on my power plant. But essentially, we have physical constraints that are made up from constraints of individual power plants. But we also have constraints that can be imposed by the institutional structure, and that could be a regulatory structure. It could be operating practice. We've always done it a certain way, and we are going to continue to do it a certain way. And continuing to operate the system in a future with a lot of wind and solar, continuing to operate the same way we have in the past may unintentionally provide some barriers that make it difficult for us to take full access of the physical flexibility that we have in the power system.

So the cost of all these flexibility options will vary, but one of the interesting things about institutional changes, like, for example, bigger balancing regions, or faster economic dispatch, they may not be the most expensive and, furthermore, they don't depreciate. If I buy a new power plant, it's going to depreciate over some period of time, but if I come up with a better, more efficient operational practice, I can use that new practice forever.

So that takes us to the [Audio cuts out]. And what I'm going to be doing here is talk about why is it that a larger balancing region can be more efficient than a smaller balancing region. And the second principle of speed, fast, why is it that fast dispatch can be more efficient and, in particular, with a lot of variable generation.

So first of all, let's look at the impact of balancing area size. Balancing area size has a couple of really important impacts. The first one is on the renewable energy itself, and that's what this particular graph shows. This graph shows the impact of geographic diversity or, in other words, larger geographic areas on the variability of wind output. The data that you see here came from an NREL data collection program where we collected one-second data from wind plants that were operating around the country.

And this particular data came from a wind plant in Minnesota, which is more or less in the north central part of our country. And we had two different strings of wind turbines. One string of 15 turbines, and you see a graph of the 15 turbines at the bottom I'll talk about in a second, and then we had another group of 200 turbines. And each of these two strings of turbines had separate metering on them, so we were able to take a look at the variability, and actually the output, of the 15-turbine group and the 200-turbine group at exactly the same time period. These turbines are all fairly close together.

But what you can see looking at the bottom—and I should point out a couple things on the scale here. We're looking at the output of 15 turbines, and we're normalizing that to the mean output, and we're doing that so that we can compare the per unit variability of both the 15 turbine group and the 200 turbine group.

On the X-axis, this is showing seconds, 30,000 seconds. This is roughly eight hours of data. And so you can think of each of these graphs of showing roughly eight hours' worth of data. So on the bottom we see the 15 turbines, and you can see that there is a lot of variability, and there are some pretty steep ramps, and a lot of jagged edges here as we have some wind gusts that the 15 turbines do respond to.

By the way, I should also mention these are older turbines that are generally not being used today. These, I think, are about 600 kilowatt turbines, and grid connected wind turbines today range from maybe one and half megawatts to three or three and a half megawatts. So these are fairly small turbines, and they're going to react quite differently to the wind as a modern turbine would.

So you can see a lot of variability with the 15-turbine group. And as you move up to the upper panel, you can see how a larger number of turbines, 200 turbines in this case, smooths out the output. And again, we've normalized the output relative to the mean output of this time period. And we only did that so that we could compare the per unit variability.

But you can see that with 200 turbines this is not perfectly smooth by any means. You can also see some sort of jagged edges, which represents some relatively large changes in output over a short period of time. But when you compare the two, I think it's startling how different the output profile looks for 200 turbines to 15 turbines.

When you're aggregating wind turbines or PV panels across larger, and larger, and larger areas, this same principle is going to be applied. And so if we were to then take a look at 2,000 turbines, or 2,000 turbines maybe spread

over a very, very large region, you would see additional smoothing in addition to what we have here on this particular graph.

So that's one aspect, the relative smoothing of the output of renewable energy. And the same principle does apply to solar energy as well. So that's one aspect of larger balancing footprints.

Another aspect of larger balancing footprints is that when you take the wind, and the solar, and the demand data all together, you have an additional benefit if you can go larger. And I want to talk about that in this simple example. Now the graph—I'm not going to talk about too much at first, but this particular hour of the graph we're looking at is one day in this example, and we're looking at what I call excess ramping. This is ramping that does not need to happen, and I'm going to explain what this means in just a moment.

But for the example that I'm going to talk about, imagine that I'm talking about this part of the graph here where you see a positive 400 and a negative 400-megawatt ramp per hour. So here's the example. We have two adjacent balancing areas. So they're right next door to each other. There is some transmission that connects the two. But initially, Balancing Area A and Balancing Area B are operating separately. And to make the example a little bit simpler to understand, and also to talk about, let's assume that there's absolutely no transactions moving between these balancing areas. If there were transactions, it wouldn't really change our argument, it just makes it more complicated to explain.

So the balancing areas are operating totally separately, and at this moment in time our number 5,284 of our year, we happen to have Balancing Area A, which is ramping up at 600 megawatts. So its net demand is going up by 600 megawatts. And so what the balancing area operator has to do is that it has to dispatch an additional 600 megawatts of generation, and that generation has to respond within the hour so that we can meet this ramp.

Well at the same exact moment in this example, Balancing Area B finds that it's ramping down by 400 megawatts, and so what Balancing Area B is doing is that it has to turn down some of its generation, 400 megawatts of its generation so that it can meet its demand in that same exact hour. But now imagine what would happen if these two balancing areas could combine? What happens to their combined ramping capability?

Well, if Area 1 is ramping up at 600 at the same time that Area B is ramping down by 400, if they combine, then that new ramping requirement is an increase of 200 megawatts. And so what's happened? We've eliminated 400 megawatts of the up ramp in Area A at the same time we've eliminated the 400 megawatt down ramp in Area B. And so we have reduced the ramping requirements by simply pooling these two areas into a single operating region, or combing their dispatch in some way, and we're going to be talking about alternative ways that you could combine the dispatch.

So that's a really powerful thing. And you can see in the graph that the example I gave is from this portion right here. This is the largest ramp

saving—here we go—the largest ramp saving of this particular week. And you can see that as we move through the week, the operation of the math is the same, but the numbers are different.

So, for example, out here in this particular day, maybe we're saving about 200 megawatts up and down of ramping. But if you think about what this means, if I combine two balancing areas, their ramping requirements will decline, but their capability of ramping will go up linearly. So if Area A and Area B each have the capability of ramping at 1,000 megawatts per hour, if they combine, they could now ramp at 2,000 megawatts an hour, but they don't really need to ramp as much because of this example that we can see.

So that's a really powerful thing. The numbers will vary in different parts of the world, in different regions. And the size of the ramp that you can save will depend on the specifics of the system, but the principle is pretty much the same anywhere you go.

So that's the impact of speed, sorry of size. The next impact is speed. And on the graph—we actually have two graphs here. On the graph on the left, we have an example of an hourly dispatch. And so let's kind of walk through this. We have time on the x-axis—and the time here is not specific. I'll say it's roughly two hours perhaps—and on the y-axis, we have megawatts. We don't have numbers here because what's really important is what's happening on the graph itself.

So what we have here in green is the demand, and you can see how the demand is varying from minute to minute, through the hour, and so forth. And now what we want to do is take a look at the hourly schedule at the hourly economic dispatch. And typically, the dispatch is done based on the average demand, or the average net demand, through the hour. And so you can see that here. It's hard to tell exactly what this average is, but roughly, for this hour you can see the average is right in here, and you have a flat dispatch block.

And then when the next hour begins—and this whole red big flat block is one hour—when the next hour begins we can ramp our generation so that they're at their new dispatch point, and they're going to remain at that dispatch point for the next hour.

Now during that hour, I don't have access to the dispatch stack, but I do have access to units that can provide regulation. And different parts of the world do regulation in different ways. In some areas, you have automatic generation control; in other areas, you have manual control, which might be based on frequency deviations. It doesn't matter how you do that, but the fact is you have to move some generation outside of the economic dispatch process, and you can see that here in green. And so these little red bars that you see stacked up represent the amount of regulating reserve that we need to have and that we're going to use in that hour, and that's quite a lot of regulating reserve.

And typically, the processes that you have to meet this sub-hourly demand are not economic. They're based on the capability of some subset of the generation fleet.

So I need a lot of regulating reserve in order to accomplish this. But if we move to the right hand graph, we can see what the impact is of a faster dispatch. So let's kind of walk through the graph real quickly here, get our bearings here. So the x-axis is exactly the same. This represents time. The y-axis is the same. The green trace here that shows demand, or net demand, is exactly the same on the right as it is on the left. And we've taken this red flat bar that represents the economic dispatch and we've replicated that over here on the right.

So everything that we had on the left hand curve we also have on the right hand curve. But what we're doing a little bit differently on the right hand graph is that we're showing what would the impact be of a five-minute economic dispatch.

Well typically, the five-minute economic dispatch is based on a forecast of the middle point of the five-minute time period, and we talked through that on the timeline a few minutes ago. So, for example, we have a point right here where my arrow is. We take a system snapshot, or we've already taken a system snapshot, we calculate the new dispatch point, and you can see we move from one dispatch point to another, and we're doing this movement every five minutes. And what that allows us to do is, it allows us to have a dispatch that closely mimics the actual net demand.

Now you can see that we still don't exactly match the net demand. So there's still some requirement for regulating reserve. And right here, for example, you can see a fairly large requirement for regulating reserve, but that requirement for regulating reserve goes away pretty quickly as the blue and the green traces come together. We just happen to have a really nice coincidence here where the demand and the dispatch move at the same time. That happens sometimes. It doesn't happen all the time.

And then again, you can see that we kind of missed it here, so we do need some regulating reserve. But if you take a look and compare the amount of regulation that we need on the right versus the amount of regulation we need on the left, it's vastly different. So we're able to pull a lot more of our operations under the sort of economic umbrella, the economic dispatch, and we can run this system a lot more efficiently.

The other thing that this does—and the graph doesn't really show this very clearly—what this does is it allows us access to generation every five minutes on the right hand graph that were stranded, were not available to the system marker on the left. So in the left, we may have a bunch of units, the ones that we've dispatched, that do have the physical capability of moving to a different dispatch point, but because of our institutional constraint, because we are operating on an hourly time step, those units are frozen and I do not have access to their flexibility, even though they physically may be capable of responding.

So this is a really important concept. I've spent a lot of time on these last two slides, the first one on size, the second one on speed, so let's move ahead and take a look at some of these impacts in a broader scale.

Now this particular graph would probably take another two hours for me to talk about in detail, but I want to kind of skip through this, or go through this fairly quickly. This is based on some work that we did in the United States, but we looked at the entire western interconnection and we calculated the amount of regulating reserve that would be used or be required under alternative sizes, and you can see that here. We have lots of small balancing areas, a few medium sized balancing areas, and one gigantically large balancing area. So small balancing areas, medium sized balancing areas, large balancing area.

And within each size, we calculated the impact of the dispatch interval, which is the first number here, and the gate closure. And the basic takeaway from this is, no matter how small or how large your balancing areas are, if you go to a short dispatch and gate closing, that will be more efficient. So if you have a lot of small balancing areas, in this example, you could reduce regulating reserve from almost 9,000 megawatts to about 2,500 megawatts. And likewise, if you are medium, you can reduce regulating reserves significantly, and likewise if you are large.

The other thing that you can note here is, regardless of how small you are, if you get bigger, you will reduce your regulating requirements. And so everything that we talk about in this webinar is really encapsulated in this one graph. Size matters. Larger is better. And speed matters. Faster is better. And that's true regardless of how larger or how small you are, and how fast you're dispatching. If you can go faster, that's going to be more efficient. If you can get larger, that's also going to be more efficient.

So those are the basic principles of large balancing regions and fast dispatch. Let's talk about alternative ways that balancing areas could coordinate. Oftentimes, if you have two totally uncoordinated balancing regions, as I talked about in the example of ramping a few minutes ago, there's really not much that's being exchanged here. There might be some scheduled transactions, but the balancing is essentially done separately for both the system on the left, and also for the system on the right.

One aspect of coordination might be reserve sharing. This is often contingency reserve sharing. So contingency reserve is having enough reserve so that if my largest unit fails, I have enough capacity online that I can restore capacity.

So in this example we have two regions. They each have 1,000 megawatts of contingency. If they are separate, they each have to maintain an extra 1,000 megawatts to meet the contingency reserve. But if they share that, each region can supply 500 and they can eliminate a total of 1,000 megawatts of reserve sharing.

A more interesting and more beneficial aspect would be a coordinated dispatch, and that can be achieved by something we call an energy imbalance market, and that's just a way of capturing a market organization that does coordinated dispatch. And so in this case we have some kind of a central market mechanism that is going to do the five-minute economic dispatch combining the two regions. But the two regions are still operating separately in many other respects.

And then finally, coordinated operation or consolidated operation, this involves doing a coordinated day ahead unit commitment, and doing the economic dispatch, and scheduling ancillary services in such a way that we can meet the combined system. So these are alternative levels of coordination.

And let's talk about alternative ways that we can get to big and fast. Let's talk first about a nonmarket type of mechanism. So imagine I'm in a country, I don't have a market, I'm not really anticipating forming a new market. I may have state owned utility. I may have regulated utilities. Let's talk about what could happen.

So to obtain a larger balancing area, what we could do is expand balancing footprints. Now that can come in a couple of different flavors. First of all, we could be in a country which is seeing a significant increase in demand, and so a balancing region may be growing because we're extending the electricity grid to regions that may not have it today. Or we could be taking two neighboring systems and combining them in some way operationally. We also might be developing renewable energy. Maybe we have a government goal or target of some type to build our renewable energy. One thing we may want to choose to consider is how geographically diverse are those wind and solar resources, because that will give us some benefits in terms of the balancing as we've seen.

We might want to coordinate dispatch in two regions. And maybe that's all we want to coordinate, and we'll talk about that in more detail in a moment. I may want to coordinate not only just the dispatch, I may also want to coordinate unit commitment, and this can all be done without any mergers of business. It can all be done without a market. You may need some sort of a contract to spell out who does what, but essentially, there's no requirement for a market. And, of course, you could merge business practices. We could actually have a merger of two or more organizations into a single organization. But again, that would not require a market.

So a couple of ways in which we could expand the size of the balancing region. The speed, we could move towards a faster dispatch, maybe five-minute dispatch, maybe a 15-minute dispatch. And that can happen, again, whether or not we have a market. So in a regulated utility context, or in a state grid context, we could simply move to a faster economic dispatch.

We could move to faster interchange schedules with the neighbors. So for a neighboring region that is not going to be part of our economic dispatch, we can still increase the speed of the interchange schedule, and that will

accomplish some of the same benefits as moving to a faster economic dispatch would within the balancing region.

And then we can also take a look at contracts to see if there's a way that we could incorporate flexibility of the contract. I know one example here where a utility had a contract with a power plant, and the utility added a lot more wind. They found that rather than only paying for energy, they would benefit by paying for flexibility, so the contract was renegotiated. The same overall amount of money was in the contract after renegotiation, but the contract could recognize flexibility. And so that's something that we think might have some significant value.

This next diagram, it shows several things that may help achieve both a large electrical footprint and a fast dispatch. And the point I'd like to make about this particular diagram is that there's no single pathway through all of these points. Achieving any one of these individually will be beneficial. Achieving many or all of them would be most beneficial.

And we'll talk about some market evolution here in a moment, but you may start with reserve sharing, maybe go to coordinated dispatch, and perhaps move to faster dispatches. Or, perhaps you would start with reserve sharing, do a coordinated dispatch—maybe you're doing dispatch every hour—and then move to coordinated commitment. So you might go Box 1, Box 2, Box 3, and then move to a faster dispatch. I haven't talked about zonal versus nodal, but this is simply how granular do you define your dispatch zones within the balancing region.

So there's no single path through all of these, but generally, as you move down here, we're seeing increasing level of coordination. And if you move to the right, we're seeing the evolution of operation, and perhaps faster types of operation. There's no single path through this. And so as you look at your own system, if you find yourself trying to achieve some of these things, it may be that your path is not the same as the path of your neighbors, for example.

India is a good case study. A couple of years ago India moved to a synchronized national grid. That's a great first step to help enable some of the things that we've been talking about today. They also modified the dispatch time step rather than doing a dispatch every hour. It's now every 15 minutes, and we think that's going to capture a significant chunk of the benefits. We don't know exactly what India's going to do, but I know that they've been thinking about alternative ways of coordinating among the state balancing areas. And what that looks like in the future, I don't know, but that's one example of a country that has made some moves towards larger and faster already. And they're thinking about whether or not to go forward with some other changes.

Let's take a look at market mechanisms. You'll note that many of the things here are the same as what we saw in the nonmarket example. Increasing the balancing area footprint, I think of particular important is increasing the market participating from generators that might be currently self-scheduling.

And what that does is that it brings more flexibility to the power system operator.

The same basic types of coordination with the neighbors are possible through markets, reserve sharing and energy imbalance market, etcetera. We can move to faster dispatch and interchange, and the shorter gate closure, all of these things that we saw before in addition to a rolling unit commitment. It may be that rather than just doing commitment once each day at 12:00 noon for the next day, we may decide that it's advantageous to do unit commitment maybe every 12 hours, or maybe every eight hours, maybe every four hours.

Often it's useful to start relatively simple and then expand from there. An energy imbalance market is a nice way to start because it requires some coordination, but not a very, very high level of coordination. It does not address unit commitment, nor does it address ancillary services, but those can be added later.

And a good example of that is the Southwest Power Pool in the United States. The Southwest Power Pool started sort of down here. It's expanded significantly; so it's gotten larger. Most recently, it expanded to incorporate this dark green region. They started as reserve sharing only. They went to an energy imbalance service, and then eventually went to a consolidated market operation. And so going to our little box chart here, the first step at SPP was this reserve sharing, then they went to the energy imbalance service with a five-minute dispatch, and then they went to a full two-day market, and then they expanded their geographic footprint. So that's their evolution.

Another example is in the western part of the United States where we have a new energy imbalance market that encompasses California and all these regions in orange. We have some new players that are scheduled to be joining later, but what you see here are a bunch of regulated utilities. They are regulated utilities, and yet, they are joining the energy imbalance market. It's conceivable, possible, that the energy imbalance market could cover this entire west. I don't think that's going to happen. And when folks started this energy imbalance market, there was a lot of reluctance and some nervousness as to whether or not can you really count on the market. But the market is expanding fairly quickly, and then we think it's going to really help with the integration of wind and solar.

Another example in the west—actually let me back up for a second. The example I want to talk about in a moment is more or less this region in Colorado and part of Wyoming, and this is simply an alternative evolution. Where this is some reserve sharing in the west, there's a new group called The Mountain West Transmission Group, which is considering forming an RTO. So if that's successful, they would jump from a simple reserve sharing all the way to the full market—coordinated dispatch, coordinated commitment, ancillary services, a 15-minute coordination with the neighbors, everything at once.

So you can see we have a couple of examples of how the evolution to fast and large might happen. It can be more gradual, or it can be a gigantic step. And

so the principles of large balancing regions and fast dispatch, I think, apply universally, but there may be differences in how different countries want to achieve that. I hope that this has given you some ideas of alternative pathways. There's no single right way to do it. We've seen examples of different types of evolution, and I expect that we're going to continue to see differences in the way that countries evolve. But I do think that large balancing footprints, and fast economic dispatch, and short gate closure will really make a big difference with how you integrate your renewable energy targets in the future and currently.

So, with that, we'll stop and take any questions that you might have. And we'll turn it over to Jen.

Jennifer Leisch

Great. Thank you, Michael. So we would definitely like to encourage everyone to please submit any questions you have through the online system here, and we'll try to get to as many as we can. So while we are waiting for some questions to come in, I think one of the first things that is on everyone's mind is at what point in time does this really matter, or at what level of renewable energy penetration do we have to start making changes like this? Is it important to do this when it's only one percent of a system, or do we have to wait until five, ten percent comes up?

Michael Milligan

That's a really good question. We've seen the evolution of large fast balancing areas even without any wind and solar. So you can capture some benefits even without any renewable energy at all.

Now having said that, if you have a lot of renewable [Audio cuts out] benefit from large and fast balancing. So then the question is, well so when do I do this? Any time is a good time to do it. You don't need to wait for large amounts of renewable energy. You will get some benefits immediately. And if you can move to a large fast balancing region at low levels of renewable energy, that will essentially put the tools in place so that when you get to a higher level of renewable energy, you don't have to scramble, you don't have to worry about how to balance the system with a lot of renewables when you've got small, slow balancing.

I think it's advantageous to do it earlier rather than later, but there's no perfect time to do it. And again, you will get some benefit even before you start seeing large amounts of renewable energy on your system.

Jennifer Leisch

Well you talk a lot about that this can be beneficial to any system. Are there certain costs and considerations that you have to make when you're increasing the speed of dispatch and moving to a larger balancing footprint?

Michael Milligan

Yes. Unfortunately, it's not free. There are some costs in doing this. The cost will depend on the system that you have, and the level of automation that you have. If you already have some form of automated economic dispatch, then the cost would be expected to be less than if you do not.

What we've seen in many cases is the adoption of existing market software moving to a different area, or being adapted for a different area. To give you

one example of cost in the western United States, there was an early cost estimate of the energy imbalance market, and the cost ranged from—I don't know the exact numbers—ten million dollars, to \$150 million. And people looked at that and said, “Why such a big difference?” Well the difference was because the low-cost estimate had to do with taking the existing software and infrastructure from an existing energy imbalance market and implementing that in the west.

Whereas, the high cost estimate came from starting from scratch and developing brand new software, brand new communications, and all of those things from scratch. So it's hard to generalize. There are some costs with communications, or there may be costs with new communications capability so that you could take the system snapshot, you can communicate the new dispatch points to the generators. There is a cost of computation. If you have a significantly computation capability today, I would expect that cost would be somewhat less than if you do not.

But as I mentioned earlier, once you move to this new fast, big fast balancing, that's a process that can be in place until you find something better. Maybe you don't ever find anything better, and so you have a good, efficient mechanism in place for years, if not decades to come.

Jennifer Leisch

And maybe just to follow up with that, we had a couple questions come in about system reliability and loss of load probability. So how does going to faster dispatch benefit that reliability, or does it benefit that reliability?

Michael Milligan

Yeah, absolutely. That's a really good question. So the flipside of having these costs of new communication and in control capability is that if you're moving to a larger balancing region with faster dispatch, in order to make that work, you're going to have a lot more, and a lot more accurate metering on your system, you're going to have a lot more visibility to what's going on in the system, and you're also going to be correcting the dispatch, or doing a new dispatch every five minutes.

So in many cases we've seen outages that were not caused by the lack of visibility, but if something is going wrong, if I can't see it, I don't have the capability of correcting it. And if you're doing a system snapshot every five minutes, that tells you that the data that you have is no more than five minutes old.

You also have recovery after the loss of the unit. So for example, a larger unit trips offline, the economic dispatch will run every five minutes. It can help you correct that imbalance economically.

So it's hard to quantify monetarily what the benefit to reliability is, but there's clearly a benefit to reliability, because you have the better visibility of what's happening on the system. You have a lot of automated response, which makes it easier to respond to emergency situations.

Jennifer Leisch

Thanks, Michael. We have had quite a few questions about small systems for island systems. So in many places this big action doesn't necessarily apply.

So really, what can be done in these small systems or island systems to increase system flexibility if there's really limited opportunity to interconnect with neighboring areas?

Michael Milligan

That's a good question, Jen, and that's a harder one to answer. In a few cases, it may be possible to string a cable from an island to the mainland. You'd have to run the cost numbers and the feasibility, and in some cases that may be difficult or impossible to do. Absent to that, if you are truly an isolated system and there's nobody else you can connect to, then I think the issue becomes ensuring that you have enough physical and institutional flexibility within the confines of your system.

There are some flexible thermal generators that you might look at aero-derivative gas driven, for example, reciprocating engines, both of which can be started up very, very quickly and moved up and down ramp very quickly, turned down to a very low level. And so in a case like that where you've got limited capability of getting larger, I think the focus there would be more on the physical flexibility, so what types of units can you get that are flexible. You may have hydro. The hydro may or may not be flexibly, but certainly, you'd want to look at that.

In some cases, you might even want to look at storage. We found that on large systems at today's price, the storage, it's difficult for the economics of storage to work out, but on smaller systems it may be that some combination of fast flexible generation, as I said aero-derivative turbines, or reciprocating engines, or something like that, possibly with batteries. And, of course, you want to also make sure that you're forecasting the wind and the solar so that you have as good of an idea as you can in terms of what's coming in the future.

Jennifer Leisch

So that's great to describe island systems. So what about systems that are very old and have a lot of older thermal generation? So conventional power plants, like coal plants, are they really capable of responding to faster dispatch, like in these five-minute increments that we're talking about? Do we need major retrofits made to them?

Michael Milligan

Again, that's a good question. There's no one size fits all answer to that. So let me sort of start with the faster dispatch aspect of that. If you're dispatching your system once every hour today, then it's possible that some of your coal plants are ramping faster with an hourly dispatch than they would with a five-minute dispatch, and let me explain why that's true. Imagine that you have a coal plant that you're going to ramp 100 megawatts as you move from the 10 o'clock hour to the 11 o'clock hour. Now every system is a little bit different, but typically, that ramp has to occur within some time period around the top of the hour.

So, for example, you might have a 20-minute time window during which that unit has to ramp. So it's go to ramp 100 megawatts in 20 minutes to get to its new dispatch point. So now, imagine that you're dispatching every five minutes and, just for the sake of the example, let's imagine the same plant has to ramp 100 megawatts, but now we can ramp that plant in small increments

every five minutes. And so its ramping rate may be actually slower with a five-minute economic dispatch.

But, that still doesn't quite answer the question, what if I have a coal unit that is not capable of ramping? First of all, it may be capable of ramping. There may be operational measures that you can take to change the way the plant is operated. I'm not an expert on coal plants. I've talked to folks who are, and they say with good training the operators, and making sure that the coal plant operators know the objective of how the plant's going to be operated, they may come up with ways that can help. It may be that the plant would benefit from some retrofit so that it can ramp faster.

So I think there are many options that may be useful. And if it's an old plant, maybe it's time to retire it and replace it with something else.

Jennifer Leisch

Last question that we have time for, sorry. Can you talk a little bit about the relationship between the speed of dispatch and the time horizon of wind and solar forecasting? Something that we talked about in a previous webinar that posted on Greening the Grid is that you can produce wind and solar forecasts at a different variety of time scales, ranging from minutes to days ahead. So what do power systems need to think about if they're implementing these forecasting programs at the same time they're considering faster operations? How do you match those time scales up?

Michael Milligan

That's a good question. I guess generally wind and solar forecasts are going to be more accurate at short time steps. So if you're forecasting ten minutes ahead, or maybe for a five-minute interval that's ten minutes ahead, that forecast is generally going to be more accurate than the forecast that's going to be an hour ahead or two hours ahead.

So moving to a short gate closure—so for example, the five-minute dispatch with a ten minute gate closure we talked about, takes advantage of the fact that now the wind and solar forecast that I need for that gate closure is only ten minutes away, and so I can get a pretty accurate forecast. And often a really good forecast, for at least the wind, is what we called the persistence forecast. So I can take a look at my system snapshot and say my wind energy is 100 megawatts now, so I can assume it's going to be 100 megawatts ten minutes from now. That's not a perfect forecast, but it's a pretty good one. And so that allows us to leverage the most accurate forecasts, which are these short-term forecasts, and fold them into our economic dispatch.

But the other, I think maybe larger point, is that as we talk about improving forecasts and, for example, maybe you say well, it would be nice if we could get a forecast that's not a day ahead, maybe it's four hours ahead. But then the question becomes, how do I align that four-hour ahead forecast with some operational time step? And it may be, for example, that if you find this might _____ or important, that that four-hour forecast also be coupled with a rolling unit commitment maybe that's done four hours in advance. Maybe you can adjust the commitment schedule for some of your units four hours in advance to take account of the more accurate four-hour ahead forecast compared to the day ahead forecast.

Stephanie

Great. Well thank you so much, Jen and Michael for –

Michael Milligan

Thank you.

Stephanie Bechler

– a great presentation and the really wonderful questions that came in from everybody. If anyone would like some more information, you can go to greeningthegrid.org and you can find a lot of answers to your questions there. We will also be exporting the question log and sending it out to Michael and Jen afterwards in case there's any pertinent questions we didn't have time to get to.

So now, before we wrap up we have a brief survey that we would like the audience to participate in. So if could please select your answer on the screen as it pops up—the webinar content provided me with useful information and insight. Thank you. The second one, the webinar's presenters were effective. Thank you. Third, overall the webinar met my expectations. Thank you. Fourth question, do you anticipate using the information presented in this webinar directly in your work and/or organization? And the last question, do you anticipate applying the information presented to develop or advise policies or programs in your country of focus?

Thank you so much, everyone, for answering the survey. On behalf of the Clean Energy Solutions Center, I'd like to extend a thank you to all of our panelists today, and to the attendees for participating in today's webinar. We've had a great audience and we really appreciate your time.

I invite our attendees to check the Solutions Center website if you'd like to view the slides, or listen to a recording of today's presentation, as well as any previously held webinars. Additionally, you will find information on upcoming webinars and other training events. And we are now posting the webinar recordings to the [Clean Energy Solutions Center YouTube channel](#), and please allow about a week for the audio recording to be posted.

We also invite you to inform your colleagues and those in your networks about the Solutions Center resources and services, including no cost policy support.

Have a great rest of your day, and we hope to see you again on future Clean Energy Solutions Center events. This concludes our webinar.