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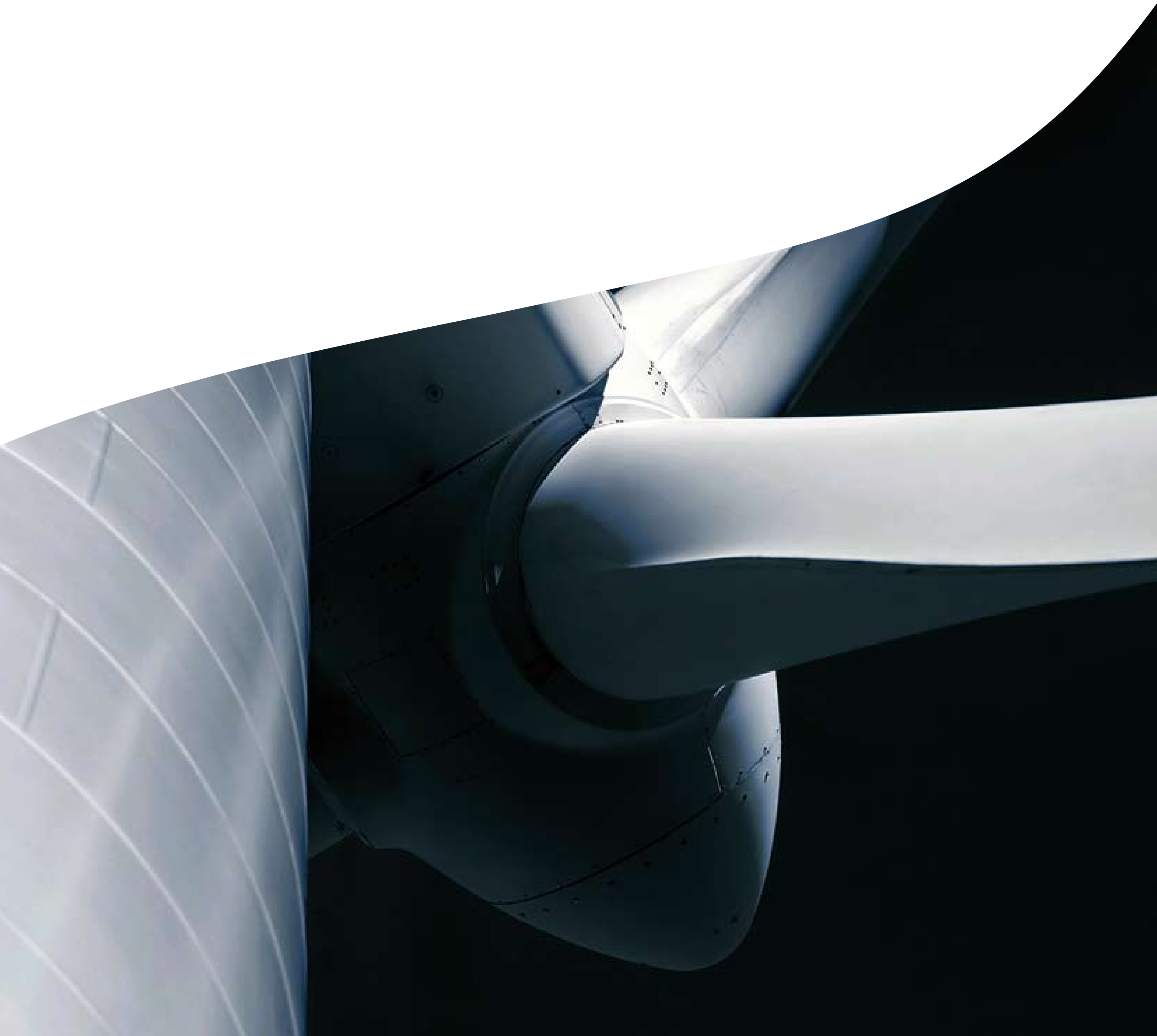
The Impact of Renewables on the Electric Grid

Point of View by Doug Houseman



The regulators are coming, the regulators are coming and they are going to force changes in our industry. With political requirements to reduce carbon, deal with global warming, be greener, allow local participation in the power grid, and try to manage the cost of energy, regulators are changing the requirements for what is allowed on the grid. Renewable generation is the buzz word today and regulators do not want to be left behind. In the US, more than 30 states now have renewable portfolio standards—mandatory percentages of power that have to be produced and delivered from renewable sources by specific dates. In some cases, the RPS requirements kick in as soon as 2010, in others the first real requirement is in 2025. But in any case, in the US, the state requirements will require that an additional 1 percent of the total electric power consumed in the US be produced by renewable sources each year. In Europe, triple 20 will force a similar requirement. The manufacturers of renewable generation devices are all running at full capacity and increasing that capacity. GE Energy will double windmill production in 2008, again in 2009 and yet again in 2010 and they are completely sold out until 2012. Other manufacturers are in a similar situation and the type of renewable generation they produce does not matter. Incentives and subsidies, rather than real economics, are driving the sales, as well as regulatory requirements.

This installation of renewables will not be without problems. None are impossible to deal with, but some are very expensive to deal with and others just take time and energy. Renewables will have an impact on the whole utility value chain and how it operates. No utility is exempt, and it does not matter if the market is fully regulated or fully de-regulated, there will be an impact. In some cases it is an engineering issue, in others it is a people issue. No generation will be installed and operate without facing some issues and problems.

To really look at the impact of renewable sources on the electric grid, you need to separate the renewables into several categories. In this document, we have made a simplistic separation into the following categories:

1. **Schedulable central station generation (S-Cent) –** This includes biomass and other alternative fuels that can be used in place of fossil fuels, and existing fossil fuel plants may be able to be retrofitted to consume them. For instance, wood chips replacing coal, ethanol replacing oil, or biogas replacing natural gas.
2. **Variable Central Station Generation (V-Cent) –** Wind farms are the best known examples of this class of asset and are the most widely deployed renewable generation sources today producing electricity. Large solar and wave power installations also fit into this category. The assumption is that V-Cent would be connected to the transmission (high voltage) network.
3. **Schedulable Distributed Generation (S-Dist) –** This is small scale generation that uses renewable fuels; normally, the generation facilities would be found on farms, in businesses and in homes. One good example would be wood-fired combined heat and power. The expectation would be that the generation can be turned on and off as needed.
4. **Variable Distributed Generation (V-Dist) –** This is the category that most environmentalists mean when they discuss the next generation of the electric network. Solar Cells on a homeowner's roof, or a small windmill in the backyard or barnyard.

These four categories of renewables bring different issues to the grid and have different levels of grid friendliness. The location of the connection and the ability to produce power on demand makes the difference in how friendly they are.

S-Cent

The S-Cent and the V-Cent are both connected to the transmission grid and have the ability to take advantage of the traditional control systems and monitoring. The existing SCADA systems and protection schemes are capable of supporting both of these types of generation. S-Cent is so similar to conventional generation that it offers few or no issues in integration into the grid. Since it is so simple to integrate, where the fuels are available and economically viable, it should be considered as the first choice in deployment. In most cases, the economic model for S-Cent matches that of conventional fossil generation. A sample of the facilities that fit into this include:

1. Large wood-fired power plants
2. Garbage and post consumer waste incinerators
3. Landfill gas generation facilities
4. Pumped hydro facilities
5. Large hydro facilities
6. Run of the river current farms.

These facilities offer very few challenges from a grid management point of view, but they do offer other challenges for site approval and operations. In some areas, incinerators that were installed only a few years ago are being shutdown because of protests by people who live near the facility.

One very clean garbage incinerator in a major city has been shut down after only 8 years of operation because people living in the area did not like the noise of the trucks and the look of the facility in their industrial neighborhood. The facility exceeded every standard that could be applied, and trucks were only allowed to deliver trash from 10 AM to 4 PM, a time when few people were home.

V-Cent

Like the S-Cent facilities, they are connected to the high voltage network and produce large amounts of power. Also, like the S-Cent facilities, they are highly visible on the horizon and cannot be hidden from view easily. Unlike the S-Cent facilities they run when the environment is right, and not when they are needed. For example, wind has to blow fast enough, and yet not too fast in order to generate power. In most cases they offer power from 7 to 40 percent of the time, depending on the location and the type of resource. These systems require some level of other generation to provide support, since the power they produce comes and goes on a change in the weather, and the load they support may not. The estimate in Colorado is that it takes one megawatt of running gas-fired generation to support 2 megawatts of wind generation in the state. This ratio has a big impact on the carbon footprint of the final delivered power. While it is cleaner than a new coal-fired power plant, the estimate is that to get the equivalent of 2 megawatts of new coal-fired power plant, 1 megawatt of gas-fired generation and 2 megawatts of wind generation have to be installed. Large variable central generation can be monitored by existing SCADA systems and controlled by existing energy management systems that are in operation by the transmission operator today. What the existing systems cannot do is to predict with any level of confidence what the output of wind power will be 24 to 48 hours in advance. New systems have to be installed to support this kind of forecasting. Forecasting the output of V-Cent is critical, as it determines when to fire up the large fossil plants to support days when the wind is either going to blow too strongly or not at all, or as in the case of photovoltaic, when the storms are rolling across the service territory hiding the sun. The global understanding of cloud paths and detailed wind forecasts is less than perfect, and as such, the impact of weather on V-Cent is likewise, i.e. less than perfect.

This less than perfect understanding means that the utility has to be ready to react to changes in power output on a very short timeline; in some cases the swing can be hundreds of megawatts in a matter of minutes. If utilities want to see this power swing in operation, visit Tennet the grid operator in the Netherlands and watch the power flow on a stormy day on the interconnector with Germany. Because conventional generation does not react as quickly as V-Cent typically does, the grid operator on the transmission network has to deal with rapid changes in voltage on the grid. In some cases, where the penetration of wind or solar is small, the rapid swing is a small part of the overall power flow and can be safely ignored. In Texas and Spain this is not the case, and both have almost lost the transmission grid to blackouts because of wind power—in Texas it was the sudden and unexpected drop in wind power production and in Spain it was too much wind generation on a wonderful spring Sunday when people decided to go outside and shut off most of their electric devices and lights. Swift action by the grid operator saved the grid in both cases, but it was close.

Geographically wind blows where it blows and we do not have the skills to modify the global weather patterns to put the wind where we want it to generate power. People mostly do not like to live in areas with strong and steady winds, it makes living tougher. This means that in most cases the locations that have the best wind are not the places that have high densities of people or power consumption. For the grid operator, that means building extensions to the transmission grid. High voltage transmission lines are not cheap—they can cost millions of euros a kilometer; for example, at AEP, one project is budgeted at 5.5 million dollars a mile. Add to the cost the fact that wind farms only generate about 40 percent of the time, and the transmission link to support a plan like the Pickens plan (a plan to replace all the fossil generation in the US with wind power and use the natural gas that currently makes electricity and heats homes to power automobiles) in the US would need to connect to three times the number of megawatts of wind power than it would for coal generation. In other words, to use wind to provide ancillary services (e.g. maintaining voltage, frequency and the integrity of the Alternating Current (AC) wave form – all required to let device work right and not burn out)—by spreading the wind farms over a wide area that receives strong wind—would cost at least three times the cost of transmission for a new nuclear plant. No one likes large steel towers in their backyard, so you can expect that even if people embrace wind mills, they will pan the transmission corridors. With these new large transmission links, there are issues with power quality and voltage management on the transmission network that did not exist before. Proper ancillary services can help fix this, but the technology to use one wind farm to support another wind farm for ancillary services, like voltage support or frequency management is not commercially available yet. The global industry has worked very hard to manage power quality, and that has allowed homeowners to have computers and other digital devices in their homes and businesses. If the network power quality falls enough, the utilities will have to either turn to using high voltage DC transmission networks and converting the power closer to the customer into AC power, or individual customers will have to return to using motor-generator sets or solid state power electronics to manage power quality. These costs have not been factored into any of the renewable portfolio standards or other plans that push for a high fraction of variable sources. These barriers are not insurmountable, but they do need to be honestly addressed with research and engineering.

In the future, as more and more of the generation becomes V-Cent the ability of the operator to prevent a blackout will decrease and more of the grid may be at risk. The most common generation sources in this category are wind and photovoltaic farms, two of the fastest growing sources in the world.

S-Dist

Schedulable distributed generation differs from V-Dist in that it is done on a more "human" scale, typically in less than 1 megawatt sizes. This means that it is not connected to the high voltage network, but rather to the low voltage or distribution network. Because it can be scheduled, it offers the ability to provide highly distributed power, close to where the customers consume it on the grid. This has a number of beneficial impacts, if the S-Dist is built to a plan that supports the needs of the grid and it is planned into the distribution grid. Unfortunately, this is seldom the case; homeowners and business owners decide they want to install generation and they do so. Today, the most common sources are not renewable at all, but rather gasoline- and diesel-fired internal combustion engines. In the future, these may be powered by bio-diesel and ethanol, making them technically renewable sources. There are literally thousands of internal combustion generators in the distribution grid today. Companies like EnerNoc were formed to install controls and schedule their operation on the grid. This resource has been ignored in the past because the distribution grid is not ready to handle two way power flows, when in fact, in many cases the way they are used is to disconnect the customer from the grid and let them run as a stand-alone island.

Changing the grid to support S-Dist means changing the relaying and the protective devices installed in the grid to allow power to flow backwards (on the grid). Today the grid is designed to allow power to flow one way, from the high voltage network to the customer; as S-Dist is installed and operated attached to the grid, power has to be able to flow in both directions. In a typical grid, there is a protective device for every 100 to 200 customers; changing these devices is a labor-intensive process that can interrupt the power to all the customers that are downstream of that device. The next issue is how to pay the generation owner for the power they generate. When a utility islands the customer, it is easy—they simply pay them for removing their load from the grid, and not for the kilowatt hours of power generated. As we integrate S-Dist, you need to create a measurement system and change the tariffs to support the payment of customers who generate power for you.

S-Dist has a further problem—most of these generators use electronic inverters to take the DC output of the generator and turn it into AC power on the grid. Because of the small size of the generator, it is too expensive to create 3 phase power, so they instead generate a single phase of power. That means that the power flows out of the generator onto a single phase of the grid. If this generator is installed on the right phase, it can be very useful in balancing the load between phases; unfortunately you have a better chance of winning in Las Vegas then you do in getting all the generators installed on the right phase, since the owner of the generation has control of their device and not the utility. This can lead to very large phase imbalances and big differences in voltage on a phase to phase basis. Phase imbalance normally leads to wasted power, in some extreme cases as much or more than the distributed generator creates.

Further, the inverters have another issue that is yet to be tackled—they create harmonics that can be harmful to the operation of the grid as well as appliances and computers that are installed on the grid. These harmonics can shorten the life of the appliances and computers. Today, harmonics in the low voltage network are normally ignored, since the cost to solve harmonics problems outweighs the value of fixing the problem. As large screen television sets and other new solid state electronic devices are installed and add their harmonics to the grid, the impact of harmonics is increasing. Since harmonics have a negative impact on the life of consumer devices this can mean that the average life span of many of these devices is decreasing. Eventually, the industry will have to tackle harmonics issues. Most utilities operate under regulations that allow them to charge the creator of harmonics the cost of fixing the problem it or force them to fix the harmonics themselves; however, almost no utility actually bothers to ensure either today. These issues may be an added cost on S-Dist that may delay installation or minimize operation in the future. Harmonics are not just an issue of S-Dist, V-Dist has similar issues as do many of the new classes of consumer electronics.

Because the S-Dist is installed in the distribution network, the transmission SCADA system does not offer the ability to operate or monitor these generation sources. Instead, the operator of the low voltage network will have to install a system to monitor and control these sources and provide information to the Energy Management System that normally resides in the transmission operations center. Some utilities are choosing to allow a third party to do this work for them, while others are attempting to install the infrastructure to support S-Dist. The Distribution Network Operators (DNOs) in the UK already have these systems installed, but have yet to use them for this purpose. They are generally well ahead of most of the rest of the industry in having the infrastructure to support these sources.

Loss of power from a system failure should cause most S-Dist systems to automatically disconnect from the grid, since they seldom are large enough to support the entire load in the remaining section of the grid that they are now connected to. This means that while the customer that owns the S-Dist has a higher level of reliability, the rest of the customers do not. Most S-Dist is very useful for shaving the peak—i.e. reducing the demand for a section of the grid when the demand for power is at its highest. This is very useful when the grid is reaching its limit for providing power. In the case where this is all the S-Dist is being used for, it might run as much as 200 hours a year. This is a huge capital investment for roughly 2% of the year. Most customers who would install S-Dist would do so for reliability rather than to support peak shaving. In many cases, the price that would have to be offered to the S-Dist owner to run their generation to shave the peak would be much higher than the cost to generate power at a central station—further reducing the number of hours that the S-Dist might run.

Finally, these generation sources typically have a site approval problem—since most are diesel and gasoline engines running bio-fuels, they are noisy and smell (imagine McDonalds French fries for bio-diesel). Many people do not want to see them installed in their neighborhood and even fewer people want to hear them run at 3 o'clock in the morning.

V-Dist

Finally there is V-Dist, the kind of renewables that most people think of when you mention renewable generation—human-scale renewables that should blend into the neighborhood. These solar and wind powered devices are owned by business owners and homeowners. They are deployed in the low voltage network and suffer from all the same problems that S-Dist does. This includes the issues with harmonics and with phase imbalance.

They have even had issues with smell and noise (for instance, solar cells that cooked tree sap giving off strong odors and windmills that make noise all night long). In addition, these devices pose another problem for the grid operator—they run when the environment is right and do not run when it is not. They use the grid like a large battery, putting excess power into the grid and drawing power from the grid when they do not make enough. In similar cases, going from a net generator to a net consumer can take seconds. This works well when the percentage of power produced from V-Dist is small, but as the percentage increases there will need to be real batteries installed on the grid, and that is a whole different story with its own issues.

Most of the best places to put wind mills and solar cells are out in the suburban and rural areas where the people density is less, and that means the power consumption is also less. In many cases, this means the size of the wires in the distribution grid are also smaller. To put larger numbers of V-Dist units in the rural areas and move the power to people who will use it may involve re-conductoring—replacing the physical wire in the distribution grid so that it will carry more power than it does today. For an overhead system, where the lines are up on poles, re-conductoring can cost as little as $100,000 a mile. For underground systems, that number can run into more than a million dollars a mile. Companies like HydroOne in Canada made the decision to re-conductor years ago and made it a multi-decade program to replace thousands of kilometers of wire when they did maintenance.

Unlike the V-Cent, these systems are maintained by the homeowner and many of them find they do not get the power output they were promised by the salesman; so they do not make the money they expected and hence do not maintain the generator. This leads to a collapse in the capability of the system to make power and can make the generator even more erratic then it was when it was first installed. One of the first components to typically fail is the islanding device and the inverter. The failure of these devices does not typically isolate the device, but rather they fail most often providing DC power into the grid even when they should be islanded. The failure of the power electronics creates a hazard for the lineman who is dispatched to fix the network outage, since they have no clue that the power is still flowing through the line and many transformers will step up the voltage for this distributed power. The ability to monitor the health of the power electronics—both the inverter and

		ABILITY TO BUILD									COST TO OPERATE					EMISSIONS						LOAD SUPPORT								
GENERATION SOURCE	Typical Size (MW)	Technology Readiness	Capital Cost	Public Acceptance	Cooling Water	Site Size	Time to build	Decommissioning costs	Similar plants in production	Lead Times	O&M Costs	Fuel Availability	Foreward fuel price	Fuel Competition	Fuel Efficiency	CO_2	Sulfur	Mercury	Particulates	Waste	Wildlife Impact (Beyond Emissions)	Dispatchable	Schedulable	Reliabity	Ancillary Services	Ramp Rate	Capital Costs (Kilowatt of capacity) USD	Source for capital costs	Cost per KWH (cents - USD)	Source for cost per KWH
Baseload																														
Conventional Coal	600																										1534	2	5.2	1
Nuclear	1000																										3540	1	7.8	1
Pebble bed Nuclear	200																										1000	4.5		
Hydro	500				NA																						1551	2		
Biomass	600																										2809	2		
Biogas	300																										1897	2		
Combined Cycle Natural Gas	300																										717	2	7.2	1
Simple Natural Gas	200																										500	2		
Clean Coal	NA																										2537	2	9.6	1
Clean Gas	NA																													
Petroleum	300																										717	2		
GeoThermal																											1110	2		
Concentrating Salt/Solar	NA																													
Peaking																														
Aero Gas Turbine	25																										473	2		
Diesel	5																										1021	2		
Fuel Cells	1																										5374	2		
Gasoline	<1																										1227	2		
Pumped Hydro	300				NA							NA															1200	3		
Variable																														
Photovoltaic	<1				NA																						5649	2		
Thin Film Photovoltaic	<1				NA																						1000	6		
Wind Mills	3				NA																						1434	2	8.8	1
Wave Machines	15				NA																						5040	7		
Concentrating Solar	50				NA																						3744	2		

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islanding device—is critical to the safety of people working on the system, and a simple fine for failure to maintain the system is not enough to remove the human hazard that exists. This human hazard can exist with S-Dist as well, but empirical data from working with both S-Dist and V-Dist indicates that the S-Dist sees fewer failures and more maintenance than V-Dist installations.

Summary

Renewable generation is an important part of the future for the electric industry—we can not avoid it and we cannot hide from it. We have to work through these problems and make integration of renewables easy. IEEE-1547 provided the basic interface for renewables to the grid, so the interconnection, the largest stumbling block a decade ago, has been solved. Now the issues move to the integration of the renewables into the operation of the grid. Some of the issues can be solved with planning—relaying and protection schemes can be redesigned and the new standard can be deployed as circuits are maintained or built. This is an important step in being ready for distributed generation, and not just renewable generation. Working with regulators to determine how to test the status of power electronics and what the utility is allowed to require for the safety of workers is also an important step. For example: Can the utility cut the wire to the power electronics and remove it, if the islanding device is not functioning correctly? What are the rules for safely operating these devices and ensuring maintenance? This will have to be solved for each utility, as there is no universal answer. Site approval is an issue that will not go away, and in most cases it is the responsibility of someone other than the utility. Putting the devices on the right phase, if they are single phase, again is an issue that takes working with the regulator to get a way to incent people to put them in the right places, or for the utility to install and support installation in the right places.

Dealing with variability is tough. The choices are ancillary services, demand response, or storage. To date there are no good answers for storage, although the battery industry keeps promising that in 5 years they will have an answer—this started in the 1970s and continues to be a 5 year promise. Demand response means installing devices that either provide information or control in the homes. This is part of many smart metering deployments. Finally, there is ancillary service—burning fossil fuels to support the integration of variable renewables in the grid or holding hydro facilities in reserve to provide instant voltage support. This is a question that will take research, planning and operational work to provide an answer for, and it will not solve the "too much power" issue on a day when customer demand drops to almost nothing.

Harmonics, reactive power, and power quality are harder problems. The transmission operators manage reactive power and many of the sensors on the transmission networks exist to handle reactive power. Capacitor banks are helpful in managing reactive power, but typically they do not exist out in the distribution network and the sensors and controls to use them effectively also do not exist. Harmonics and power quality for the smaller customer to date have been ignored as too expensive for the benefits delivered. The question is when the tipping point is reached and these problems have to be sorted out.

Integration of hundreds or thousands of generation sources into existing Energy Management Systems and Distribution Management Systems, as well as developing the operating rules is another significant chunk of work. Knowing what is really happening in the distribution network is more than just the renewable issue; most of the distribution network has very little in the way of sensors available to provide information on what is happening. Putting this issue on to renewables is unfair, but it is a gating item for successfully installing S-Dist and V-Dist. Smart Metering is a step in the right direction for sharing this cost.

The good news is that nothing new needs to be invented—only improved and deployed (with the exception of storage). Renewables are a key part of fixing the carbon issue and providing electricity where the cost of power is not tied to the cost of fossil fuels. Fuel price swings and the move to carbon markets will tend to accelerate the move to renewable. The new US Energy Team under President Obama will also accelerate this move in the US and that will have an impact on the rest of the world. Regulators, customers, utilities, manufacturers and independent power producers will all have to work together to make this work. For more than 100 years, we have been improving, perfecting and investing in the existing electric grid. One estimate for transmission alone indicates that the US would have to spend over $900 billion to support a plan like the Pickens Plan. Globally, it would amount to trillions of dollars.

We have a long way to go, we need to make the journey, but knowing the issues we will encounter along the way and planning for them in advance will make the journey more likely to succeed. This is a journey that we need to take, let us all do it with the highest possible chance to succeed.

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