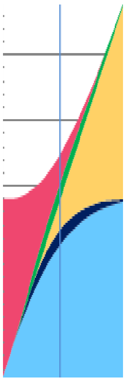


Wind Power is only Energy, no guaranteed power even with batteries

The confusion between power and energy has made it possible for wind turbines to sell the wrong product to the wrong market.

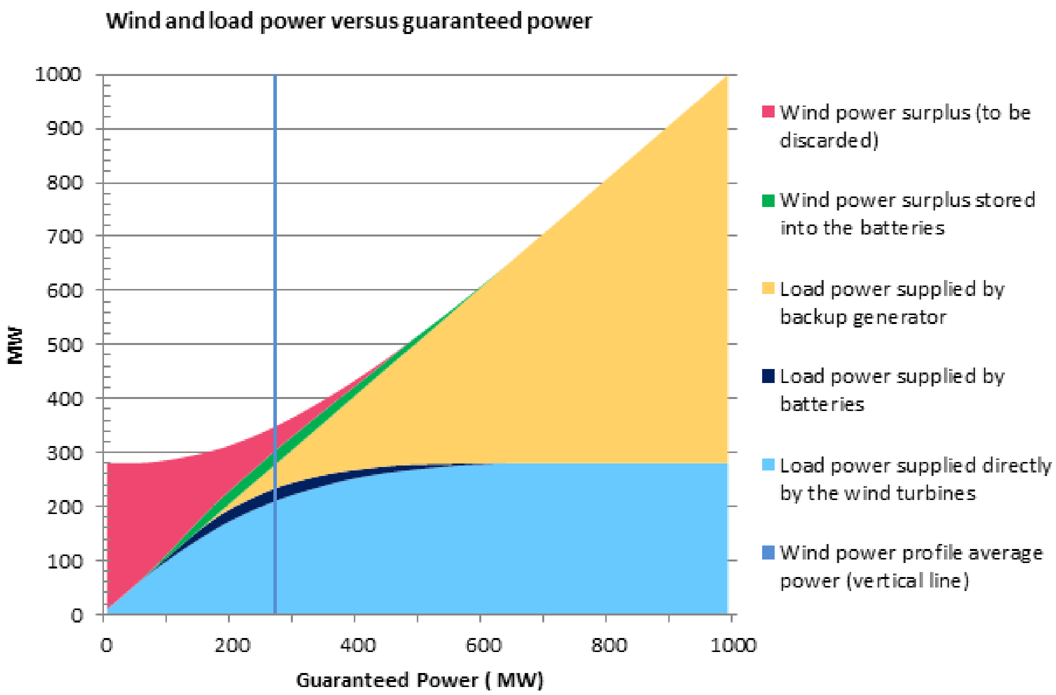
Marc Deroover; May 2021

Summary

An electrical power network is all about power: at any moment, the network must deliver the power called upon by its customers. But wind turbines produce only variable power. Therefore the networks have to transform this variable power into a fixed guaranteed power in order to integrate it into their production plan.

This transformation requires backup generators, backdown generators, and, supposedly, various other exotic means like backup batteries or hydrogen storage. The costs of these tools are difficult to evaluate because they are hidden in the daily network's operations. But we can have an idea of the type and magnitude of the problems encountered if we force the wind power plant to provide a fixed and guaranteed power and look at what has to be done to reach that goal.

The behavior of a wind power plant that has to provide a fixed and guaranteed power is illustrated in the following figure that shows, for each guaranteed power level the average value of the various power flows in and out of the system



The figure is drawn for a 1000 MW power plant, with a wind load factor of 28%, coupled with backup power generators and 4GWh batteries. The values are calculated for each guaranteed power value based on the day by day simulation of the system. The resulting daily values are then aggregated over the period to show the average power flows. Looking at the figure, one can see that:

- For all levels of guaranteed power, the wind turbines need some backup power to be able to provide the guaranteed power – except if this one is very low, which wouldn't make much sense

- A wind turbines power plant cannot even sell all the energy it produces if it must guarantee a power equal to its average power. In our example, about 25% of the wind energy produced by the wind turbines will need to be discarded and replaced by the production of some backup generators

- Once the guaranteed power reaches the wind power average power, nearly all additional power will be provided by the backup generators, except for a few percent more of the wind power surplus that could finally be used to feed the load

- The batteries can only be filled using a fraction of the wind power surplus: with or without batteries, the fraction of the wind power that can directly feed the load remains unchanged

- In our example, 4 GWh of batteries will allow for the saving of 9% of the wind power produced, thereby reducing the wind power surplus from 25% down to 16% of the wind power produced – probably at a huge price

- The batteries are totally useless when they are full and there is too much wind, or when they are empty and there is not enough wind. This happens up to 50% of the time in our example. This is mainly due to the fact that the batteries are always too small with respect to the installed wind power (because of their cost)

- When the guaranteed power increases, the batteries become useless, because there is no enough wind power surplus to fill them. They remain empty most of the time.

- More surprisingly, the batteries become also useless when the guaranteed power decreases. This time it is because there is not enough wind power deficit to use the energy stored in the batteries. They remain full most of the time

If you understand how a wind power plant forced to produce a guaranteed power works, you will also understand that any time someone promises you that wind turbines will provide some "magic things" that are not shown in the previous figure, what they really mean is that they intend to use the resources of the network to let you think that wind power is, well, "magic".

You can try to add batteries in the customer houses, or use some hydrogen storage. But, because these things need to be filled with some power before being useful, they will behave as the main batteries of our example - very inefficiently.

That wind turbines are some kind of magic engines that could violate the laws of thermodynamics is one of the great illusions of our time. Only by pumping for free the resources of the network can wind turbines pretend to provide useful services.

There comes a time when people will realize that the laws of physics apply even if they don't know them…

Electrical power network is all about power, not energy

An electrical power network is all about power: at any moment, the network must deliver the power called upon by its customers.

Energy is a derived value. It is very convenient to compute the price that will be invoiced to a customer, and is therefore well known by the general public. Although most people think they are paying for energy, there are in fact paying for the power they require at each moment (simply said, the energy is a measure of the average power called upon).

So when the electrical utilities were managed by engineers, the network managers used to buy enough power production from their suppliers (power plants) in order to meet the expected customer load, plus some reserves to handle unexpected events. Energy was never part of the game.

Now that the electrical utilities have to obey the politicians, all that has changed: the network operators are now forced to buy the production of wind turbines.

But wind turbines do not produce "power" in the sense of "guaranteed power" as required by the network. Wind turbines only produce some energy at variable and not controllable power.

The politicians and wind power pundits know that very well. They always say "the wind farm will produce the energy equivalent to the consumption of so many households". They never say "the wind farm will produce the power required to supply so many households", because they know wind turbines cannot guarantee any power level.

So the basic problem with wind turbines is that they produce the wrong product for the wrong market.

Wind turbines: the wrong product for the wrong market

To be integrated into the network production plan, the variable wind power needs to be converted into a fixed guaranteed power.

This is done by the network that has to provide backup generators that will increase their output when there is less wind than expected, backdown generators that will decrease their output when there is more wind than forecasted, and various other exotic means like backup batteries or hydrogen storage.

All these required tools, as well as their associated costs, are hidden into the daily operations of the network. It is therefore difficult to identify them and to estimate the real damages inflicted to the network by the variability of wind power.

However there is a way to visualize the work that the network has to do in order to transform the wind variable power into a guaranteed power it can use.

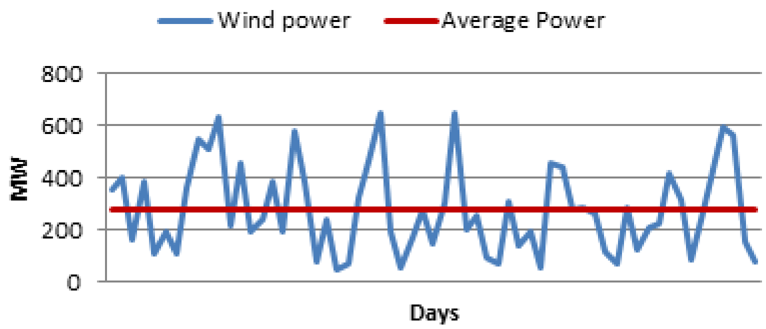
Instead of forcing the network to take the variable wind power, let's force the wind power plant to provide a fixed and guaranteed power, and therefore to provide and pay for any mean required to obey that constraint.

By doing so, we will see better what the network is doing to handle the wind power. We will also have a glimpse at to what our networks would look like if the push to increase the installed wind power would ever succeed.

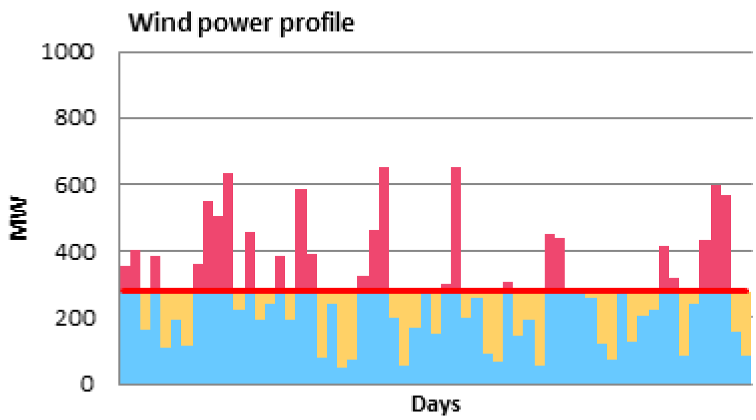
If a wind power plant had to provide a fixed guaranteed power...

Before going into the little model that will help us to understand how a wind power plant operates, let me stress first that the goal here is just to describe the way things work, and maybe to provide some order of magnitude of the problems encountered. The results that will be presented depend heavily on the data used, in particular the wind power profile, and can therefore not be applied as such to other systems.

The first thing we need is a wind power profile. I have selected two months of a real wind power profile in Western Europe, and rescaled it to get an installed wind power of 1000 MW while keeping the original 28% load factor:

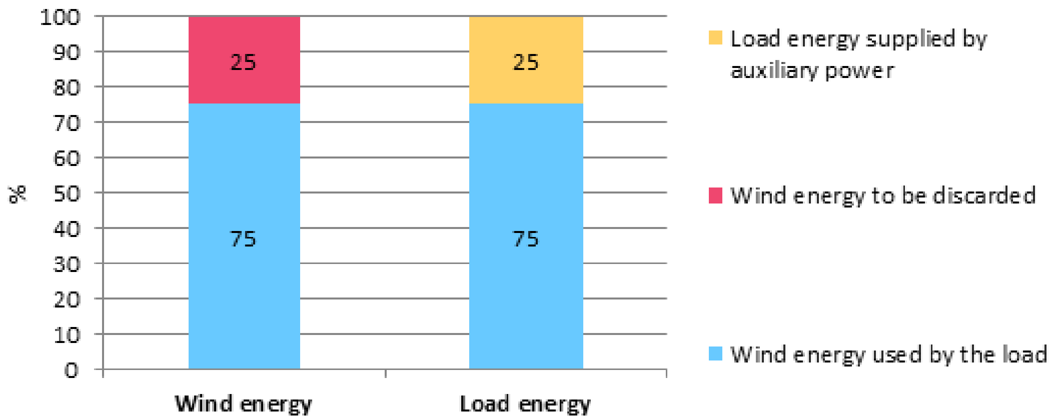


If we first make the assumption that the wind turbines owner want to sell an amount of energy equal to what its turbines will produce, that is to guarantee a power of 280 MW, the wind power will be used as follows without batteries:



- the horizontal red line represents the guaranteed power PG
- all wind power that is below PG will be used by the network (blue)
- all wind power surplus (above PG) has to be discarded (red)
- backup power must be provided to reach PG when the wind power is below PG (yellow)

The balance of the average power (or energy) is shown in the next figure (please remember that when PG=Wind average power, the energy produced be the wind turbines is equal to the energy feeding the load):



The first thing that we see is that a wind turbines power plant cannot sell all the energy it produces if it must guarantee a power equal to its average power.

About 25% of the wind energy produced by the wind turbines will need to be discarded. This power corresponds to the power produced above the guaranteed power.

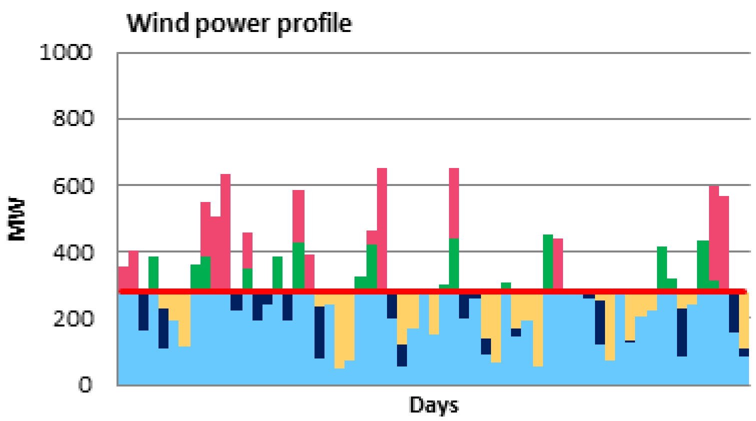
Therefore, to supply the guaranteed power, the same 25% of the load will have to be supplied by some auxiliary power (”backup power”).

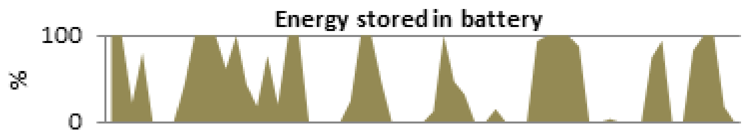
We will see later how these values change when the guaranteed power is increased or decreased.

Batteries behave counter-intuitively

Let's now look at the same system but coupled with 4 GWh batteries. Note that this means that 4 MWh batteries have to be installed for each MW of wind turbine power. This is incredibly expensive, and probably economically impossible. But let’s look at what benefits such a level of batteries capacity would provide with respect to energy flows.

We still suppose that we want a guaranteed power equal to the average power of the wind turbines (28% LF, or 280 MW). In this case, the wind power profile would look like this:





The upper graph is the same as the previous one, with two differences:

- part of the wind power surplus (in red) is replaced by the power that is used to fill the batteries (in green)

- part of the power that was produced by the backup generators is replaced by the power provided by the batteries (in dark blue)

The lower graph represents the chronological charge level of the batteries. Note that the batteries are full at the beginning of the period. You can see that the energy stored in the batteries increases with the green lines, and decreases with the dark blue lines.

We can now understand how batteries work with a wind power plant forced to guarantee a fixed power output:

- If on a given day the wind power exceeds the guaranteed power level, the system will first use the power surplus to fill the batteries. Once the batteries are full, the remaining wind power surplus has to be discarded.

- If on a given day the wind power is below the guaranteed power level, the system will first use the energy stored in the batteries to supply the load. Once the batteries are empty, the remaining missing power has to be provided by the backup generators

Looking at the evolution of the energy stored in the batteries, we can observe a somewhat expected characteristic of the batteries: they are totally useless

- when they are full and there is too much wind

or

- when they are empty and there is not enough wind

One can also see on the same figure that nearly 50% of the days are “death days” for the batteries – days when the batteries were simply not operational.

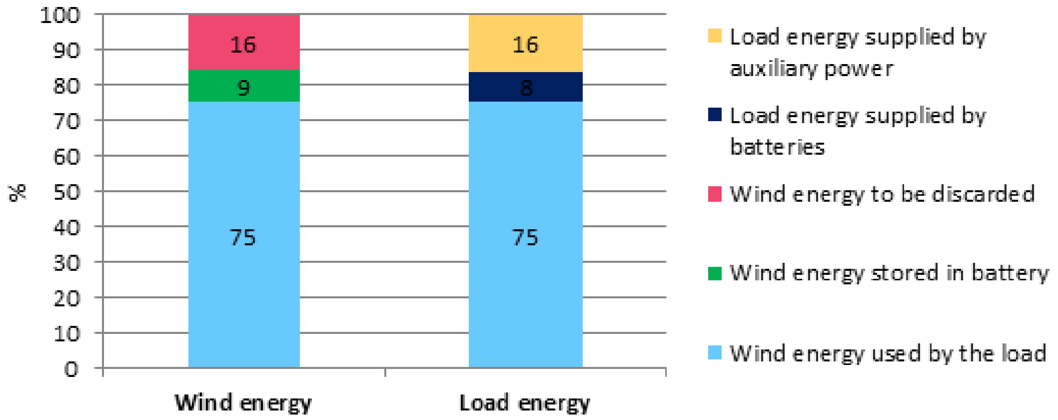
The main explanation for the high number of “death days” is that the batteries are too small.

If the wind produces 200 MW more than the guaranteed power, this will mean 4.8 GWh over the day, or more than the 4 GWh of installed batteries. Therefore the batteries are filled in less than one day, and remain useless until there is a deficit of wind power.

The same is true when there is a deficit of power. The whole batteries can easily be emptied in one day, after what they remain useless until there is a surplus of wind power.

Of course one could increase the size of the batteries, but we will see later that it does not change a lot on the final power balances, although it is a very expensive option.

With the batteries, the balance of the average power (or energy) now looks like this:



- This figure shows another characteristic of the couple wind power-batteries: the batteries can only be filled using a fraction of the wind power surplus. With or without batteries, the fraction of the wind power that directly feeds the load remains unchanged.

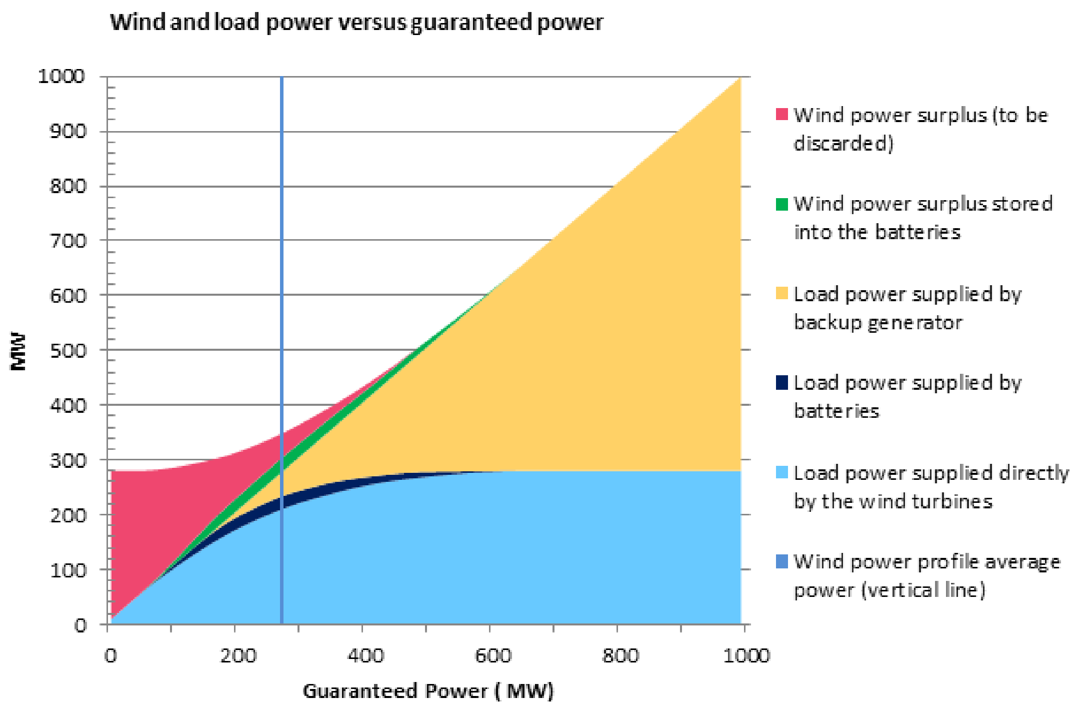
- The figure shows that the 4 GWh batteries will allow for the saving of 9% of the wind power produced, thereby reducing the wind power surplus from 25% down to 16% of the wind power produced.

- If we make the rough assumption that the investment cost of a 1 MWh battery is about the same as a one MW wind turbine installed, the energy provided by the batteries will cost about 33 times more than the energy directly provided by the wind turbine (in terms of investment costs).

The overall picture

The question now is to understand how the values calculated in the previous figures change when the guaranteed power is modified.

This can be done by calculating these values for the whole range of guaranteed power and showing them as in the following figure:



There is a lot of information in this figure, but let us first understand how to read it:

- The abscissa shows the guaranteed power. It varies between zero and the installed wind power (1000 MW in our case)

- The vertical blue line is set at the average power output of the wind power plant (in our case 280 MW, or a 28% Load factor LF)

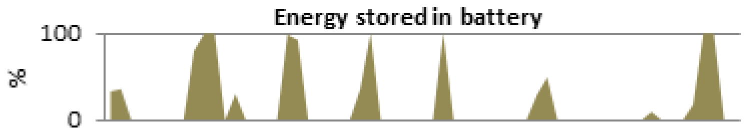
- The ordinates of the graph represent the average power produced or consumed by source of power, calculated as shown in the previous sections of this document. Such a graph would usually represent the energy produced by each source, but I prefer the concept of average power because it rescales linearly the values between 0 and 1000, allowing for an more intuitive comprehension of the physics involved in the process

- The diagonal represent the points where the total power produced is equal to the guaranteed power. It split the plane into two sub-spaces:
  - below the line are the various powers that feed the load: wind power directly usable, batteries discharge power and backup generators power
  - above the line is the wind power surplus that must be either discarded or used to fill the batteries

So when you have a wind power profile, you can calculate and draw this graph. Once this is done, you can easily know what will be the energy (or average power) that will feed your load, feed the batteries or have to be discarded for any guaranteed power: simply draw a vertical line at the chosen guaranteed power, and look at its colors.

Amongst the many observations one could make while looking at this graph, the most significant are the following:

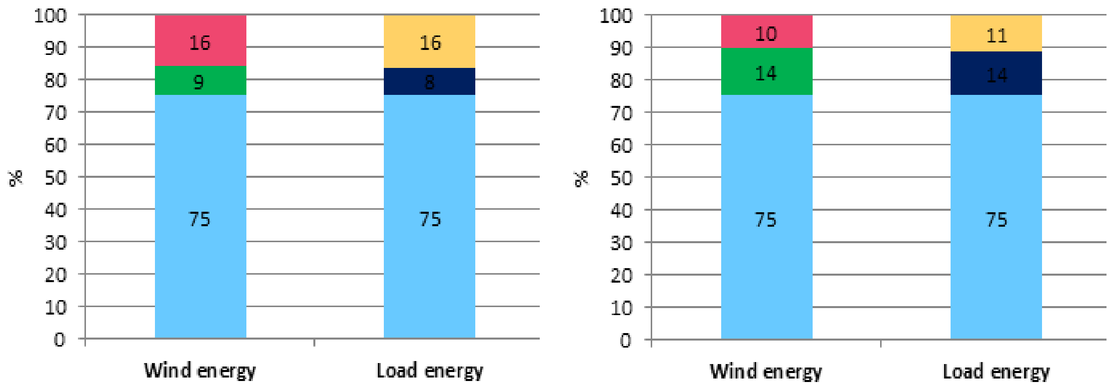
- for all levels of guaranteed power, the wind turbines need some backup power to be able to provide the guaranteed power – except if this one is very low, which wouldn't make much sense
- once the guaranteed power reaches the wind power average power, nearly all additional power will be provided by the backup generators, except for a few percent more of the wind power surplus that could finally be used to feed the load
- as already seen, the batteries can only use a fraction of the wind power surplus, and they are too small with respect to the installed wind power. They are therefore pretty useless, saving only about 10% of wind turbines energy when the guaranteed power is equal to the wind average power (28%)
- when the guaranteed power increases, the batteries become totally useless, because there is no enough wind power surplus to fill them. The batteries remain empty most of the time, as shown here below (PG=400 MW)



- more surprisingly, the batteries become also useless when the guaranteed power decreases too much. This time it is because there is not enough wind power deficit to use the energy stored in the batteries, although there is a lot of wind power surplus to fill the batteries. The batteries remain full most of the time, as shown here below (PG=160 MW)

What about doubling the batteries storage capacity?

The following figure show the average power flows with a 4 GWh battery (left) and with a 8 GWh battery (right)



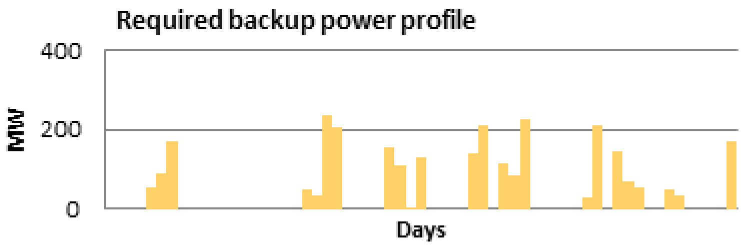
As you can see, doubling the batteries capacity will allow for the additional saving of 5% of the total wind power production. This is a ridiculous amount if you consider the related investment costs.

When the wind power plant is inserted into the network...

So what happens when the wind power plant is inserted into the network, as it is currently done everywhere in the world?

➢ ... the backup power must be provided by the network

To begin with, the backup power must be provided by the network. In our example, the backup generators must be able to provide 234 MW, with a load factor LF of 19%. Their generation schedule is show in the next figure:



This shows that the backup generators have the characteristics of what is called “peak units”. For economic reasons they should probably consist of open gas turbines or diesel units (high fuel costs, but low investment costs - and high CO2 emissions).

There is a believe that this is a false problem, because the network could supposedly use the backup power it already manages to alleviate the risk of blackout in case some power plant would fail.

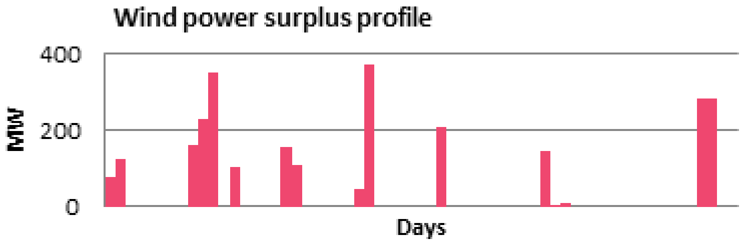
But this is a spurious argument. The backup power for controllable units is calculated to reduce down to an acceptable level the risk of blackout following the failure of some power plant.

Any time you use this power reserve for any other purpose, you reduce accordingly the overall reliability of the network. This has a cost, even if you cannot see it as long as everything goes well.

- ... the network must get rid of the wind power surplus

Because the networks are forced by law to buy all the power provided by the wind turbines, they have to get rid of the wind power surplus.

In our example, this power surplus has a maximum value of 370 MW and a load factor of 12%. Its profile is show in the next figure:



If you want to use this power for some useful load, like feeding a hydrogen production plant, you will need some controllable unit that in reality will produce most of the power used by the load (they should therefore be called “Backdown power”: power that is produced most of the time, but can be reduced to compensate for the wind power surplus).

Improving wind power performances: the great illusion

If you understand how a wind power plant forced to produce a guaranteed power works, you can get an idea of what the network has to do (and pay for) to use the variable wind power.

You will also understand that any time someone promises you that wind turbines will provide some “magic things” that are not shown in the figures of this article, what they really mean is that they intend to use the resources of the network to let you think that wind power is, well, “magic”.

Let’s just take a last example. People will tell you that by installing batteries in the customer houses they will save energy and improve the efficient use of the wind turbines.

This is a nice idea. It could indeed reduce the load at some point. But these batteries need to be filled, and will behave exactly as the main network batteries (supposing these ever exist). And as shown in this simulation, it means very little savings for a huge cost.

The same goes for other proposed solutions like hydrogen storage. After all, hydrogen storage is just a sophisticated battery, and hydrogen needs to be produced before it can be used. And therefore it will also behave as the main network batteries…

That wind turbines are some kind of magic engines that could violate the laws of thermodynamics is one of the great illusions of our time. Only by pumping for free the resources of the network can wind turbines pretend to provide useful services.

There comes a time when people will realize that the laws of physics apply even if they don’t know them…