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February 14, 2021
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Is a "100% Renewables" Power System Really Feasible?

On Wednesday January 27, 2021 RTE (Electricity Transmission System Operator for France) officially presented at a press conference a study done jointly with the IEA (International Energy Agency) entitled:

"*Conditions and requirements for the technical feasibility of a power system with a high share of renewables in France towards 2050*"

The study was commissioned by the French government. While it does address the essentials, it is an archetype of a publication that allows dual reading, undoubtedly with the intention of satisfying different readerships, where each will find what it is looking for. A cursory reading may lead to the conclusion "it is possible"! However, a more attentive and in-depth examination of the conditions and requirements leads to the conclusion that the challenges to be met are in fact considerable...

This dual-reading aspect stands out right at the beginning as we read:

"Even if they still need to be proven at large scale, there is a general scientific consensus that technological solutions to maintain power system strength – and hence system stability – without conventional generation exist [...]. This solution has been successfully tested in the laboratory (for example, in the European project MIGRATE) and on microgrids, but not yet at the scale of a large power system, where other complications could arise. Full-scale experiments are needed in the coming years to validate this concept."

Further down, in the text body we find:

"There is now a broad scientific consensus on the theoretical stability of a power system without conventional generation."

We will pass over the fact that a consensus that focuses only on "theoretical" aspects cannot be "scientific", since the very nature of the scientific approach is to confront theory with reality. The important point here is that the reality referred to is limited to laboratory results and experiments on microgrids, which are far removed from large grids; in fact, the study notes this a little further on:

"*[...] given that there is no proof of concept regarding the integration of high shares of variable renewables –such as wind and solar PV– in large power systems, technical challenges are bound to come up.*"

So, matters are quite clear: everything remains to be done in terms of experimental validation on large grids. Indeed, "*four sets of strict and cumulative conditions*" would have to be met to allow the integration of a very high proportion of renewable energy:

1- **Maintain power system stability and strength** at a level equivalent to what it is currently despite the **reduction of current dispatchable means**. This is the sine qua non requirement for the viability of such a system, it conditions all the rest and is the subject of more detailed developments below,

2- **Develop new means to cope with the considerable variability of wind and solar PV** including, in particular: new dispatchable peaking units that will have to use synthetic gas fuels such as hydrogen or biomethane to avoid CO_2 emissions; large-scale storage facilities of these synthetic or biological fuel gases; considerable demand-side flexibility i.e., simply stated, widely adapting demand to match wind and solar PV production.

3- **Thoroughly resize security reserves so as to balance production uncertainties**. Reserves will have to be significantly increased to cope with the uncertainties, and with intermittent, variable, and decentralized character of wind and solar PV productions.

4- **Significantly extend and reinforce the transport and distribution networks to cope with additional electricity flows from wind and solar PV and their large spatial distribution.** This will have a notable impact on land use and social acceptability.

If words mean anything, "*strict and cumulative conditions"* means that if any one of these conditions is not met, the whole edifice collapses. Now, combining four conditions, each of which will be difficult or very difficult to satisfy, considerably reduces the overall probability of success. Moreover, other non-technical but equally essential difficulties will add on to this, if only social acceptability, which is very much a cross-cutting issue for three of these four conditions.

The first of the conditions stated above is the most critical because it implies a radical change in the design and operation of power grids. Its complete fulfillment determines the technical viability of such systems. The main reasons for this are detailed below.

Maintain power system stability and strength despite the reduction of today's dispatchable generating means.

Instantaneous stability is the most fundamental condition for the proper operation of a power system. In a 100% renewable power system, the generating sources would be connected to the grid through power electronics (inverters) and no longer through synchronous alternators, of which only those of hydro and biomass power plants would remain. Such a massive removal of synchronous alternators would have two major consequences:

* In the current system, the inertia provided by the alternator rotors plays an essential role in the stabilization of the frequency by damping its rapid variations, leaving time for the power regulators on the machines to re-establish the supply-demand balance. However, there is a palliative solution which is indicated in the study. It consists in using "synchronous compensators" which are nothing more than alternators that rotate freely, without producing electrical power. The issue could therefore find a proven solution, but "*a generalized roll out in the context of large-scale system strength has yet to be evaluated*" according to the RTE study.

* Contrary to the alternators which generate their own frequency and voltage wave and synchronize themselves autonomously to form the grid naturally (they are called "grid-forming" for this reason), today's inverters are unable to do so (they are called "grid-following"). A new type of inverter, capable of performing the same apparent "grid-forming" function as alternators, has been developed. They have been successfully tested in the laboratory and on microgrids. But this in no way guarantees their ability to operate on a massive scale in large grids. Not only do they not synchronize autonomously like alternators, but a new factor must be taken into account: the "multitude challenge". Indeed, since intermittent sources have much lower unit capacity than large alternators and their production is much more uncertain, tens of thousands of "grid-forming" inverters would have to be mobilized to form the grid, whereas currently fewer than a hundred large alternators are sufficient. This large number of inverters would have to be able to operate together in parallel in a stable manner, without priority conflicts, without power oscillations between them, etc. There is no proof that this is possible as long as we do not have extensive and thorough experimental validations on this large scale. This is a major uncertainty that could hinder further progress if guaranteeing stable operation in this way proves impossible.

Moreover, this large number of inverters would imply multiplying by a considerable factor the number of control-command links required to drive both the power-frequency and the voltage of these "grid-forming" inverters in real time. Such a system would require extensive use of artificial intelligence (see below).

* Finally, a power grid is designed to transport electrical currents, which, combined with voltage, generate electrical power. However, these currents can vary in considerable proportions, in particular during incidents such as frequently occur on the grid under the effect of lightning or technical failures, etc... These incidents produce short-circuits leading to very high currents. Most of them are fugitive and are eliminated naturally within a few seconds or less. During these incidents, the alternators can be subjected to transient overcurrents up to 5 to 6 times their nominal current. As they can withstand these without damage, they can remain connected to the grid and resume normal production as soon as the fugitive default is eliminated.

Conversely, electronic inverters can withstand only very limited overcurrents (of the order of 1.2 to 1.5 times their nominal intensity). In order to avoid their being damaged in the event of short-circuits on the grid, it would be necessary to disconnect them during such incidents, leading to the loss of their production, which could seriously disrupt the overall supply-demand balance. There would then be a risk of cascading failures. To avert such risks, it would be necessary to either increase the rating of the inverters to allow them to withstand significant overcurrents, or to use a profusion of synchronous compensators and/or batteries to protect them; these different solutions would probably have a considerable cost.

To sum up: this is nothing less than a complete technical overhaul of the current technology which, since it was invented 130 years ago, has allowed the development of today's power systems worldwide, with remarkable reliability and security levels. Moving away from this technology obviously requires careful consideration and thorough validation to ensure that these achievements will be preserved. Everything remains to be done in this respect.

Can a power system driven by a necessarily hypercomplex artificial intelligence be absolutely cyber-secure?

Obviously, controlling the frequency and voltage of tens or even hundreds of thousands of inverters in real time will not be within the reach of human action. An additional digital layer (digital telecommunications network) will have to be added that will have to rely on artificial intelligence, given the hyper-complexity of the overall power system management. In addition to controlling the generation units themselves, the system will also have to drive energy storage / destocking, demand flexibility and exchanges with neighboring countries. And it will have to do so safely and in an economically optimal way.

A digital system of such complexity and geographical extension will raise the major question of its resilience. It will have to be flawless given the consequences of a cyberattack which could lead to an event as severe as a generalized blackout. This issue, despite its major impact, is curiously not mentioned in the RTE study. Yet, it will represent a new risk compared to the current situation where the alternators are naturally synchronized robustly in base load production by the laws of physics so that they require only a reduced number of links with no or little digital support for their remote control. Indeed, experience demonstrates the resilience of current power systems: like other industrial infrastructures, they are subjected to numerous cyberattacks. To date, only one of these (attributed to the Russians, aimed at Ukraine) seems to have succeeded, and even then it did not concern the alternators but the circuit breakers in the grid substations.

The validation on existing real grids will probably be exceedingly difficult...

This difficulty is due in particular to the fact that these grids are not laboratory instruments available for experiments but must continue to meet the needs of citizens and the economy of an entire country at all times: it would not be acceptable to jeopardize their supply for experimentation purposes. Moreover, to be relevant for all circumstances, the full-scale trials will have to be carried out at the right scale. Can a test conducted on a "small" grid such as an isolated island or a portion of a large grid be valid? Can we be sure that expanding to a whole large grid, strongly interconnected with the European grid, will not reveal phenomena that cannot be detected on a smaller scale? Only experiment can bring the infinite richness and diversity of reality and its lessons. Obviously, the answers to these questions are not simple but they must be part of the investigation.

Finally, since insurmountable difficulties may arise during the deployment of these new solutions, it should be possible to back out, which implies retaining the existing system for as long as it takes to validate the new one with complete certainty.

At the end of the day, a development that presents the risk of deteriorating the security of supply.

The above assessment of the changes inherent to the transition to a very large share of intermittent generation leads to a much greater complexity of the power system and its management, bringing new risks of deteriorated overall reliability: very significant increase in the variability of production due to the massive contribution of intermittent generation, drastic reduction of the remaining dispatchable means (hydro, biomass), reduced grid inertia that is more or less well compensated, considerable increase in the number of generation units connected to the grid but also of the compensation means (storage / destocking, massive load shedding, increased exchanges, inside the country and with foreign countries) that will have to be managed, and finally, probably most critical, introduction of cybersecurity risks that are totally new in this field.

It is then legitimate to fear decreased overall security of supply compared to the remarkably high level reached decades ago. Would the citizen-consumers accept this?

In-depth risk studies should be conducted on these issues, including this perfectly legitimate societal concern, which should be added to the already long list of other social acceptance issues identified by RTE.

Power system evolutions must be based on proven technologies.

The clear conclusion that we can draw from the above is that we are still far removed from being able to say that all this is "possible". A great deal of R&D is needed, particularly full-scale validations on real grids for a sufficiently long time before we can reach the conclusion that "this is possible". According to RTE itself, this will take years and there is, today, no guarantee of success.

Until then, as announced by RTE, the studies will be supplemented by autumn 2021:

* With a cost estimation of the power system as a whole, the only appropriate approach as it includes the cost of all the necessary balancing and compensation means.

* With an exhaustive evaluation of the environmental footprint including: CO_2 emissions; land use of the numerous additional power lines, wind farms and ground-mounted photovoltaic power plants; and finally, the critical materials needs for these new technologies,

* Finally, last but not least, with an evaluation of social acceptance which already involves several areas and would be worsened by lifestyle changes (logic inversion between demand and production leading to a more or less extensive demand-side response to the production of the moment) that would overturn the current setup.

This information will be crucial to shed light for the future. But since the technical feasibility will not be established by 2022 (and probably will not be for a long time), no strategic decision committing the country's energy future to a hypothetical "100% renewables" solution can be made in the short term. Indeed, with a power system that will provide more than 50% of the country's final energy by 2050, the country's future itself will rest on it. Note also that the power system is classified as one of France's vital infrastructures and that RTE has been designated operator of vital importance for national security, including the military.

The conclusion is clear: the future of the power system can be based only on technologies that are already fully proven and resilient at the time the decisions are made.

At this point, a question arises: why should we undertake such complex, uncertain changes in the electrical system, that are likely to entail risks that are very difficult to control? There is no need to do so. A smart combination of nuclear and renewable energies is a much more rational, efficient, and safe response to the climate change challenge. Such a combination minimizes the need for adaptation as well as the difficulties and the risks identified above.

In their interviews by the French daily *Les Echos* on January 28, 2021, the IEA Director General and its President said no differently, stating respectively:

"These emerging technologies have been proven on a small scale and on small power grids. Moreover, if they are available, that does not mean that they are economically and socially desirable."

And:

"It would be a mistake to shut down the French nuclear power plants. Nuclear energy is a national asset for France. Over the past few decades, its development has been one of the ingredients of French economic growth and, technically, it has proven that it operates on a large scale [...] The goal of reaching zero emissions by 2050 is a Herculean challenge. We do not have the luxury of depriving ourselves of one or the other of the clean energies. For France, nuclear and renewable energies are complementary."