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Dear readers

A warm welcome to the second number of the JPR Focus in 2023.

The energy transition was decided a very, very long time ago by today's standards. Today, it has had its day as a buzzword and has been replaced by other keywords such as climate change and decarbonisation.

At the beginning, the 2050 time-horizon seemed to give us plenty of time. Meanwhile, the issue of climate change has become more urgent. In addition, the scope of the task has been identified as going far beyond the issue of energy supply. However, the true scope is not yet fully recognised today. Last but not least, the events in Ukraine have once again heightened the urgency.

For many, the pace of implementation is completely insufficient. The reasons for this are manifold. Two are worth highlighting. One is the misjudgement of the complexity of the task. People are still caught up in the thoughts of the last century, according to which only a few solutions can bring the answer to all questions. In the future, we will have to come up with a variety of combinations. On the other hand, the changes are much more profound than thought and consequently require a different, broad approach.

The following report is intended to provide some clarification and suggest a possible solution. I hope you enjoy reading it.

Best regards
Yours, Jean-Pierre Rickli

The electrical grid oft he future

1. Introduction

The energy transition was decided a good decade ago. It was built on the following pillars:

- Switching energy supply - heat and electricity - away from fossil and nuclear energy sources towards renewable resources.
- Shutdown of the existing nuclear power plants as soon as safe operation would no longer be guaranteed. This should be the case by 2035 at the latest. No new nuclear power plants will be built.
- Since a production gap was foreseeable as a result, it was to be compensated by savings in the order of 30%.
- Mobility was deliberately disregarded, as it cannot be directly influenced from Switzerland, although it contributes to about 30% of the fossil energy consumption.

In the meantime, the path has been taken and implementation has begun. The initially envisioned highway has turned out to be a rocky, narrow road. Many factors have led to this unfortunate development. The most relevant ones are listed here in loose order:

- Use of terms that do not reflect the competencies and responsibilities. We have an energy law at the federal level. Since the federal government is only responsible for electricity, this law is actually only an electricity law. The building sector, and thus also building heating, is subject to the competences of the cantons. However, both levels only use the word energy and understand it to mean something specific. This federal energy law thus roughly covers only one third of our energy consumption. One third is within the competencies of the cantons and the remaining third has been excluded. If a plant is of a certain size and is to produce heat as well as electricity, the approval process has to go through both federal and cantonal authorities.
- Energy supply is considered a strategically important issue. This increased importance has led to much being set at the legislative level. These laws have a centralised energy supply as their basis and often stand in the way of a rapid conversion to renewable energy sources.
- Savings in the order of 30% can no longer be achieved simply by increasing efficiency. As already shown in an earlier JPR Focus (see JPR Focus No. 01/19), the potential for savings through efficiency improvements is relatively small - today's level of efficiency is already very high; improvements can only be achieved with a steadily greater effort - and even at one point the maximum of what is possible has been reached. Thus, such targeted savings can only be achieved by abstaining. The observed general trend, however, is the opposite. Thus, in practical implementation, an inventory of the energy consumed is the very first step followed by a questioning of each item whether it is necessary or not. Nobody likes to talk about such things.
- The entire discussion is always conducted only at the level of the quantity of electricity, i.e., the kWh, MWh or even TWh. This is certainly important for the market and the trade. For grid operation, however, it is rather irrelevant. What is important there, is the power that is currently being called up or can be called up. In general, there is little talk about this. Why? Out of ignorance and also because people prefer to dismiss critical topics as "details to be solved by specialists" instead of getting their fingers burnt. More on this later.

- Due to the characteristics of the renewable energy source - low energy density, time-limited availability, local, production not or only limitedly adjustable to consumption - a change from the previous forms of energy to renewable ones is not simply a switch to another supplier for the buyer or consumer, as many still think. Far-reaching adjustments are often necessary.
- With such necessary adjustments and a target share of 40%, substantial changes to the electricity grid are to be expected. A new approach is necessary and small changes based on the current status can hardly be successful.
- The realisation that by far not only electricity production based on fossil energy sources is solely responsible for the climate misery has led to more and more sectors being brought into the issue - often through the back door - such as mobility and its conversion to electrically powered vehicles. This has, by no means, made the issue any easier, as its 30% share must suddenly also be covered primarily by electricity. Flight mobility continues to be an issue in itself. Solutions are still a long way off. Only ideas for certain applications are available.
- The energy transition has clearly been pushed into the background. Today, people are talking about decarbonisation. This opens the next Pandora's box. It won't be long before people really realise that coal, oil and natural gas are not only energy sources, but also sources of raw materials that also need to be replaced. Hydrogen is the hot candidate for this. This brings us back to the electricity needed for electrolysis. The spiral continues and the electricity grid is not yet aware of it.
- Thinking and acting in politics and business is still strongly influenced by the belief that there will only be one or a few solutions in the future. The fact that the future will be characterised by a multitude of solutions and combinations has not yet arrived. As a result, there is a lot of trench warfare for the respective solution.
- There is no realistic assessment of the availability of resources and production capacities. The assessment is in each case politically adjusted to the timeframe for achieving the goals.
- A top-down view of the problem is missing, as is an overarching concept.

As we can see, we already have a considerable number of questions in front of us that we cannot solve simply by applying some cosmetics to the established situation. A structured, holistic approach is necessary. This report is intended to help a little and to point out possible solutions.

2. Today's network structure and its functionalities

The impact of decarbonisation on the electricity system is not equally strong on all parts of the system. Sometimes the physical part is not affected, but only the transport performance or the clientele, sometimes it is more about the tasks themselves. In order to better assess these impacts, a brief description of today's grid and its functionalities shall be given here.

In principle, the Swiss electricity grid is structured very similarly to most grids in the world. It consists of different voltage levels for efficient electricity transport and distribution. The alternating current with the usual frequency in Europe of 50 hertz cascades from the higher voltage levels to the lowest, the distribution grid.

Seven voltage levels are defined. Power plants are connected to the top 5 (levels 1 to 5). These levels serve to transport electricity internationally, nationally and supra-regionally. The principle of load control of these levels via frequency is relatively simple, even if its implementation is not always so easy, especially in a highly dynamic environment. The grid frequency is given by the speed of the connected production machines. If the load in the network decreases, the production machines experience less resistance, which is reflected in an increase in speed or frequency. Then it is only necessary to close the supply organs accordingly and the power is adjusted. Conversely, if the load in the network increases, the speed or frequency will be lower and then the feeders must be opened. As an alternative to regulating the machines feeding in at the level concerned, it is possible to regulate the power from the higher voltage levels.

It is a very direct and inherently closed way of regulating power. In this way, a change in electricity demand is compensated for almost instantly by adjusting the production line. Even large changes can be absorbed in this way, provided there is a certain degree of predictability. The great inertia of the rotating masses compensates for very short events and, in the case of longer-lasting problems, gives some time to react until the measures take effect. This situation will not change much in Switzerland thanks to the large share of hydro power plants.

This brings us to the already mentioned issue of the limited consideration of the amount of energy (kWh, MWh, GWh, TWh) in the energy problem. For the grid operators, the currently exchanged power is important for grid stability and it can change within a very short time. Very little is said about this. Maybe because it is very well solved today. Here are two examples:

- It's early in the morning, everything is asleep, including the sun, and household electricity consumption is practically at zero. Within half an hour, all the radio alarm clocks go off. Switzerland wakes up - no matter if it's summer or winter time - the rooms are lit up, water for tea or milk is heated, the coffee machines start. Showers are taken, hair is dried. All electrically, of course. TVs or radios are switched on to catch up on the latest news from the night and to know the weather reports for the day. This peak in consumption, which lasts about 2 hours, means the switching on of power plant capacity; on the 24 hours of the day, these 2 hours are only a twelfth of it in terms of energy consumption.
- A major sporting event takes place: a World Cup international football match. The match is approaching half-time. Televisions and dimmed lighting are on. The referee blows the whistle for the end of half-time and within seconds rooms are lit up, cookers are switched on to heat water, coffee machines are in full operation, people are queuing in front of the toilets. Power plant capacity is needed for this extra output. After exactly half an hour, the whole spat is over; until the end of the match, when consumption skyrockets again. Uncertainties in planning are the additional-match time and result. The operator has only a few minutes to know the exact start of the peak and its duration depends on whether the national team has won and there is still much to discuss and celebrate, or whether people, frustrated, will quickly go to bed.

The medium voltage level (level 6) has a dual function. On the one hand, it takes the power from the small power plants connected to it, so it is also frequency regulated. On the other hand, it serves to distribute the electricity to the industrial consumers, to the larger consumers such as the hospitals and to all medium-voltage stations to supply the distribution network (level 7).

Level 7 is designed as a pure consumer level according to the principle of cascading power flows. Since the load of this level cannot be regulated via production machines, it must be made via voltage. According to the laws of electricity, the voltage is highest near the supply station. From there, with load and distance, it steadily decreases. Thus, the voltage is regulated at the medium-voltage stations.

However, with the rise of photovoltaics, the principle of the pure consumer level has no longer been strictly adhered to. This has led to constellations where local overvoltage has occurred, with corresponding consequences for the service life of the connected devices.

The supply network of the railways has a special position here. Its frequency is different, 16 2/3 Hertz, and consequently it is managed separately from the general network. It is excluded from the current consideration, although if the supply of the railways increases, an extension of the current links between the two networks would have to be taken into account.

3. Where and how will the electricity be produced in the future?

The only renewable energy source in Switzerland for a significant electricity production at power plant level is hydropower. It will continue to serve grid levels 1 to 5. Not much actually changes there. However, there will be no significant replacement for the lost production from nuclear power plants at these levels. Despite the affirmations of promoters of solar power plants in the mountains, their significance at these levels for the future power supply will be rather small. Perhaps, they will be able to replace a few percents of the lost production of the nuclear power plants.

The other renewable source that can be tapped is photovoltaics. However, this can only be used very locally in Switzerland, where there are human settlements. Its potential is relatively large and must be used efficiently. Various studies and designs of houses with high energy standards show that it could cover about 70% of household needs - heat and electricity.

Other energy sources such as wind power, biomass, deep and medium geothermal energy will certainly also make their contribution, but only locally or, in the best case, regionally, where photovoltaics would prove insufficient.

Wind power for pure electricity production. For biomass, there will be two main applications. One is combined process heat and power. Some industries need process heat at a temperature level that can only be achieved by combustion or oxidation (hydrogen). An efficient energy conversion is to combine this heat production with electricity production. The other application is district heating plants. Biomass enables seasonal shifting, the production of heat for building heating and also electricity production to partially compensate for the reduced electricity production from photovoltaics.

Geothermal energy has a special position. In Switzerland, medium depth geothermal energy is only used for district heating due to the low temperature level that can be achieved. With deep geothermal energy, electricity production is possible. However, this will not be used for feeding into the grid, but primarily for the district heating network's own needs. Feeding into the grid would only be conceivable in the summertime. However, this could be advantageous in the early morning hours to cover a higher demand if photovoltaics were insufficient for weather reasons.

4. How can the future production be integrated into the grid?

4.1 Basic principles

We have seen that there is a gap of about 30 % in the conversion from fossil to renewable energy sources, and this already when the energy transition was decided. At that time, the approx. 30 percent of road mobility were not even taken into account. In the meantime, they are included in the decarbonisation. Here, the only thing that really matters as a substitute is electricity, regardless of whether the electricity comes from a battery or from a "Power to X" solution. We are talking about enormous amounts of electricity.

Decarbonisation in industry will reveal other electricity supply gaps. It is therefore the order of the day to use electricity as efficiently as possible.

When handling electricity in the grid, losses occur at various places:

- During transport
- When changing the voltage
- When converting direct current to alternating current and vice versa
- When the energy is converted into another form
- In storing and recovering the electricity.

There is a lot of talk and writing about efficiency. It is often overlooked that the greatest savings are achieved when actions and consumption are left out altogether. Quite simply, leave the switch in the "off" position. With many appliances it is even better if the switch is at the very front and not, for reasons of cost or convenience, after functions that continue to run in the background and consume electricity. Then you really have saved 100%. On the other hand, with the optimisation of functions or processes you can often only get a few percent and that without taking into account the effort for the optimisation. Of course, not all actions can be avoided. Then, only then, must the optimisation take place.

The consequence of applying this principle is that the electricity should be consumed at the production site if possible. Then, under certain circumstances, several conversions could be avoided.

4.2 Integration at the level 7

This level will play a central role in the future. According to the unanimous opinions of various studies, the main share of electricity production from renewable energy sources will take place at this level and to about the same extent as that of the individual consumption.

This means, taking into account the principles of efficiency, that local production is to be consumed first where it is produced. If the production cannot be consumed immediately, but within a tangible timeframe, it should be stored locally whenever possible.

Furthermore, load control via frequency no longer works as in the previous grid. Most of the production takes place as direct current and the frequency is no longer an indicator for the load. It is only necessary for the various consumer drives in the grid. Since, today, the alternating current in many devices is first converted into direct current before use, the question arises as to how long the conversion into alternating current will still be necessary.

The simple and unambiguous load control via the voltage from the mid-station has also had its day. Overvoltage or undervoltage can occur anywhere in the grid depending on production and consumption constellations. These must then be handled decentral, locally. Load control locally will no longer affect electricity production or supply alone. It will influence both sides. In the case of overproduction - high voltage - the electricity is first stored and then made available to others. If there is underproduction, the storage facilities will be emptied or the electricity will be purchased from others.

All these considerations determine the structure of the future grid level 7. This level will consist of many islands. Each of them will have at least one production facility, one storage facility, a connection to a neighbouring island and a control system that determines according to certain criteria where the electricity must be routed to cover the island's demand (consumption and storage) or where it must be drawn from to cover the demand.

The smallest island would be a house. These small islands are then connected to form a larger island, the street or the neighbourhood. These in turn form a larger unit until they are connected to level 6, the medium-voltage station.

Such a structure would enable a fast, direct balancing of demand fluctuations, even those such as those described in chapter 2, without large-scale electricity transport. If the storage is designed for about 70 to 80 % of the reference size, good supply security can be achieved with efficient use of the valuable materials that were necessary for the fabrication of the storage.

The activity on this level will then be very dynamic with changing flows and also with changing flow directions. If the solar potential is really exploited, this grid level could be considered self-sufficient and exchange electricity with the medium-voltage level only in exceptional cases.

The grid operator is then no longer primarily responsible for supply, but for an efficient exchange between the near and far neighbourhood and the equally efficient management of surpluses through storage or provision on a supra-regional level.

The bidirectional measurement of current flows and protection then become complex tasks.

4.3 Integration at the level 6

Due to the strongly local character and the limited available capacity of renewable energy sources in Switzerland, the power plants based on renewable energy sources will be connected primarily at this level. In the future, it will primarily have to supply industrial consumers and ensure interregional balancing. Thus, a high dynamic will take place at this level. Many "power-to-X" plants will probably be fed from this level for seasonal balancing. This would also be reasonable, because the seasonal difference in electricity consumption will have a strong impact on this level 6.

Since the surpluses that could not be balanced locally are fed into this level for regional or supra-regional balancing, the aforementioned dynamics are reinforced by the bidirectional power flows.

4.4 Integration at the levels 1-5

At first glance, the possibilities for electricity from renewable energy sources at these levels seem rather limited. On closer inspection, the following thoughts come into play.

The electricity produced by run-of-river power plants as well as by wind and solar power plants has priority in use. However, if the grid load is so low that such power plants would have to be cut back, they should be left on load and the surplus electricity stored. Various options are available here: Pumped storage, a "Power to X" solution and, if necessary, a battery. If storage is installed near a production plant, even electricity transport losses could be avoided, as well as, possibly, voltage conversion losses. Since many other factors are involved, a more detailed consideration is necessary in each case.

In future, the regular and foreseeable demand peaks will primarily be covered directly at level 7. This is a welcome relief, as the peaks in demand from industry remain, which now have to be covered with a greatly reduced park of controllable and dispatchable hydropower plants. The irregular and, above all, the unexpected events of greater magnitude remain as the task of this reduced machine park.

The choice of the "right" solution depends on many factors such as debatable surplus power, grid status, current market and consumption dynamics, filling status of the storage lakes, need for seasonal load shifting, state of charge of the batteries, etc.

The main suppliers from these levels will primarily be the hydropower plants. Apart from international transport, the other producers from renewable sources will play a rather marginal role.

5. Tasks to be solved for the implementation

Now that we see where the journey is going, it is possible to identify the hurdles and tasks ahead and find ways to solve them.

The entire electricity industry is highly regulated. The grid levels, their tasks, the fees are regulated in laws. Now, lawyers have to sit down with grid specialists from the operating companies, recognise the web of laws and regulations that has developed over time and adapt it to the new requirements. This will be a first step towards better planning security for the new network.

The duties and rights of builders, owners and tenants are defined in various works; many at cantonal level. Many fee ordinances use these terms. Some of these regulations do not take into account the possibilities of an exchange of services and joint ownership. Some even stand fully in the way. Here, too, a thorough combing and revision is necessary. Intercantonal coordination would be advisable here.

We have seen and experienced several times that the limitless abundance in energy supply is a fairy tale and even more so with a supply based on renewable energies. Furthermore, the local conditions are very different. There are locations with very favourable conditions. In others, however, they are much less good: strong shadows, poor orientation, unsuitable roof shapes, etc. Therefore, the principle should be that all possibilities in one place should be exploited as fully as possible, so that something can also be distributed for the less optimal ones.

Where electricity is needed for heating in winter, for the heat pump for example, the installation of solar collectors with heat storage should definitely be examined. The use of this heat could save more electricity than the PV modules would produce on this surface occupied by the solar collectors in winter.

If you want to use energy carefully and responsibly, the very first step is to become aware of your own needs. Since we are all very different, we also have different needs. Even if the bottom line is that the differences in watts or watt-hours are not great, it is important for one's own acceptance and the good feeling of having been taken care of, that one went through this exercise.

This consumption figure is then the basis for dimensioning the storage capacity. It depends on the living conditions of the residents. As a starting value for optimisation, one can take about 70 % of the daily consumption. This way, 2-3 days of bad weather can be bridged. Covering regular demand peaks is also part of it. However, the space for storage should be kept rather flexible, because life circumstances can change and so can the need for storage. It is also possible that one's own production does not result in a surplus that is sufficient for storage. Then the storage must be loaded from the grid or the grid must provide it.

The electricity that is not immediately consumed or not stored for prompt use is then fed into the grid and is available for use by others. The reverse is also possible. This creates a lively exchange in the immediate vicinity in the grid. Again, the statistical value has to be stored again in a storage unit over a few days. This storage is at the transition point to the next similarly constructed local small network. Such small networks could in turn balance each other out in a larger network where a certain storage capacity would again be available. Such a build-up of storage capacity from the bottom up can contribute significantly to grid stability as well as to better operational and supply security. Furthermore, a storage capacity built up in this way will be smaller than a central storage covering all cases. This means that valuable and critical materials are used responsibly, not least because the existing grid could continue to be used with virtually no changes.

Optimisation tools for all these tasks need to be developed.

6. Business opportunities for the grid operators

As we have seen in the previous chapters, first and foremost the business environment of the players on the distribution grid will change. On the one hand, the focus of activities will shift away from the mere supply of electricity to the dynamic management of electricity flows in both directions and their storage in the grid.

This means that today's primary source of income, the supply of electricity, will become much smaller. Instead, there will be other, new tasks and the complexity of the business will increase. The business model - to buy electricity as cheaply as possible, to determine the costs for maintenance and possibly the expansion of the grid, and from this, taking into account a reasonable expense for administration, to determine the sales price - is completely inadequate under the new conditions.

The costs for the grid infrastructure will not be lower, on the contrary. It will no longer be sufficient to measure the electricity purchased at the entry points and the electricity delivered to the consumers and charge the latter accordingly. All electricity flows will have to be recorded in both directions, and in absolute terms, since the price structure could be different depending on the direction of flow. For this, through the exchange and balancing of needs, local points or network strings could become overloaded. Such situations would then have to be recognised in time and corrective measures initiated, which will make necessary additional measuring points and possibly connections.

The distribution grid will thus coordinate and optimise the basic supply and ensure it in the event of disruptions and unusual weather conditions as well as seasonal differences in consumption patterns. If individual players support such tasks, their performance must be measured and rewarded accordingly. Appropriate metering points and tariff structures must be created for this purpose.

Many consumers could be overwhelmed by these new tasks. The grid operators could then offer "contracting solutions".

On the higher network levels (levels 1-5), the changes will be less extensive. They will essentially remain the same, only their priorities will change. The amount of electricity will become smaller because the production of the nuclear power plants will be replaced by solar production on level 7. In return, the grid services become more important and can no longer disappear in the total volume. This means that the whole cost and revenue structure has to be revised.

All these measures cost something. The bottom of the energy price has long since been passed. Higher electricity costs are therefore unavoidable. We have to reckon with this and adjust accordingly with our choice of solutions. It is still open to what extent consumption will be affected.

7 Special cases

The railway power has already been mentioned. It was not looked at whether the increased electricity demand from SBB due to the expansion of the transport service can be offset by the production of its own power plants. However, an expansion of its own production facilities is questionable. Thus, the 50 Hz grid would have to ensure the balance.

Covering the energy needs of aircraft traffic without fossil fuels is still an open question. In my view, it will hardly be hydrogen. The waste product of fuel cells or direct oxidation - water - is harmless at ground level. In the higher atmosphere, where it would be released as water vapour, it is very harmful - destruction of the ozone layer, strong greenhouse factor - which practically rules out its use for powering aircraft. This leaves only aviation kerosine from the synthesis of hydrogen, CO2 extracted from the air and water. However, the production quantities are so gigantic, not to mention the costs, that production in Switzerland is unthinkable.

In the case of road mobility, some daydreams have already been shattered by the events in Ukraine. Today, there is only enough electricity for electric vehicles if there is enough oil and natural gas. If this is not the case, one has to rely on extremely mild weather, primarily in winter, and on everyone saving electricity so that the few e-cars can consume electricity unless they can be charged by their own solar system.

It should be noted that electric cars only make sense in terms of environmental protection if the electricity generated for them comes from photovoltaics or is at least climate-neutral. Thus, the primary supply level for this electricity in our country is level 7. Otherwise, the only option is to rely on methanol produced by a process similar to that used for aviation kerosine. Of course, imported from abroad.

Central charging stations are fed from level 6. This level could be the bottleneck of energy supply in the future. Not least because the electricity together with the heat for the buildings, in winter, is produced and made available via thermal power plants and the heat is distributed via district heating networks.

Hydrogen is practically the only possible raw material substitute for fossil products that are no longer acceptable. This will probably happen primarily abroad, as is the case for fuels for mobility. Of course, local inland and above all niche solutions will be possible at home in particularly suitable places.

8 Conclusions

The following insights can be drawn from this report:

- The distribution grid will essentially be self-sufficient and powered by solar electricity. It will primarily provide for balancing between producers/consumers (prosumers) and between grid islands and for matching partial storage. In the event of power shortages, it will draw power from the higher levels via the medium-voltage stations.
- The producers/consumers will ensure that they can produce as much electricity as possible and, at the same time, consume as little as possible themselves, so that the surplus electricity can be made available to others after the appropriate own demand has been stored.
- Storage is part of the electricity price, either on one's own system or in the grid.
- The business models of the network operators must be redefined. The tasks essentially remain, but their priorities are shifting strongly, as is the revenue and cost structure.
- The legal structure - federal and cantonal - must be reviewed. Many regulations are only valid for a central supply of fossil and nuclear energy sources. A thorough revision is necessary. Only then, the above-mentioned changes in the grid will be possible.
- There will be a multitude of solutions and technologies, varying according to region, requirements and needs. The world will be refreshingly diverse and multi-layered.

I hope to have provided some clarity in this field with this essay. It is sobering to note how little foresight has been shown by the media-rich statements of companies, politicians and experts. There is not necessarily bad will behind it; but certainly, a lot of ignorance and many conflicts of interest. Perhaps the ideas listed here can bring further ideas and actually bring us closer to the goal.

Jean-Pierre Rickli

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