# Grid connection of 50 gigawatts photovoltaic systems in Switzerland

Discussion paper on solutions for the grid integration of solar power - September 2023

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## Management Summary

Switzerland's Energy Strategy 2050 focuses, among other things, on the strong expansion of new renewable energies. The majority of this is to be photovoltaics (PV). The foreseen power of all PV plants (around 40-50 GW) exceeds the maximum vertical grid load of today (around 8-10 GW) by a factor of five. Against this background, it is obvious to anticipate grid bottlenecks despite the coming decentralised use of flexibility and to demand rapid grid expansion.

It can be assumed that there will be an oversupply of solar power throughout Europe at the same time as production peaks from PV systems in Switzerland. 50 GW of PV are necessary for the energy transition, but the potentially resulting power peaks cannot be absorbed by the power grid and probably cannot be exported due to a lack of demand at times of solar power production surplus in other countries. These power peaks must therefore be absorbed or avoided in a decentralised manner (in the building, in the area, in the neighbourhood). Even if the distribution grid were expanded to absorb the expected power peaks, these power peaks could not be fed into the grid, or only at times of low or negative market prices.

In the view of the authors, it is more expedient to invest in the decentralised handling of power peaks than in the expansion of the distribution grid. A large part of the presumably limited solar power that can be fed into the grid can be absorbed in intelligent, decentralised systems (heat pumps, storage, electric mobility). Corresponding products and solutions are available on the market and have been used in various projects for many years. However, in order for these systems to reliably relieve the electricity grids or enable PV expansion without additional excessive grid load, the following framework conditions must be adapted:

- The absolute feed-in priority of solar energy must be discussed. There must be no right to feed power peaks into the grid that are not very relevant in terms of energy but are challenging and uneconomical for the overall system.
- Grid operators and regulators must allow decentralised, flexible systems and motivate grid-friendly behaviour within the framework of an appropriate incentive system.

The expansion of PV systems can be further accelerated in the process, because the most important measures for grid integration are already available today and can be implemented immediately.

Various historically grown realities in today's electricity supply system, such as the tariff structures, the nightly heating of hot water storage tanks or the control power concepts, are today taken as given and hardly questioned. So far, this has only hampered the expansion of new renewable energies in individual cases. However, these structures and habits are not suitable and too inflexible for the future, much larger addition of PV systems.

This discussion paper identifies a number of possible solutions that would serve to integrate 50 GW of PV systems into the Swiss power grid.

## 1 Foreword

This discussion paper was prepared as part of Bern University of Applied Sciences BFH's Laboratory for Photovoltaic Systems (PV Lab)'s contribution to the SWEET EDGE project. The discussion paper focuses on one topic: solutions for grid connection of photovoltaic (PV) systems when the share of solar power in the Swiss energy mix is very high. This topic concerns various stakeholders, namely:

- Politics and administration
- The transmission system operator (TSO) Swissgrid
- Distribution system operator (DSO)
- Installation companies
- Operators of PV systems
- Manufacturer, research, laboratories

The aim of this discussion paper is to stimulate and support the technical discussion on the grid connection of PV systems. In contrast to scientific publications, it not only presents recognised or proven facts, but also proposes unproven solutions as a basis for discussion. In doing so, the authors strive to keep these points apart in a transparent manner.

As with the chicken-and-egg problem, the various stakeholders justify the sometimes slow pace of finding solutions for grid connection with mutual dependencies. DSOs do not introduce advanced grid connection conditions because the regulatory basis does not permit it. The regulatory basis is based on laws which, in turn, are not adapted quickly enough because they do not yet represent a bottleneck with the PV power connected today. Thus, there is not enough political pressure for adjustments. The purpose of this discussion paper is to highlight interdependencies and to build a bridge between the stakeholders.

Prior to initial publication, the discussion paper was presented to representatives of all stakeholder groups. Feedback from about twenty people (from industry, distribution and transmission system operators, and research) was received and incorporated into the discussion paper. However, the present version represents the opinion and interpretation of the authors, and not a consolidated opinion of all stakeholders.

It is the authors' intention to solicit further feedback from all stakeholders, engage in discussion, and incorporate findings one or more times into a new version of this discussion paper.

## 2 Introduction

Until about ten years ago, PV systems were tolerated on the power grid as grid-following decentralised energy resources (DER). They had to disconnect from the power grid if the latter showed a malfunction. When this behaviour was prohibited by the German System Stability Ordinance[1] in the summer of 2012, the PV power in the European interconnected grid was probably already more than ten times greater[2] than the primary control power that would have had to compensate for the failure in the event of synchronous grid disconnection of the PV systems at a grid frequency of over 50.2 Hz.

Today, we are a big step further: if the grid frequency rises above 50.2 Hz, the PV systems do not disconnect from the grid, but stabilise the power grid with the multiple control power of the primary

[1] https://www.clearingstelle-eeg-kwkg.de/gesetz/1956, https://www.bdew.de/energie/systemstabilitaetsverordnung/502-hertz-problem/

[2] Wood Mackenzie, New European solar installations to double over next 3 years, https://www.woodmac.com/press-releases/new-european-solar-installations-to-double-over-next-3-years/

control (50.2 Hz Retrofit Program I and II of ElCom[3]). This is probably the most important step in the transition from “grid-following” to “grid-supporting” PV systems, and solar power shares of ten, possibly twenty percent can be integrated into the grid (Figure 1).

However, the time gained is short. Because 50 GW of PV systems cannot be efficiently connected to the power grid in Switzerland with correct over-frequency behaviour only. Because this power, even if it could be absorbed by the distribution grid, cannot be transported anywhere if there is no simultaneous demand or available storage capacity. Therefore, the key does not lie in the expansion of the distribution grid[4]. PV systems, electrical vehicle charging stations and battery storage – in other words, all available flexible power sinks or sources – must be better integrated into the distribution grid and take on a more active role in grid stabilisation. To this end, policymakers and grid operators must create attractive framework conditions. Grid-friendly behaviour, for example by means of export power control, should be rewarded in the future.

It would also be desirable for Swissgrid to make a trend-setting statement: how many gigawatts of cumulative feed-back from the distribution grids will it one day be able to absorb into the transmission grid? Since Germany, France, Italy and Austria are implementing their own solar strategies, summer solar power exports from Switzerland will probably not make any relevant contribution to grid integration of solar power. So what is the point of expanding a distribution grid, if the power is not needed at times when there is a lot of surplus production, and therefore the excess energy cannot be sold? The sum of the outputs of all local grid transformers (grid level 6, transition from medium voltage to low voltage) is already likely to exceed the maximum absorbed power of the transmission grid by far.

Decentralised solutions offer a remedy for this. Where the power peaks occur, they should also be intercepted. The following chapters of this discussion paper show how this could be done.

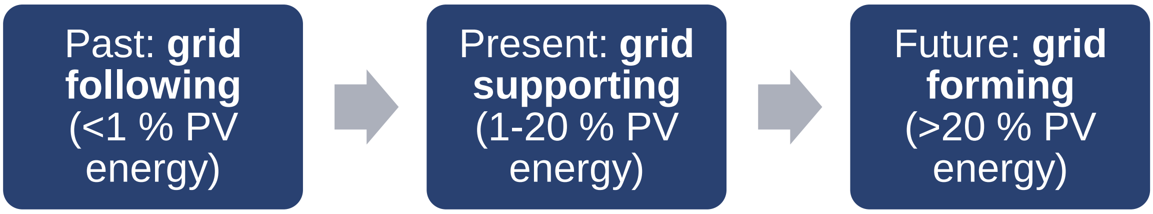


Figure 1: Levels of grid integration of PV plants. The percentages are indicative and imply that even with relatively little solar power in the annual energy mix (20% energy share) in a synchronous grid, PV plants must dominate production at certain times and thus assume system responsibility.

# 3 Grid connection of PV systems

## 3.1 “Every kilowatt hour is worth the same”: not a model for success

Solar power is the backbone of the global energy transition. As indispensable as the energy of PV plants is, their peak power is challenging for the infrastructure. One of the biggest disadvantages of PV systems in grid integration is their low capacity factor of about CF = 1000 kWh / (1 kW * 8760 h) = 11.4%, and their high simultaneity: to feed in 1 MWh of solar power per year, a grid connection of about 1 kW is needed, if every kilowatt-hour is to be fed into the grid. However, if the grid operator allows dynamic active power curtailment and legislation allows curtailing of, for example, 5% of the energy, the grid

[3] ElCom Directive 1/2018, Behaviour of decentralised power generation plants in the event of deviations from the standard frequency, https://www.elcom.admin.ch/elcom/de/home/dokumentation/weisungen.html

[4] See also Jan Remund et al, Firm PV power generation for Switzerland, Meteotest, 2023, https://www.aramis.admin.ch/Default?DocumentID=68985&Load=true

requirement for the plant concerned can be halved[5]. With intelligent integration of electric car, heat pump and possibly battery storage, a further halving can be expected[6]. Thus, for 50 GW of PV systems, we do not need a power with a hosting capacity of 50 GW; a hosting capacity of around 10-15 GW should be sufficient. This does not require a comprehensive expansion of the distribution network in most grids, because the power grid already supplies loads of this magnitude[7]. This assumption does not apply to selective connection reinforcements (especially for large-scale plants) or strategic grid expansion as part of target grid planning.

In other countries, active power curtailment has been practiced for many years. Germany, for example, already stipulated in 2012 in the Renewable Energy Sources Act (EEG) that certain PV systems may only feed in 70% of their output[8]. In Austria, the term “zero feed-in” is used when a PV system is allowed to be connected to the grid but is not allowed to deliver any energy to the grid[9]. Decentralised control systems ensure that these requirements are met.

Three steps are recommended so that PV systems in Switzerland can be better integrated into the grid:

1. The grid operators should allow concepts of flexible feed-in limits. For example, it should be possible to connect a PV system of 50 kVA to a grid connection capacity of 15 kW and to ensure with a corresponding system that never more than 15 kW is fed in. Technically, this can be implemented in a similar way to zero feed-in in Austria.
2. The legislation should allow the grid operator to demand corresponding optimisation measures on the customer side instead of grid expansion. Not every kilowatt hour should have to be purchased. It would be conceivable, for example, that PV systems would only have a feed-in right of 30-50% of the nominal power. More is possible and desirable on a situational basis if the grid allows it. Market models such as local trading of grid connection power could be examined to optimise grid access and flexible assets in the grid.
3. Legislation and grid operators should create incentives for plant operators to benefit from grid-friendly plant operation. For example, the “Energieförderungsverordnung” could be used to pay higher subsidies for plants that require less grid connection capacity. The capacity factor could be multiplied into the subsidy payment. Thus, the more someone is willing to curtail their PV system, the higher the subsidies would be. DSOs can do the same: each PV plant receives a minimum return tariff, for example 6 cts/kWh. Those who limit the grid feed-in and thus prevent grid expansion costs receive a feed-in tariff that is higher by a factor of X for each halving of the feed-in power. Flexible, load-dependent grid and/or energy tariffs would be a different, market-based solution for better utilisation of the grid infrastructure. Valuable electricity is remunerated at a higher rate with these incentive systems.

In certain grid areas, installations with dynamic active power limitation are not permitted by the DSO today. This is justified by the risk that the systems may not behave correctly and thus pose a risk to power quality. Chapter «4.1 Functional and safety gains with smart metering» proposes a solution for controlling the correct functioning of decentralised systems. This could prevent the energy transition from being slowed down and made more expensive by unnecessary grid expansion.

[5] The effective power reduction is strongly dependent on the mix of PV systems. For south-facing systems, the power reduction is smaller; for mixed alignments, as often occur in the distribution grid, larger power reductions are possible.

[6] The effective potential depends on the assumptions. Figure 2 is a worst-case scenario. Self-consumption or battery storage reduces the grid demand while balancing losses remain the same. See also Ch. Bucher, Photovoltaikanlagen, Faktor Verlag Zürich, 2021, Bild 21.2.

[7] Swissgrid, vertical grid load: https://www.swissgrid.ch/de/home/operation/grid-data/load.html

[8] This regulation was partially repealed again in 2023.

[9] Explanatory document NC RfG / TOR Erzeuger, dated 2022.02: https://oesterreichsenergie.at/fileadmin/user_upload/Oesterreichs_Energie/Publikationsdatenbank/Diverses/2022/20220113_Erl%C3%A4uterungsdokument_NC_RfG_TOR_Erzeuger_OE_design.pdf

Figure 2 shows that irradiation peaks are of little energetic relevance. The grid expansion to the nominal plant capacity would thus primarily serve the integration of summertime power peaks, which are not very relevant from an energy and financial point of view.

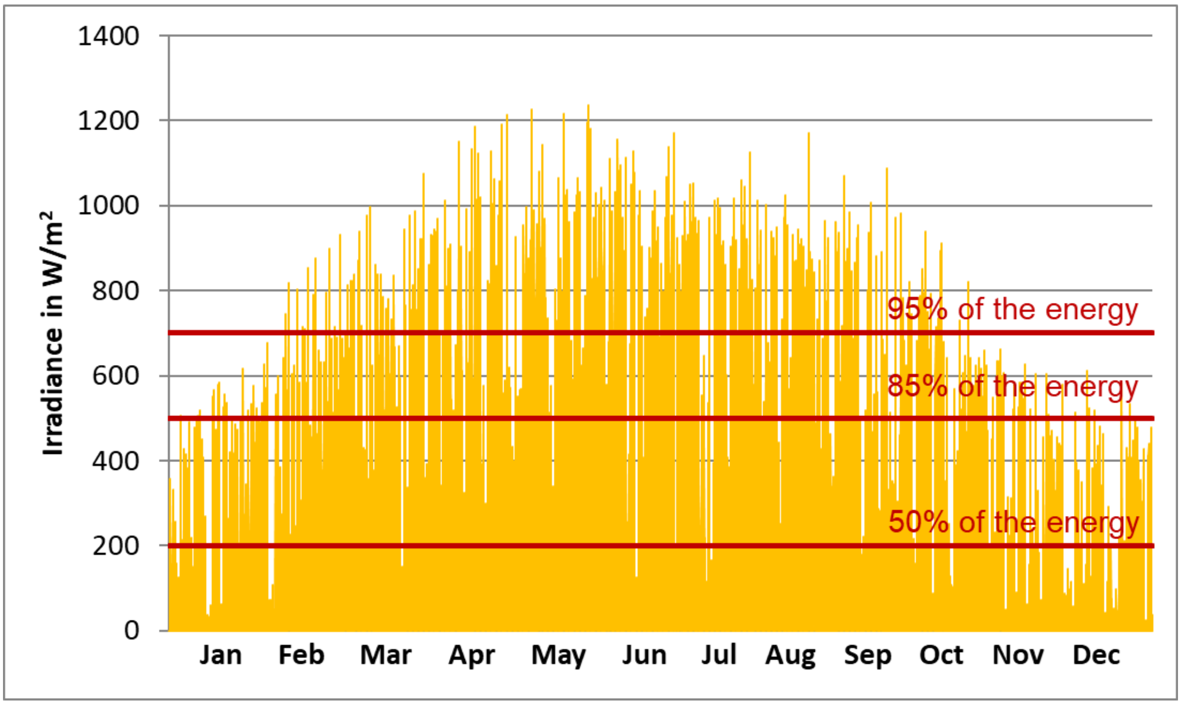


Figure 2: Irradiation peaks and thus power peaks of PV plants are not relevant in terms of energy. For 50 GW PV power in Switzerland, it is not expedient to expand the grid to 50 GW. This is true even if no decentralised solutions are implemented (data: minute data, reference year, Meteonorm).

### 3.2 Plant controller for large systems and feed-in management

All PV plants are supposed to have grid-friendly behaviour and inherent decentralised stable regulation. However, without a communication device, a PV plant cannot know whether the transmission grid capacities are exhausted or not. The grid operators should therefore make a forecast of what proportion of the solar electricity may be fed into the grid at any time within the framework of a static specification at the grid connection point (e.g. all PV systems up to 100 kVA may feed 50% of their rated power into the grid at any time), and which systems must be able to be additionally controlled via remote access. An optimisation controller manages the energy system under these specifications. A safety controller also ensures that in the event of a failure of the communication systems, more than the safe (static) feed-in limit is never fed into the grid (Figure 3). Whether the optimisation and security functions are implemented on one or several devices, and who is responsible for them, is irrelevant for the basic concept.

Central to an efficient overall system is that the grid operator does not regulate any systems, but rather sets feed-in requirements at the grid connection point. A so-called plant controller (in the context of prosumers also called energy manager) then independently controls the system consisting of PV, electrical vehicle charging stations, heat pumps, battery storage units and other flexible consumers in a decentralised manner. The task of the plant controller is, for example, to check which electricity production, which electricity demand and which storage options are available, based on the specified maximum feed-in power, and to operate these in an optimal manner. If this is useful for the overall system, it can also limit the power of the PV systems.

Certain grid operators abroad do not regulate the PV plants themselves, but delegate this task to aggregators, e.g. direct marketers[10]. These follow the market signals and operate the plants in such a way that they optimise themselves against the market and thus fundamentally reduce the risk of congestion. However, aggregators are forced to allow themselves to be overridden by grid requirements (congestion management). Systems necessary for this can be efficiently implemented with plant controllers.

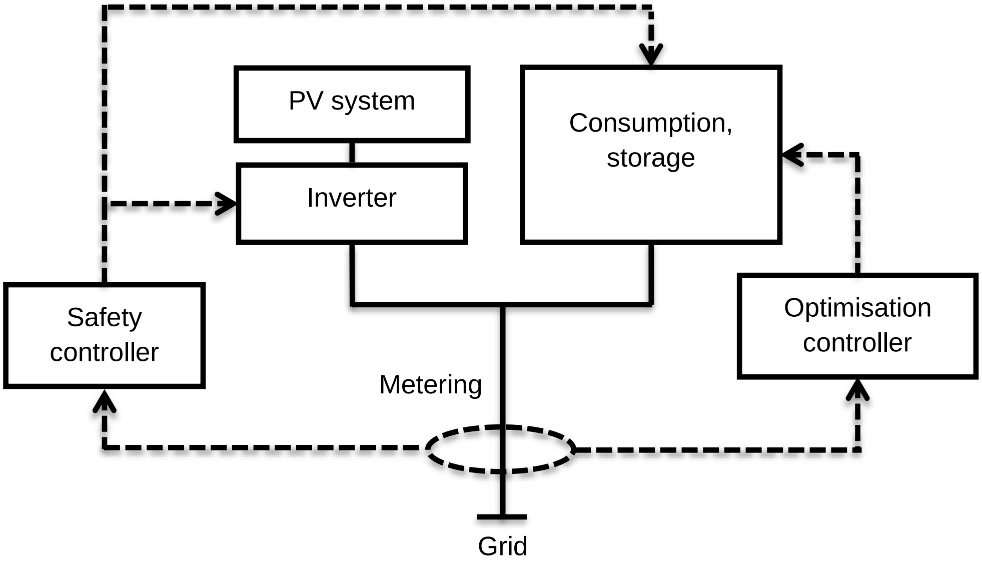


Figure 3: Block diagram of the system control: A controller prevents excessive power from being delivered to the grid, even if self-consumption optimisation is not available. Optionally, the grid operator or an aggregator can specify dynamic feed-in limits.

### 3.3 Intelligent management of flexible producers and consumers

The intelligent management of flexibilities, e.g. the switching on and off of heat pumps or the time-delayed charging of electric vehicles, is likely to become a key component for the integration of large amounts of solar and wind power into the electricity grid. If the maximum feed-in and feed-out power is limited or provided with highly progressive prices, the operators of corresponding flexibilities will behave in a grid-friendly manner for their own economic optimisation.

By this, two goals can be achieved:

1. The grid is relieved.
2. A decentralised infrastructure that can potentially be used for grid stabilisation is being built.

According to the Swiss “Botschaft zum Bundesgesetz über eine sichere Stromversorgung mit erneuerbaren Energien”[11] (Dispatch on the Federal Act on a Secure Electricity Supply with Renewable Energies), flexibility belongs to the operators of the corresponding production or consumption units. Third parties can access flexibility sources through contract. This opens up a new field of grid integration possibilities that has been known for a long time but has hardly been managed so far.

[10] IRENA (2019), Innovation landscape brief: Aggregators, International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Aggregators_2020.pdf?la=en&hash=34E90050F80DD1B012F2E6C9E4C90EE11BED6A82

[11] https://www.bfe.admin.ch/bfe/de/home/versorgung/stromversorgung/bundesgesetz-erneuerbare-stromversorgung.html#kw-98256 **and** https://www.fedlex.admin.ch/eli/fga/2021/1666/de

Today, in most grid areas in Switzerland, there are no incentives to operate PV systems, electric vehicles or battery storage systems (which are actually supposed to support the grids) in a grid-friendly manner[12]. The strict separation of grid and energy makes it difficult, for example, to promote grid-friendly behaviour of storage systems via the feed-in tariffs of PV systems. Although this "unbundling" of monopoly and market areas[13] is desirable, in this case it is a hurdle to implementing efficient systems.

Proposed solutions are presented here in an exemplary manner:

- Those who operate their battery storage system in a grid-friendly manner receive a 20% higher feed-in tariff for the solar electricity or for the electricity fed into the grid from the storage system.
- Those who keep the ratio of produced solar power (energy) to fed-in peak power (output) high (for example, above 2000 kWh/kW) receive a 20% higher feed-in tariff.
- Those who connect their electric car to a charging station controlled by the grid operator receive a cheaper charging rate. If he still wants to fully charge the car quickly, he pays a higher tariff for this full charge.

These proposals can be varied, optimised or adapted to given structures as desired. Individual grid operators already offer flexible purchase and feed-in tariffs[14]. Relevant players in the electromobility industry also see the rapid grid integration solution in the intelligent use of existing grid capacities and not in grid expansion[15].

The politicians / the regulator / the grid operators are challenged to find ways to implement these proposals or at least to eliminate the current hurdles to do so. The current Swiss "Mantelerlass" (decree) on energy and electricity supply legislation offers opportunities to implement this.

### 3.4 Grid stability: power-based, decentralised primary and secondary control

In the European interconnected grid, so-called control power is used to ensure that electricity production and consumption are in harmony at every second. For this purpose, power plants are paid by means of tenders to increase or decrease their production within seconds (primary control), minutes (secondary control) or hours (tertiary control). These regulations are part of the system services required by Swissgrid and serve to maintain grid frequency.

A major obstacle to high shares of fluctuating renewables are the current balancing energy markets. These assume fixed, plannable operating times for power plants. This fits well for thermal power plants and storage hydropower plants, but practically excludes wind and solar power plants from the market. For this reason, PV and wind power plants have to be throttled or switched off in certain regions, while gas-fired power plants operate alongside them. From a technical point of view, PV and wind power plants could also provide primary and secondary control power. For this, the markets would have to be changed from a time-based to a power-based regime. For Switzerland, for example, this could look like this: whenever the sun shines, the 50 GW PV plants, which then have to be curtailed, provide primary control power and the plants integrated into communication systems also provide secondary control

[12] Bern University of Applied Sciences, Bat4SG, Grid-optimised operation of decentralised, customer storage systems. Final report dated 16.12.2021. https://www.bfh.ch/dam/jcr:cad6ba8b-3cc2-44cd-a1aa-28b42b189115/8168-2021.12.pdf

[13] Unbundling in this context means that DSOs are not allowed to mix their monopolised business areas such as network operation with their market activities, for example electricity sales to large customers.

[14] For example, Primeo Energie with its «mobility tariff», https://www.primeo-energie.ch/privatkunden/elektromobilitaet.html, and the "optional tariff" for the feed-in of electricity, https://www.primeo-energie.ch/privatkunden/strom-produzieren/ruecklieferung-wahltarif.html

[15] Mitnetz Strom, Elli, Innovation impulse for a sustainable grid integration of electromobility, report on the pilot demonstration and further simulation results for concept testing, 23.1.2023, https://e-bridge.de/wp-content/uploads/2023/03/20230123_Elli-Mitnetz-E-Bridge-Bericht-Untersuchungen_Elli.pdf.

power. As soon as their output falls below a certain limit (for example below 8 GW), the pumped storage power plants ramp up their production and in turn provide control power.

In addition to PV systems in curtailed operation, all types of charging devices (for example charging stations for electric cars) should also have a frequency power function: taking into account a dead band of, for example, 10 mHz, they could only charge 95% of their nominal power at 50 Hz. If the mains frequency drops, they throttle the charge down to 90%. If the grid frequency rises, they increase the charge up to 100%. With the fleet of electric vehicles that is expected to be available, the primary control power required today would presumably be significantly exceeded[16]. Whether an individual vehicle is connected to the grid or not is irrelevant: there will be enough vehicles connected to the grid at any given time. This functionality can be implemented in specific devices such as inverters or in a higher-level plant controller.

In a microgrid in island operation, this functionality simultaneously stabilises the local grid. A central power plant unit in the microgrid, for example a combined heat and power plant or a PV system with battery storage, is capable of black start and determines the grid frequency. The connected inverters follow the grid frequency and throttle or increase their production accordingly.

Today, microgrids often seem to be precursors for grid-forming functions of decentralised DER in the interconnected grid. Various functions, without which a microgrid would not function at all, can also become relevant in the interconnected grid with a high share of fluctuating renewables. Against this background, it should be reviewed whether the current primary, secondary and tertiary control system is still suitable with regard to temporal and control requirements. Similar to the departure from the current form of anti-islanding, the restructuring of the balancing power markets is also a disruptive approach that cannot be implemented without an in-depth holistic examination and any corresponding accompanying measures. In particular, measures affecting the grid frequency must be coordinated across the entire European interconnected grid. Less disruptive approaches such as the creation of more flexible products (e.g. an hourly supply of balancing power) would be easier to implement, but would probably only tap a small part of the potential. The design of the balancing power markets must always be considered and harmonised across Europe.

### 3.5 Anti-islanding: a protection concept from the old days

All PV systems (incl. the plug & play balcony systems) today have a detection of unwanted island grid operation, the so-called anti-islanding. Typically, this works in such a way that the inverter attempts to slightly destabilise the grid (frequency shift procedure, active islanding detection). If it succeeds, it disconnects from the grid. If it does not succeed, it remains connected to the grid. But what if 50 GW PV systems are connected to the grid in Switzerland and actively try to destabilise the grid? Similar to the 50.2 Hz problem, this does not seem to be a good idea. The grid operators are therefore rightly calling for a so-called “Fault Ride Through” (FRT): the PV plants must not disconnect from the grid for a certain time, even in the event of grid faults[17]. A decision must be made here: FRT or anti-islanding. Both together are not possible at the same time, because an inverter cannot support the grid and try to destabilise it at the same time. A possible solution is to set FRT for 3 seconds in the event of an incident, and then anti-islanding for another 5 seconds.

In the future, entirely new solutions are also conceivable. As the interconnected grid becomes larger and more complex, a possible black start scenario becomes a process with more and more unpredictable factors for the grid operators. At the same time, some inverters today already have grid-forming functions, i.e. they can be operated as a voltage source, not as a current source. In doing so,

[16] For the sake of plausibility: if only 5% of one million electric vehicles were charged with a charging capacity of 10 kW, this would already correspond to a charging capacity of 500 MW, which could be flexibly managed or integrated into a balancing power system..

[17] https://www.swissgrid.ch/dam/swissgrid/customers/topics/transmission-code-2019-en.pdf**,** chapter 6.5

they do everything within their performance parameters to keep the power grid stable. For example, it would be possible to use a so-called “microgrid” to separate a distribution grid with a sufficient number of PV systems, electric charging stations and storage units from the transmission grid and continue to operate it as an island. Even the black start of such an island is conceivable and technically possible. A certain challenge in this case is the short-circuit power, which is usually not large enough from PV inverters alone to trigger fuses. However, if one assumes that the connected inverter power will exceed the grid power several times over, the inverters can also provide the necessary short-circuit power for safe stand-alone operation. In the LINDA pilot project[18], a consortium of German industrial and scientific partners has designed and successfully demonstrated such a concept.

The grid protection will have to be redesigned in such a project. Work safety for work on an islanded distribution network will also be affected. However, if the “5 + 5 vital rules: Electrical Installation” of the SUVA (“Schweizerische Unfallversicherungsanstalt”) are consistently followed, safe work on electrical installations would already be possible today in such a concept.

Of all the new concepts presented in this discussion paper, this is one of the most disruptive, with many unknowns. Various aspects of grid operation and black start procedures would have to be redeveloped. However, new functionalities would also be gained: security of supply and, in particular, incident prevention against a Europe-wide blackout would be raised to a previously unthinkable level – and at the same time the grid integration of a large share of solar power would be enabled. However, before this is possible outside of pilot projects, the measures described above must be implemented.

### 3.6 Interface protection: symbolic politics with consequences

The requirement for interface protection is undisputed. It is implemented differently depending on the country and grid operator. While in the USA no external interface protection equipment is required regardless of the power of the PV system, but rather relies on the correct functioning of the inverters, in Europe additional external protective relays and circuit breakers are required depending on the country, grid operator and system power. Actually, this does not matter, because at least on paper, external interface protection does not change the safety of a PV system, neither in a positive nor in a negative sense.

With the new standard SNEN 50549-10[19], Switzerland now has a valid standard with which proof of the correct function of the interface protection integrated in the inverter can be provided, regardless of the power or number of inverters.

Today’s processes around external interface protection can be critical for system safety. It is sometimes argued that the correct function of the inverters cannot be checked by the grid operator, but that of the external interface protection can. However, the grid operator only ensures that the external interface protection is installed and parameterised correctly. The settings on the inverter itself are not checked. This works well for small amounts of solar power in the grid, because individual misconfigured inverters do not have enough power to significantly destabilise the grid. However, if the PV systems become the dominant source of electricity at certain times (for example, with 50 GW of PV in Switzerland), even a small percentage of incorrectly set inverters could cause significant grid disturbances.

Regardless of what solutions the future will bring: grid operators should actively engage with inverters and understand the associated processes and sources of error. They should train their staff and set up processes to ensure that only compliant and correctly adjusted inverters are connected to the grid by

[18] LWE Verteilnetz GmbH, LINDA: “Local island grid supply and accelerated grid reconstruction with decentralised generation plants in the event of large-scale power failures”, https://www.lew.de/ueber-lew/zukunftsprojekte/abgeschlossene-projekte/linda, as well as follow-up project LINDA 2.0, https://www.lew.de/ueber-lew/zukunftsprojekte/linda-20

[19] SNEN 50549-10: Requirements for generating plants intended to be operated in parallel with a distribution system – Part 10: Test requirements for assessing the conformity of generating units

the PV industry. If this is ensured, the question of interface protection should answer itself from the authors' point of view.

With the smart metering systems to be introduced nationwide, monitoring the correct function and settings of the inverters should also become much easier in the future. The DSO will know at least for every quarter of an hour how each individual PV system has behaved individually or as part of a prosumer. It can set automatic evaluation and alarm criteria to warn incorrectly set systems (see also Chapter «4.1 Functional and safety gains with smart metering»).

### 3.7 Good news for PV plant operators

Solar electricity is a valuable commodity. For PV system operators, it is difficult to understand why the grid operator wants to be able to curtail PV systems or switch them off. At the same time, the feed-in of power peaks slows down the energy transition because the allocation of grid connection capacity based on these power peaks, instead of being optimised for energy maximisation, blocks or delays the construction of further PV plants.

The concepts presented in this discussion paper outline a win-win situation. PV systems, electric vehicle charging stations, heat pumps and storage systems should be built flexibly. The DSOs should only be allowed to make specifications for grid connection, but not to shut down the individual plants without safety-relevant reasons. With such systems, both parties benefit:

- PV system operators can increase their own consumption and have to feed less electricity into the grid on sunny summer days, for which the grid operator will presumably pay less and less.
- DSOs can connect more PV systems to the grid without having to expand it. This allows to increase the PV penetration in the grid much faster.

In the end, the costs for the electricity grid are not borne by the DSO, but by the end consumers. If such systems are implemented, the energy transition and thus electrical energy use will become cheaper for all parties involved.

## 4 Supporting measures in the power grid

### 4.1 Functional and safety gains with smart metering

Thousands of decentralised controllers that are replaced or at least updated every few years indicate an incalculable risk in terms of secure grid operation for the DSO. However, thanks to the smart metering infrastructure that is currently being set up, the DSOs will soon have an instrument that empowers them to automatically control the behaviour of individual prosumers. Thanks to an established metering system or a state estimation by means of a digital twin, they can know the current state of their network almost in real time. In addition, the DSO knows which power may be fed into the grid at which interconnection point (static or dynamic) on the basis of the connection permits.

With the information available through smart metering, grid monitoring software could be configured to sound an alarm if a PV system or prosumer is not behaving in a compliant manner. The grid operators would thus have a tool to systematically check if PV plants are behaving correctly, not just in random checks on site. This would enable them to determine, for example, whether a PV system is feeding into the grid even though it has received a signal to switch off. Or whether it follows a predefined P(U) curve. The same applies to reactive power draw or the implementation of any control signals from Swissgrid (e.g. for congestion management or frequency maintenance).

It is therefore advisable that DSOs or smart meter operators become aware of the importance of suitable smart meter systems for grid operation and make investments in appropriate solutions that not only fulfil the minimum requirements of the legally required intelligent metering system (iMS). In return, thanks to smart metering, the DSO can obtain the certainty that the systems installed in its network area behave correctly.

In the longer term, DSOs can also potentially save considerable effort in commissioning control. For example, time-consuming commissioning measurements could be eliminated – these can be carried out automatically by the smart metering system during the first days of operation.

### 4.2 Classic measures in the distribution network

Many strategies for increasing the PV hosting capacity of electricity grids are exclusively dedicated to the topic of grid expansion or measures on the electricity grid. This discussion paper attempts to show why this is only partially effective.

Measures to increase the PV hosting capacity of the electricity grid are now well known and have been tried and tested. According to the NOVA principle (grid optimisation before reinforcement before expansion), this could mean[20]:

1. Decentralised reactive power control of the PV systems
2. Dynamic voltage management in the substation
3. Adjustable local network transformers
4. Selective network reinforcement
5. Grid expansion
6. *Decentralised, grid-supporting storage systems*[21]

These measures are important and can in part be implemented cost-effectively and immediately (points 1 and 2). However, the DSOs should clarify with their respective upstream grid operator and, in the last instance, with Swissgrid, what proportion of the output of the PV systems their distribution grids are allowed to feed back into the overlaid grid when implementing the energy strategy. The power that can be fed back from the distribution grids into the transmission grid at the same time is presumably so low that an area-wide expansion of the distribution grids does not make sense.

[20] The measures presented in this document, such as dynamic active power control, are intentionally excluded from this list.

[21] In the order of the NOVA principle (German: “Netzoptimierung vor Ausbau”), the position of the storage systems is controversial. In the future, it is likely to be strongly dependent on the areas of application of the storage systems as well as their costs.

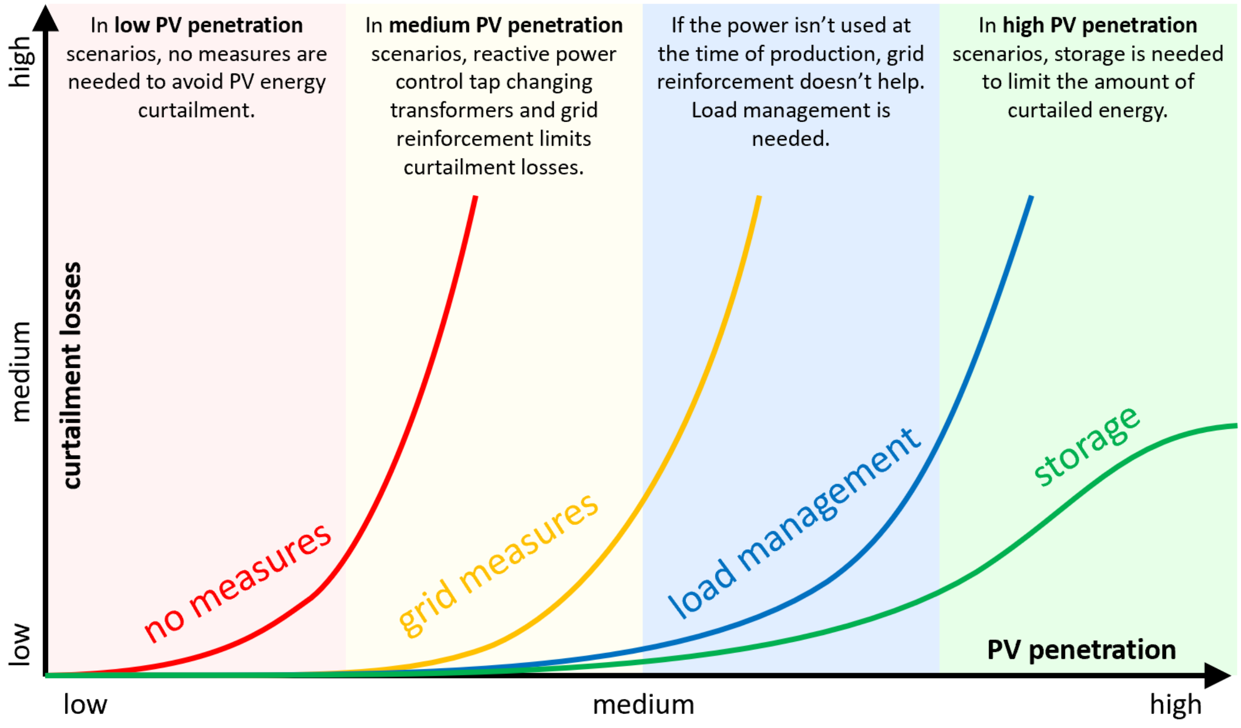


Figure 4: PV systems can simply be switched off. This results in energy yield losses. Measures in the grid can only compensate for this to a limited extent: they do not solve the problem, they shift it to another location. Production, storage and consumption must be brought into balance. Because PV production can hardly be influenced and export possibilities are limited, decentralised load management and storage are better suited to integrating a lot of PV than grid expansion.

In return, unavoidable grid reinforcements should be considered as part of the energy strategy and synergies of various expansion measures should be used. Suitable strategic network planning should prevent the same network components from having to be reinforced several times in succession.

Because Switzerland's neighbouring countries are planning similar energy strategies, it will hardly be possible to export large amounts of solar electricity abroad. Figure 4 illustrates qualitatively that grid reinforcements ultimately cannot sufficiently reduce the regulation losses of PV plants. An electricity grid is only useful for solar electricity if electricity can be consumed or stored elsewhere at the same time as production. This does not seem realistic for the power peaks of a full expansion according to the energy strategy.

The situation in the transmission grid is different from that in the distribution grid: the exchange of energy between geographically or even climatically different regions (Alps with the Swiss Plateau, North Sea with the Mediterranean, East with West) would be valuable for the integration of wind and solar power, but requires a large increase in transmission capacities. This in turn is hardly feasible without strong social and political will. If wind energy is to be imported into Switzerland from the North Sea, or if large alpine PV plants in Valais or Graubünden are to be connected to our grid, the transmission grid must be expanded. The north-south transmission capacity in particular must be increased to many times the current capacity. Here, a strategic grid expansion to the corresponding capacities makes sense from the authors' point of view.

# 5 Standards and rules for grid connection

Rules and standards for electricity grids have so far been firmly in the hands of the individual DSOs. This works well as long as the grid operators can negotiate or enforce their requirements with each power plant. In Switzerland, however, over 150,000 PV plants[22] are already connected to the grid today. A small but growing proportion of these systems are equipped with inverters built outside Europe. It is therefore increasingly unlikely that an internationally active inverter manufacturer will respond to the individual requirements of a Swiss DSO.

It is therefore becoming increasingly important to incorporate Switzerland's requirements into international system and product standards. The task of the standards is to enable safe, efficient, reliable and mutually coordinated products and systems. With the SNEN 50549 series of standards valid in Switzerland (Requirements for generating plants to be connected in parallel with distribution networks), standards are now available on how inverters must behave on the grid and how this should be tested in the laboratory. The series of standards IEC 62786 (Distributed energy resources connection with the grid) and IEC 63409[23] (IEC TC 82: Photovoltaic power generating systems connection with grid – Testing of power conversion equipment), which are currently in progress, will globally harmonise the contents of EN 50549.

For grid operators in particular, SNEN 50549 offers new options. They no longer have to monitor the commissioning of each individual installation, but can introduce the following process, for example:

1. They only allow the installation of appropriately tested inverters (refers to power control, fault ride through and NA protection).
2. They specify the settings on the inverters (Swiss country settings plus deviating settings of the grid operator) and have them confirmed by the system operator.
3. They set up their smart metering system in such a way that violations of the connection conditions are automatically detected (e.g. sign errors in reactive power control).

# 6 Excursus: measures beyond the grid connection

### 6.1 Energetic measures

The proposals presented here provide a possible response to the new realities in the electricity grid. In addition, however, there is a whole range of other measures, some of which are even more important, which also need to be urgently addressed, but which are not in competition with this article:

- Sufficiency and more efficient use of energy (which, however, can often lead to higher electricity consumption, e.g. heat pumps and electromobility).
- Backup power plants and corresponding energy reserves. Such can apparently be planned, built and commissioned in a year. In the medium term, the energy reserves needed for this should come from renewable energy sources, e.g. hydrogen (produced in Switzerland or imported).
- Renewable and combined heat and power networks to reduce the need for winter electricity imports. General coupling of combustion processes with electricity generation (combined heat and power plants, combined heat and power).

[22] https://www.uvek-gis.admin.ch/BFE/storymaps/EE_Elektrizitaetsproduktionsanlagen/

[23] The IEC 63409-4 project teams (Part 4: Interface protection and fault ride through) as well as IEC 63409-6 (Part 6: Power control functions and grid support) are currently led by the PV Laboratory of Bern University of Applied Sciences)

### 6.2 Hydrogen and synthetic fuels

From the perspective of the system stability of the electricity grids and the distribution grid integration of PV systems, hydrogen and synthetic fuels do not play a role. However, it is hardly possible to imagine the discussion about the energy transition as a whole without them. In certain circles, they are presented as the beacons of hope for the energy transition par excellence. If hydrogen and synthetic fuels were available on a large scale, ecologically and cost-effectively, many of the challenges of the energy transition would be solved. If they are not available, however, it will be difficult to achieve all the goals of the energy transition.

On the positive side, many challenges can be met or at least addressed without hydrogen and synthetic fuels. The remaining fossil fuels should be used with much caution as a transition technology. While oil and gas heating systems are extremely problematic from a climatic point of view and do not bring any system advantages, fossil-fuelled combined heat and power plants and district heating networks operated with combined heat and power have the advantage that they produce a lot of winter electricity in addition to providing winter heat. Although they should not be primarily relied on, they can support the implementation of the Energy Strategy as a transitional technology until synthetic fuels or green hydrogen become available and are gradually fired by renewable energy.

In view of the climate goals, however, it would be negligent to rely on fossil fuels until synthetic fuels are available in sufficient quantities. For this reason, the remaining fossil resources should only be used where they serve as enablers of sustainable solutions.

## 7 Example: the PV system of tomorrow

Let us look at the following example: a development with 30 residential units has an annual consumption of 200 MWh (incl. electric mobility and heat pump) with a connected load of 200 kW. PV systems with a total output of 250 kW are connected to the roofs of the building. In the underground car park, there are 30 electric charging stations with a connected load of 20 kW each, i.e. a total of 600 kW. The development may draw a maximum of 200 kW from the grid and feed a maximum of 75 kW into the grid due to the many PV systems in the neighbourhood. A higher feed-back (up to 200 kW) would theoretically be possible, but only if the neighbouring PV systems do not feed into the grid.

This overall system can be integrated into the network as follows:

- An energy manager qualified for safe operation[24] monitors and regulates the entire system.
- The Energy Manager receives static and/or dynamic specifications from the grid operator (for example, lower feed-in limits at Sunday noon)
- The energy manager or the systems are built to be fail-safe[25]: if they lose the control signal from outside, they automatically switch to a safe operating mode (cosphi = 1, feed-in and reference power limited to a predefined value, for example 75 kW).
- The charging power of the electric vehicles is limited in total. If they all charge at the same time, a maximum of approx. 6 kW, realistically 5 kW, can be charged per vehicle. An innovative payment system should make it possible to charge 20 kW at any time in individual cases, but at significantly higher rates. In this case, the other vehicles charge more slowly, but more cheaply.

[24] Today, energy managers are primarily optimisation devices. In this context however, they also have the function of power limitation in addition to optimisation and must therefore fulfil higher safety requirements than before.

[25] Fail-save means that the system automatically switches to a safe state when it fails. It is therefore irrelevant for system safety whether a system works or not.

- In the event of a “capital error”, e.g. the simultaneous charging of all vehicles or the full feed-in of the PV system, the fuse of the grid connection line is triggered. It remains the primary protection element against the electricity grid.
- The grid operator monitors the feed-in of the PV system with the smart meter. If it feeds more than 75 kW or the communicated limit into the grid at any time, it instructs the system operator to correct the situation and announces to disconnect the system from the grid, if the faulty behaviour is not fixed.
- With the help of the energy manager, a grid disconnection system and an inverter that can be connected to the island grid, the entire settlement can be operated in island mode for some time (depending on the electricity demand and the weather). During this time, the energy manager stops the operation of the heat pump and the charging of the electric vehicles and, if necessary and permitted by the owners, draws energy from the vehicles. With an electric car charged to 80%[26], a single flat (without space heating and hot water) can be supplied with electricity for about a week.

Whether the latter functionality makes economic sense (incident prevention) or the corresponding resources are better invested in an overall more robust infrastructure is a socio-political question. Currently, however, there are planned projects where the prospect of such temporary autonomy is the motivation for implementing an area network which can be operated in a grid-friendly way.

# 8 Tasks of the stakeholders

Some of the concepts proposed in this discussion paper involve major political, procedural or technical changes. In order for them to succeed, the various stakeholders have different tasks. These are described in summary form in the next sections.

## 8.1 Politics / Administration

- Create stable framework conditions so that PV systems are built and renewed to the necessary extent.
- Create a stable framework for PV plants to be allowed to be de-energised.
- Create stable framework conditions that allow network operators and aggregators to send price and control signals to end customers in different ways.
- Create stable framework conditions for network operators to invest in strategic network planning.
- Create a framework that allows grid-friendly behaviour to be promoted by grid operators.
- Lead the discussion with the industry on responsibilities: who is liable for damages caused by the distribution grid that originate from decentralised, intelligent systems?

## 8.2 Swissgrid

- Shows how PV systems must behave on the grid in the future (FRT, primary control, dispatch capability, maximum feed-back into the transmission grid incl. forecast of time availability).
- Develops new concepts for grid operation based on the future realities of decentralised feed-in and decentralised flexibility and coordinates these with the industry. This discussion paper can be used as a collection of ideas.
- Develops solutions together with the DSOs to implement this target network strategy and network operation concepts (technical, regulatory, market design).
- Coordinates the requirements for decentralised feeders and flexibilities with regard to their impact on the transmission grid together with the DSOs.

[26] Assumption: 20 kWh/100 km, 400 km range, 80 kWh storage, electricity demand for the building per year 3'500 kWh.

- Examines and demonstrates the extent to which concepts presented in this discussion paper are in contradiction with current industry documents, and whether and how these contradictions can / should be resolved.

### 8.3 Distribution system operator (DSO)

- Together with Swissgrid, make specifications on how PV systems shall interact with the grid.
- Develop processes / routines (e.g. commissioning checks, operational checks with smart metering) with which you can ensure the correct behaviour of the PV systems.
- Change the tariff structures and connection conditions in such a way that end customers are a) allowed to build grid-friendly installations and b) actually build them.
- Test new concepts with pilot projects on grid-friendly behaviour of PV systems, flexible consumers and storage systems, or at least tolerate them.
- Evaluate and use the strengths of smart metering in their network area.
- Examine and demonstrate the extent to which concepts presented in this discussion paper are in contradiction with current industry documents, and whether and how these contradictions can / should be resolved.

### 8.4 PV system operators and installers

- Install and operate systems that increase self-consumption and keep the power peaks of the grid feed low.
- Carry out their role as owners and users of flexibilities.
- Waive a few kilowatt hours of feed-in to greatly relieve the strain on the grids.
- Give grid operators (virtual) access to your plants as required (usually at the grid connection point, not at inverter level).
- Bear the risk of implementing innovative pilot projects that are compatible with the energy transition.

### 8.5 Research, laboratories, manufacturers

- Develop safe, efficient and functional concepts, systems and products.
- Support the regulator and the stakeholders in the rapid implementation of the latest findings.
- Support product and system standards for the grid connection of decentralised systems.
- Create bases for the other decision-makers by means of simulations, analyses and measurements.
- Accompany pilot projects in the field, test the associated systems in the laboratory.

## 9 Conclusion

In the authors' view, the grid integration of solar power is currently not on track. The following changes would support the transformation:

- The power peaks of PV systems are to be absorbed in a decentralised manner[27]. For this purpose, the grid operators must be allowed to a) permit and b) demand dynamic active power control.
- Policymakers and grid operators should create legal requirements and/or incentives so that PV plants do not feed in high power peaks.
- PV systems and inverter-based storage systems or loads with storage functions should provide primary control power as standard in certain operating states.

[27] In the short term, to accelerate the energy transition; in the long term, to maintain the economic viability of the energy system.

- Decentralised, flexible electricity producers and consumers (throttled PV systems, storage, electric vehicles, heat pumps) are to be integrated into an incentive system or feed-in management of the grid operator or an aggregator connected to the grid operator.

It is not realistic that all the points presented here will be converted from one day to the next. However, it must be avoided that PV systems are installed on the basis of today's rules, of which we already know that they will have to be converted again shortly. In particular, dynamic active power control at the feed-in point should therefore be enabled by all stakeholders (federal government, grid operators and installation companies / operators) as soon as possible. Systems should already be built today so that they are 50 GW PV compatible.

***We must not wait with the expansion of renewable energies, until the electricity grids are ready. We must build the plants in such a way that a large part of the discussed grid expansion measures are not even necessary.***

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