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Instruction / Application of the grid code specifications to hybrid power plants

17.10.2023

Table of contents

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Change history

Date	Version	Change
17 October 2023	1.0	First version

1 Introduction

These instructions describe how the VJV2018 /1/ and SJV2019 /2/ grid code specifications should apply to hybrid power plants.

A hybrid power plant is a power plant where plant sections of different types are connected to a single connection point. For example, power plants with different primary energy sources (solar, wind, hydro) or grid energy storage systems with active or reactive power controlled by a central controller may be connected to one connection point.

A central controller is a controller that makes the operation of the plant sections dependent on each other. The following are not defined as central controllers:

- Controlling the tap-changer of a main transformer shared between the various sections of a hybrid power plant
- Slow upper-level intra-plant reactive power control (see VJV2018, Appendix B, section 22.4), which is only permitted for connections with both production and consumption

If the power plant sections operate independently of each other and are controlled by dedicated controllers, the sections are considered independent power plants. Examples of independent power plants include conventional hydroelectric power production units where the turbines have dedicated water routes and voltage control based on the terminal voltage of their generators.

The physical locations of plant sections in relation to one another are irrelevant to the definition of a hybrid power plant.

These instructions only apply to hybrid power plants.

1.1 Compliance monitoring process and operational notification procedure

The compliance monitoring process and operational notification procedure in VJV2018 apply to hybrid power plants.

If a hybrid power plant project is constructed in phases, the connecting party must agree with Fingrid and the network operator on the phasing of the VJV grid code compliance monitoring process and operational notification procedure, taking into account the deadlines set in the VJV for the validity of the interim operational notification (ION). In principle, every plant section should be completed without delay, avoiding unnecessary extensions to the compliance monitoring process. Between the construction phases, Fingrid must have access to the latest technical and modelling data that reliably describe the plant's operation.

1.2 Modifications to existing plants

Converting an existing power plant into a hybrid power plant requires the initiation of a VJV compliance monitoring process in accordance with VJV2018 to re-examine the individual plant sections as required and assess the compliance of the hybrid power plant entity. The starting point for designing a hybrid power plant is to ensure the uniform operation of all plant sections in line with the existing VJV2018 requirements.

In principle, the applicable grid code specifications apply to plant modifications. If an existing plant section is designed to fulfil the grid code specifications that applied before VJV2018, the connecting party must evaluate the plant section's capability of meeting the VJV2018 requirements and endeavour to adapt its operation accordingly. If an existing plant section requires technically and financially significant modifications, the connecting party may ask Fingrid to limit the scope of the modifications. Fingrid decides whether to limit the scope of modifications on a case-by-case basis, provided that the modifications do not prevent new plant sections from complying with the requirements.

2 Dimensioning values of hybrid power plants

2.1 Rated capacity and minimum output

The type class (A-D) of a hybrid power plant and corresponding technical requirements are based on the hybrid power plant's rated capacity and the connection point's voltage level in accordance with the classification in VJV2018 and SJV2019. For example, a type D hybrid power plant is defined as an entity with a rated capacity of at least 30 MW or a connection point voltage level of at least 110 kV.

The rated capacity of a hybrid power plant (P_{max}) is its highest active power production level measured at the connection point, as specified in the connection agreement or otherwise determined between the network operator and the connecting party. The rated capacity of a hybrid power plant must be at least as high as the active power of the largest plant section without any software based limitations on the active power. The rated capacity of a hybrid power plant may be no higher than the combined active power of the rated capacities of each plant section ($P_{max\ 1}$–$P_{max\ n}$). The hybrid power plant's rated capacity and the rated capacities of the individual plant section must always be agreed upon with the network operator at the connection point, and the agreed capacities must not be exceeded.

The minimum output of a hybrid power plant (P_{min}) is based on the hybrid power plant's largest plant section. It can be no higher than 10% of the rated active power in accordance with section 16.3.2.1 of VJV2018. If the plant sections are equal in size, the hybrid power plant's minimum output is determined according to the plant section with the highest minimum output. In addition, the minimum output must be determined for each

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plant section ($P_{min\ 1}$–$P_{min\ n}$) based on their actual technical performance. No minimum output is defined for grid energy storage systems.

In 110 kV and 400 kV switchgear connections to Fingrid's network and 110 kV transmission line connections along a Fingrid transmission lines built in accordance with the general connection terms YLE2021, a hybrid power plant's rated capacity (P_{max}) may be limited by software. The rated capacity is not based on the sum of the rated capacities of plant sections. In line with YLE2021, a hybrid power plant's largest stepwise power change at the power plant connection may not exceed 1,300 MW.

2.2 Reactive power capacity

A hybrid power plant's reactive power capacity requirement is determined according to the plant's type class. The requirement is valid in full when the hybrid plant's largest section is operating above its minimum output. The reactive power capacities of other plant sections allocated for voltage control and with readiness to produce must not be restricted by software below the actual technical capability of the equipment while operating below this minimum output level.

If individual plant sections can also operate independently (for example, when the other plant sections are not operating), they must then meet the reactive power capacity requirement according to the plant section's rated capacity at the point where the hybrid power plant's reactive power capacity requirement is defined.

The reactive power capacity requirement for type C and D hybrid power plants corresponds to sections 12.2.2 and 17.2.1 of VJV2018 (Figure 1). If a hybrid power plant includes a type C or D grid energy storage system, the reactive power capacity requirement also applies to this plant section when in consumption mode (Figure 2). If a plant section has less than 10% of the main transformer's nominal power, the relevant network operator at the connection point will specify the reactive power capacity requirement for the specific plant section on a case-by-case basis.

Figure 1. The VJV2018 reactive power capacity requirement for type C and D power generating facilities.

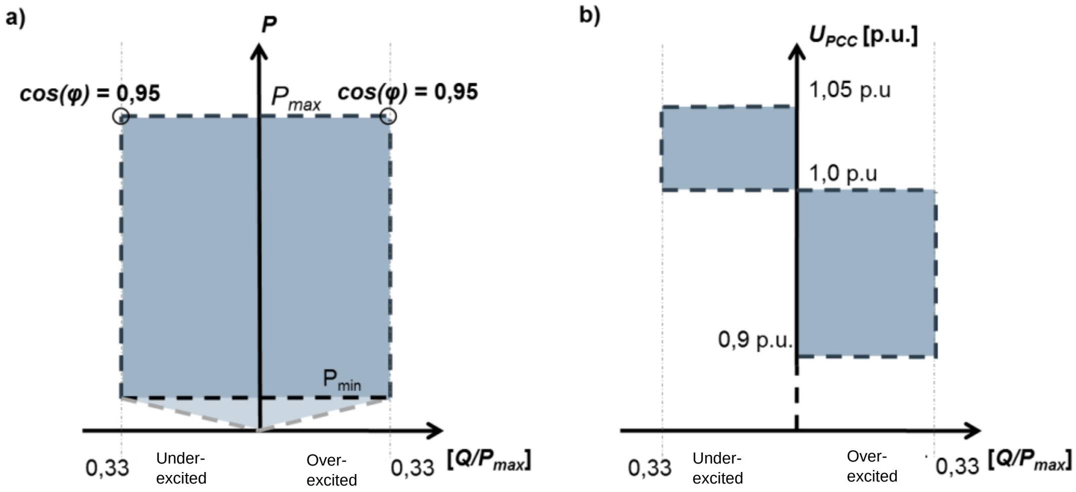
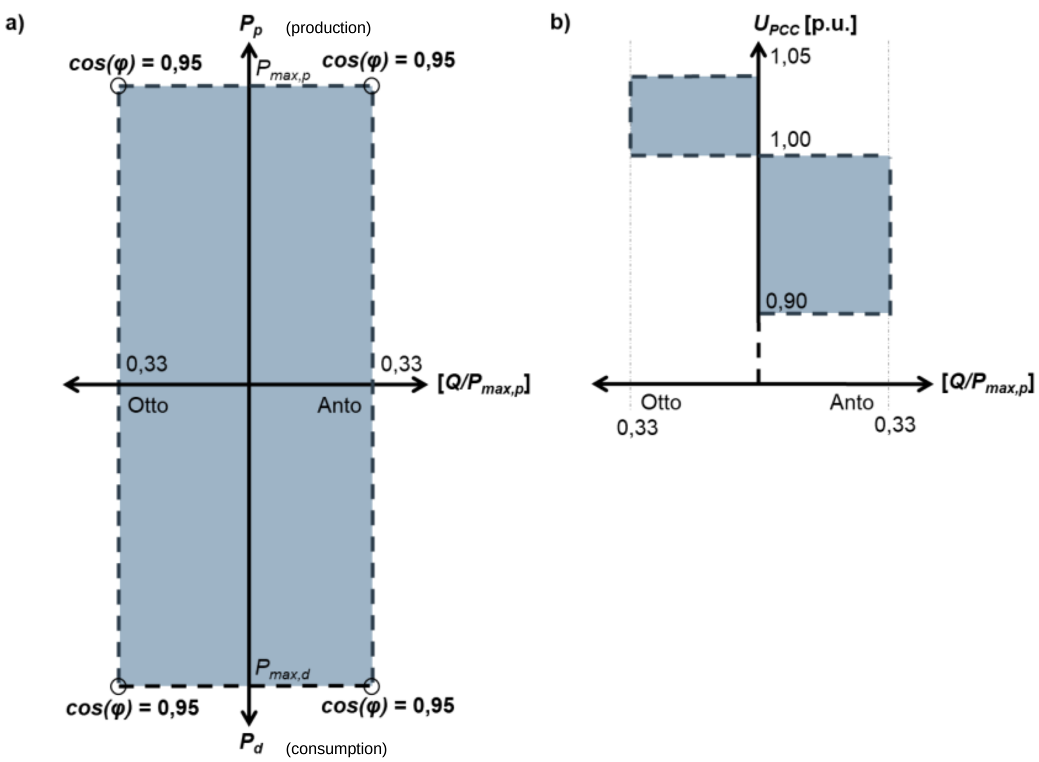


Figure 2. The SJV2019 reactive power capacity requirement for type C and D grid energy storage systems.



In accordance with VJV2018 and SJV2019, the hybrid power plant's reactive power capacity requirement must be met at the power plant's connection point. In line with Fingrid's prior interpretation – see /3/ chapter 2 – the terminals on the high voltage side of a hybrid power plant's main transformer (or a busbar shared between several main transformers) may be used as the point at which a hybrid power plant's reactive power capacity requirement is determined instead of the connection point. In such a case, the hybrid power plant's imputed rated capacity will be the highest active power defined to this point. Connection networks and associated losses between the main transformer and the connection point do not affect the hybrid power plant's rated capacity or the determination of the reactive power capacity. However, additional reactive power capacity may be required if a power plant has a very long connecting line (section 17.2.2 of VJV2018). This should be agreed upon separately with the network operator at the connection point.

The reactive power capacity requirement for a hybrid power plant and plant sections operating independently can be met using a combination of reactive power capacities from plant sections contributing to voltage control. The reactive power capacities of plant sections contributing to voltage control must not be needlessly limited by software. Dimensioning should take into account the functional constraints of the plant sections, including the following:

- Minimum output (e.g., the reactive power production capacity at zero active power)
- Sections causing constraints (e.g., the capacity of a shared main transformer)
- Operational constraints (e.g., availability at specific times)

The reactive power capacity should primarily be dynamic. In other words, the reactive power capacity should be implemented with converters offering rapid, step-free control. Note that switchable additional compensation, such as mechanically switchable capacitors, do not count as dynamic. If the total reactive power capacity of a hybrid power plant's production-ready (connected) sections without any software limitations is insufficient to meet the reactive power capacity requirement based on the rated capacity, up to 15% of it may be covered by switchable additional compensation. However, the hybrid power plant shall be capable of meeting the reactive power capacity required in full without switchable additional compensation when the power plant's active power output is less than 85% of the rated capacity (P_{max}). Instruction /3/ provides more detailed guidance on the operation and dimensioning of additional compensation.

If a hybrid power plant is incapable of meeting its reactive power capacity requirement according to the rated capacity for its operating state at any given time – for example, due to the technical failure of an individual plant section – the power plant's active power should be limited to a level corresponding to the reactive power capacity at the time (for type C and D plants, $Pmax \leq |Qmax/0.33|$, taking into account the voltage conditions).

If a hybrid power plant has a very high reactive power capacity, it may be necessary to use software to limit the reactive power capacity at Fingrid's request. Even then, the reactive power capacity requirement conforms to the VJV/SJV requirements.

2.3 Fault ride-through

A hybrid power plant's fault ride-through requirement is determined according to its type class at the hybrid power plant's connection point.

If individual plant sections can also operate independently (for example, when the other plant sections are not operating), they must then meet the fault ride-through requirement according to the plant section's type class at the hybrid power plant's connection point.

2.4 Voltage control

According to /4/, the primary control method for all power plants with a power of over 10 MW or a connection point voltage level of at least 110 kV (type C and D power plants) is constant voltage control. This also applies to hybrid power plants. If a hybrid power plant consists of several plant sections of less than 10 MW, but its rated capacity exceeds 10 MW, or the voltage at its connection point is at least 110 kV, it must operate under continuous voltage control.

All the plant sections contributing to meeting the reactive power capacity requirement of a type C or D hybrid power plant must operate under continuous voltage control. The rated reactive power (Q_n) used to determine the voltage control slope (VJV2018, section 22.3.1) is based on the hybrid power plant's rated capacity ($Q_n = 0.33 \times P_{max}$). If plant sections operate independently, the rated reactive power is based on each plant section's rated capacity ($Q_{n1} = 0.33 \times P_{max1}$ etc.)

In principle, the voltage control point (reference point) for the entire hybrid power plant is at the high-voltage side of the power plant's main transformer, which is typically at the power plant's 110 kV busbar. Voltage control can also be implemented for specific plant sections (the plant sections control the same busbar voltage with the same voltage slope configuration) while taking into account the capability to manage the total reactive power at the connection point. This avoids overloading the common plant-level components, such as the main transformer.

The lower-level controls of specific plant sections shall be coordinated with each other and the upper plant-level control so that voltage control functions stably under normal operating conditions and disturbances and no harmful interaction phenomena arise.

2.5 Protection and fault current injection

Hybrid power plants are not permitted to supply active power in excess of their rated capacity into the grid. Only short-term and attenuating power fluctuations in excess of the

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rated capacity are permitted when caused by the power plant's dynamic response to transient phenomena in the power system. If the active power simultaneously available from a hybrid power plant's sections may exceed the plant's rated capacity when not restricted by the controller, the hybrid power plant must be equipped with a protective device to ensure the plant does not exceed its rated capacity. The protective device must measure the power plant's active power and disconnect the power plant or an individual plant section if the power exceeds 105% x P_{max} for 20 seconds. The total power measured at the high-voltage terminals of the power plant's main transformers may be used as the active power measured by the protective device if no measurements are available at the actual connection point. The protective function can be realised as part of an existing protection relay (separate protection function).

If the plant is connected to a 110 kV Fingrid transmission line, the fault current injection of the plant sections must be taken into account and limited according to YLE2021 section 2.5 to 1.2 times the nominal current based on the hybrid power plant's rated capacity (300 ms from the onset of the fault). The number of converters connected in each operating state must be taken into account in fault current injection.

If the plant is connected by switchgear to a Fingrid substation, the fault current injection of plant sections must not be limited unless separately agreed upon with Fingrid.

2.6 Measurements and remote control

Hybrid power plants must provide the following real-time measurements:

- Active and reactive power measurements for each plant section and total powers for the plant as a whole.
- Switching device position indication in a scope specified on a case-by-case basis based on the plant's single line diagram. In principle, the plant should send status data on the (high-voltage) circuit breaker, disconnector and earthing switch from the power plant's substation to the grid, as well as the main circuit breakers in each plant section.
- Voltage measurement from the busbar that the plant uses to control the voltage when operating at constant voltage control. This applies to types C and D.
- Status information of the power plant's plant-level control state (voltage control/reactive power control/power factor control). This applies to types C and D.

A type C or D hybrid power plant must also be capable of receiving maximum power orders as electronic remote control commands from Fingrid and acknowledging receipt of the information and compliance with the order. Electronic remote control will be implemented between the SCADA systems of Fingrid and the operator responsible for the hybrid power plant's operation.

Fingrid's real-time information exchange application instructions provide more detailed requirements for real-time data exchange /6/.

All the plant sections in a hybrid power plant must always be controllable with a 15-minute response time in accordance with VJV2018 section 10.4.1. If the operation of the plant is based on remote operation (remote control) from the control centre of the entity responsible for the power plant's operation, as authorised by the connecting party, the performance of the remote control functions must be verified during the commissioning phase, as soon as the plant sections begin supplying power to the connection point.

Fingrid recommends equipping hybrid power plants with continuously operating data loggers that provide the operator responsible for the power plant's operation with immediate access to the measurements. The data logger should measure the currents and voltages at the connection point with a high sampling rate (> 5 kHz). A 30-day memory capacity is also recommended. The purpose of the data logger is to enable the operation of the hybrid power plant to be analysed in its normal operating state and in the event of disturbances and changes in the power system.

2.7 Other technical requirements

If the control of a converter-connected plant section is based on Grid Forming (GFM) control, the technical operating principles of the installation should be agreed upon with Fingrid on a case-by-case basis. The voltage control functionality of such a plant section must be carefully coordinated with other converter-connected plant sections - which are typically operating in the Grid Following (GFL) control - by taking into account the interactions between individual controllers and plant-level controls. The design must consider the following:

- Fault current injection and restoration from faults
- The implementation of voltage control and active power control. Plant-level controls must not significantly restrict GFM control from responding rapidly to change phenomena in the grid.
- When installations based on GFM control are installed on 110 kV transmission line connections, they must be prevented from unintentionally entering island operation by implementing a disconnection datalink to the hybrid power plant if the line does not have a protection datalink.
- Switching to house load operation, synchronization to the grid and possible blackstart capability.

3 Technical data and simulation models to be provided for hybrid power plants

3.1 Information to be provided

A PSS/E simulation model, model documentation, plant documentation, calculations (voltage control performance, reactive power capacity and voltage disturbance calculations) and the material required due to any specific study requirements (VJV2018, section 5) set for the project must be provided for hybrid power plants of type C or D (VJV2018 and SJV2019) in accordance with the VJV, the SJV (if applicable) and Fingrid's modelling instructions /5/. A PSCAD simulation model and model documentation must also be provided for type D hybrid power plants.

The plant documentation must contain a detailed system description of the hybrid power plant's operating principles, such as the following:

- The operating modes of plant sections: active power supply constraints and the technical background for them, the order of precedence of the production forms, an estimate of each plant section's annual production (power, energy and distribution over the hours of the year)
- The implementation of reactive power capacity, taking into account the instantaneous availability of plant sections (may be presented as part of the reactive power capacity calculation)
- Whether power converters are always online, irrespective of the readiness for active power production (for example, the STATCOM feature of wind turbine converters, "Night mode" in grid energy storage power converters when operating without batteries, operating mode of solar power plant power converters in the winter)

The information referred to above should be submitted to the relevant network operator for review at least 6 months before the power plant is commissioned, that is, when the plant is intended to begin supplying power to the grid.

3.2 Modelling requirements

Fingrid must have simulation models that describe the power plant's true operation in adequate detail and conform to the requirements before the power plant begins supplying electricity to the grid. The simulation models provided for hybrid power plants must include all the plant sections and equipment used to control them, such as the central controller. If the model consists of several separate models, the connecting party is responsible for the functional coordination of the models.

When the connecting party plans its project schedule, it is important to remember that reviewing and correcting the model is an iterative process that typically takes several months. Hybrid power plants are very challenging to model, considering the multiple supply limits and technical complexity due to the implementation of control. Fingrid checks the provided models with the network operator at the connection point. The simulation models must be approved before an Interim Operational Notification (ION) can be issued.

PSS/E and PSCAD models do not need to be submitted for grid energy storage systems installed to synchronous machine power plants to balance the frequency control of the plant if the rated capacity of the energy storage system is less than 5 MW and it is incapable of operating independently.

The voltage disturbance calculation, voltage control performance calculation and the calculations required by the specific study requirements shall be prepared separately for all the planned operating states of the hybrid power plant – meaning when the plant sections operate together and independently – and submitted as a report. Fingrid verifies the other functionalities required of the models by VJV/SJV (such as power control) as part of its model review, and the connecting party does not need to report them.

The modelling data for type C and D hybrid power plants is verified based on the results of commissioning tests with respect to the plant's reactive power capacity and the operation of the related restriction controls. Section 4.2 describes the verification related to the monitoring period included in the commissioning tests. The modelling data for type D hybrid power plants shall also be verified with respect to any special regulation functionality tested during commissioning. If a hybrid power plant's voltage control is tuned according to the VCSCR value, Fingrid will validate the model against the voltage control performance results obtained from commissioning tests and this is not required from the connecting party.

4 Commissioning tests for hybrid power plants

The reactive power capacity tests required by VJV2018 and SJV2019 for type C and D plants must be performed at 60% or more of the rated capacity. However, it may be difficult to arrange the simultaneous operation of the hybrid power plant sections at high power in practice. Moreover, the rated capacity agreed for the connection point may not even permit the plant sections to operate simultaneously at such high power. For this reason, the hybrid power plant's reactive power capacity can be verified for each plant section individually according to the VJV/SJV requirements. The central controller's allocation of reactive power between the plant sections is then verified by a separate test performed at a lower power level in accordance with Table 1.

During the commissioning tests, at least 90% of the tested plant section's production units must be available in the test and operate normally.

If a new plant section is added to a hybrid power plant, all the commissioning tests should, in principle, be repeated to the full extent. If it is possible to show that the addition of the new plant section will not affect the performance of the existing plant sections in a certain area, there is no need to repeat the commissioning test for the said area.

4.1 Commissioning tests

Table 1 shows the minimum scope of commissioning tests for type C and D hybrid power plants. The scope of testing is supplemented when necessary, for example, with testing of the special control functions of a specific hybrid plant. If the plant sections are also capable of independent operation under the control of a separate section-specific controller, commissioning tests must be performed on them in this operating state in the scope required by their type class under VJV/SJV.

Table 1. Commissioning tests for type C and D hybrid power plants.

Commissioning test		Entire hybrid plant (all plant sections operating under the control of the central controller)	Test each plant section separately
1	Limited frequency sensitive mode – over-frequency (LFSM-O)	Yes	No
2	Limited frequency sensitive mode – under-frequency (LFSM-U)	Yes	No
3	Frequency sensitive mode (FSM)	Yes	No
4	Rate of change in active power	Yes	Yes
5	Constant voltage	Yes	Yes
6	Control reactive power control	Yes	Yes
7	Constant power factor control	Yes	Yes
8	Reactive power capacity test and	Yes. Test when all plant sections are operating simultaneously at a	Yes The test is performed at all three power

	restriction of active power	minimum power of 20%. The test should also verify the possible substitution of the plant sections' reactive power capacity with capacity from other plant sections in accordance with the plant-specific design principles. During the test, an individual plant section is entirely or partially prevented from operating. The test demonstrates the capability of the other plant sections to meet the reactive power capacity requirement or implement active power curtailment if the reactive power capacity is insufficient.	levels in accordance with VJV/SJV.
9	Rapid down-regulation of active power	Yes	No (Does not apply to grid energy storage systems. See SJV2019.)
10	Shut-down and start-up	Yes. In addition to normal start-up and shut-down, the test includes restoration to production following a 10-minute network outage in which the power plant's external electricity and telecommunications network connections are lost.	Yes. Testing of the normal start-up and shut-down of the plant section.

11	Fault ride-through	The necessity of the test is considered on a case-by-case basis.

Commissioning tests for type B hybrid power plants are conducted in the scope described in VJV2018 section 19.2.

4.2 Monitoring period

A monitoring period of at least 30 days must be arranged to demonstrate the continuous operation of the hybrid power plant's central controller. A report must be prepared on the monitoring period to show that the plant's controls function according to the principles in the plant's system description.

During the monitoring period, the power plant's phase currents and voltages are measured and reported on the high-voltage side of each main transformer. The measurements are used to calculate the active and reactive power and frequency. The sampling rate of the measuring instruments must be at least 1 kHz, and the recording frequency must be at least 50 Hz. The power plant's disturbance/oscillation recorders may be used for monitoring if they have suitable continuous measurement features.

The largest network disturbance/incident during the monitoring period is selected and used to validate the simulation models. The voltage and frequency recording of the event from the connection point is repeated in the simulation model, and the responses of the power plant's various plant sections are compared with the measurements in the corresponding situation. A representative network incident is agreed upon with Fingrid at the end of the monitoring period, and the validation results are included in the report.

5 References

/1/ Grid Code Specifications for Power Generating Facilities VJV2018, https://https://www.fingrid.fi/globalassets/dokumentit/en/customers/grid-connection/grid-code-specifications-for-power-generating-facilities-vjv2018-.pdf (Accessed 17 October 2023)

/2/ Grid Code Specifications for Grid Energy Storage Systems SJV2019, https://www.fingrid.fi/globalassets/dokumentit/en/customers/grid-connection/grid-energy-storage-systems-sjv2019.pdf (Accessed 17 October 2023)

/3/ Reactive power requirements for power park modules and switched reactive power compensation, https://www.fingrid.fi/globalassets/dokumentit/fi/palvelut/kulutuksen-ja-tuotannon-liittaminen-kantaverkkoon/voimalaitosten-loistehokapasiteettivaatimus-ja-lisakompensointi.pdf (Accessed 17 October 2023)

/4/ Supply of reactive power and maintenance of reactive power reserves, https://www.fingrid.fi/globalassets/dokumentit/en/customers/power-transmission/supply-of-reactive-power-and-maintenance-of-reactive-power-reserves-2021-id-269130.pdf (Accessed 17 October 2023)

/5/ Modelling instruction for PSS/E and PSCAD models, https://www.fingrid.fi/globalassets/dokumentit/fi/palvelut/kulutuksen-ja-tuotannon-liittaminen-kantaverkkoon/fingrid-modelling-instruction-for-psse-and-pscad-models-2024_01_12-002.pdf (Accessed 17 October 2023)

/6/ Real-time information exchange, https://www.fingrid.fi/globalassets/dokumentit/en/customers/power-transmission/real-time-information-exchange_.pdf (Accessed 17 October 2023)

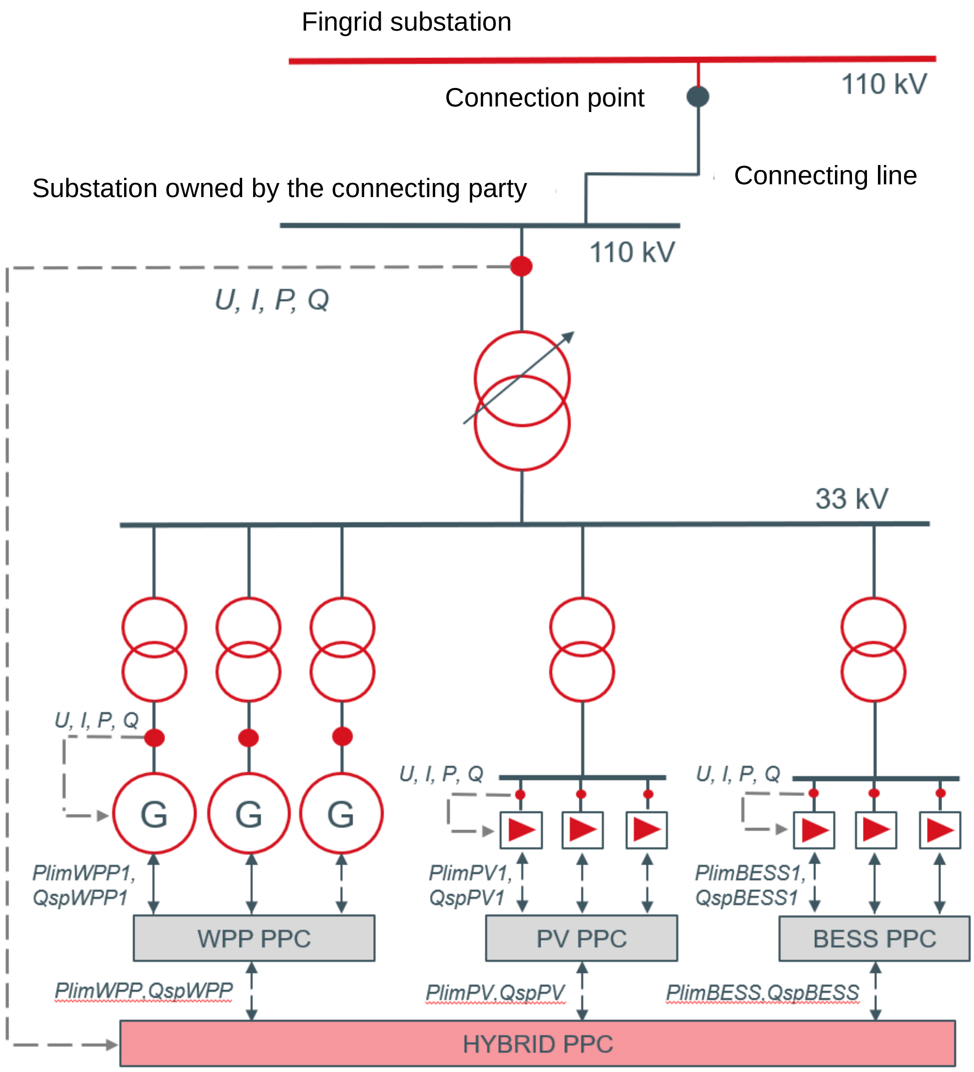
Appendices

Appendix 1 Application examples

Appendix 1 Application examples of hybrid power plants

1 Example 1

Hybrid plant: Wind farm with DFIG turbines $Pmax_{WPP}$ = 100 MW, solar power plant $Pmax_{PV}$ = 50 MW, and grid energy storage $Pmax_{ESS}$ = 20 MW. The connection agreement states that the hybrid power plant's rated capacity (Pmax) at the connection point is 130 MW. The power plant has an 8 km connecting line to the connection point specified in the connection agreement.

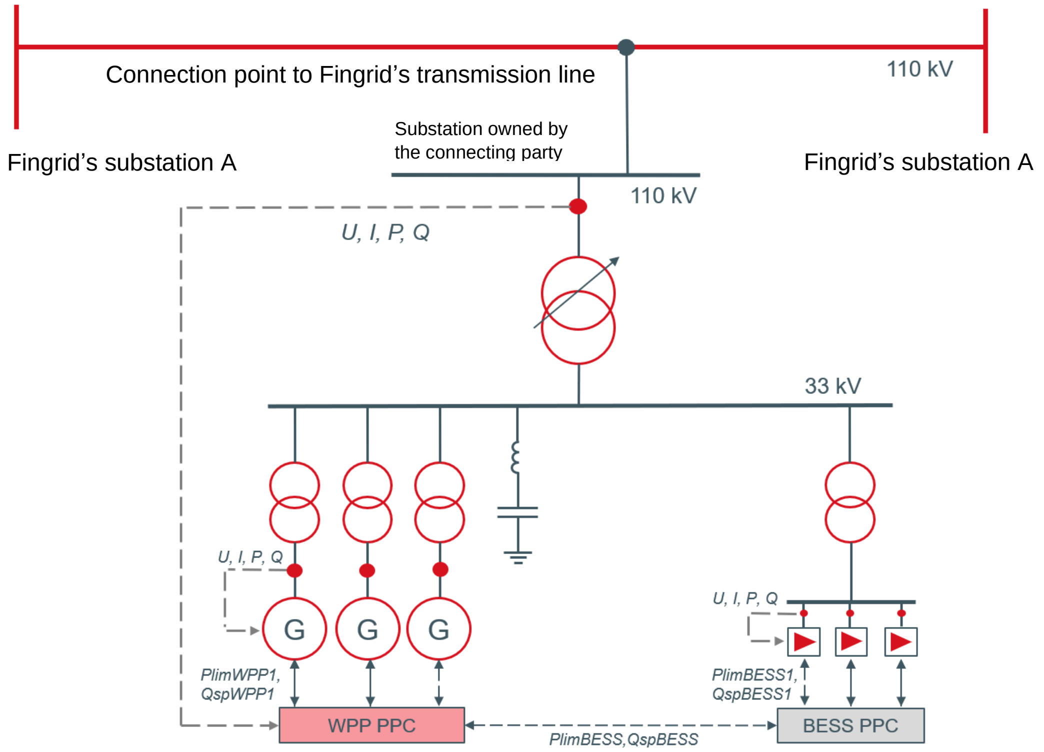


- Control implementation
    - The hybrid power plant in this example has a plant-level central controller ("Hybrid PPC") that measures and controls the plant's active and reactive power and voltage at the high-voltage side of the high-voltage transformer. The active power is limited to 130 MW in all operating states. Reactive power slopes are implemented for the central controller.
    - Every plant section has a dedicated controller, which receives active and reactive power commands from the central controller. The controllers of the plant sections independently control their individual production units based on the terminal quantities of each production unit's power converter.
    - The central controller is at least one order of magnitude (1/10) slower than controlling individual power converters to avoid cross-control.
    - The tap-changer in the power plant's main transformer controls itself based on the 33 kV busbar voltage.

- The hybrid power plant is a type D plant. Its reactive power capacity requirement is +/-0.33 x P_{max} at the high-voltage terminals of the power plant's main transformer (taking into account the voltage limits in Figures 1 and 2). In other words, it is +/- 0.33 x 130 MW → +/- 42.9 Mvar. This reactive power capacity is implemented as a combination of the reactive power capacities of various plant sections. The power converters are dimensioned accordingly. The plant does not have any mechanically switchable capacitors.
- The reactive power capacity requirement applies when the largest plant section – in this case, the DFIG wind farm – operates above its minimum output of 5%, which is 5 MW. However, the reactive power capacities of the power converters belonging to the solar power plant and grid energy storage system are not restricted by software, even when the wind farm does not operate above its minimum output.
- The solar power plant and grid energy storage system are capable of operating independently. In such a case, they operate under voltage control, adjusting to a voltage of 110 kV, and the reactive power capacity required for the main transformer's high-voltage terminals is +/- 0.33 x 50 MW → +/- 16.7 Mvar for the solar power plant and +/- 0.33 x 20 MW → +/- 6.7 Mvar for the grid energy storage system.
- The wind farm's power converters are dimensioned so that when it operates at full power, the reactive power capacity of the solar power plant's full power converters is used to produce the required reactive power capacity of +/- 0.33 x 100 MW → +/- 33.3 Mvar.

2 Example 2

Hybrid plant: A 30 MW wind farm and 15 MW grid energy storage system on the same transmission line connection to a 110 kV Fingrid transmission line. One main transformer of 31.5 MVA. The connection agreement states that the hybrid power plant's rated capacity (Pmax) to the connection point is 30 MW. No connecting line, as the connecting party's substation is located in the immediate vicinity of Fingrid's transmission line.



- Control implementation principle
  - The hybrid power plant in this example has a wind power plant park controller ("WPP PPC") that operates as the plant-level central controller, measuring and controlling the plant's active and reactive power and voltage at the high-voltage side of the high-voltage transformer. The active power is restricted to 30 MW in all operating states. Reactive power slopes are implemented for the central controller.
  - The grid energy storage system has a dedicated controller, which receives active and reactive power commands from the wind farm's park controller. The controllers of the plant sections independently control their individual production units based on the terminal quantities of each production unit's power converter.
  - The central controller is at least one order of magnitude (1/10) slower than controlling individual power converters to avoid cross-control.

  - The tap-changer in the power plant's main transformer controls itself based on the 33 kV busbar voltage.

- The hybrid power plant is a type D plant. Its reactive power capacity requirement is +/-0.33 x P_{max} at the high-voltage terminals of the power plant's main transformer (taking into account the voltage limits in Figures 1 and 2). In other words, it is +/- 0.33 x 30 MW → +/- 9.9 Mvar.

- The reactive power capacity requirement applies when the largest plant section – in this case, the wind farm – operates above its minimum output. The turbines have full power converters (FCs), so the minimum output is 0 MW (0%). The reactive power capacity (voltage control) must be available when the power converters are in production-ready mode and connected to the grid.

- The wind farm and grid energy storage system are capable of operating independently. In such a case, they operate under voltage control, adjusting to a voltage of 110 kV, and the reactive power capacity required for the main transformer's high-voltage terminals is +/- 0.33 x 30 MW → +/- 9.9 Mvar for the wind power plant and +/- 0.33 x 15 MW → +/- 5.0 Mvar for the grid energy storage system. Capacitors are connected to the 33 kV busbar to allow the wind farm to operate independently. The capacitors supplement the power plant's reactive power capacitor at high active powers.

- The requirements for the fault current injection of power plants and grid energy storage systems are parameterised according to VJV2018 section 10.3.3 and SJV2019 section 10.3.3. As this plant has a transmission line connection, the hybrid power plant's fault current injection must be limited according to YLE2021 section 2.5 to 1.2 times the nominal current (300 ms from the onset of the fault). Therefore, when both plant sections are operating, the fault current must be limited to 1.2 x (30 MVA / sqrt(3) / 110 kV) = 189 A.

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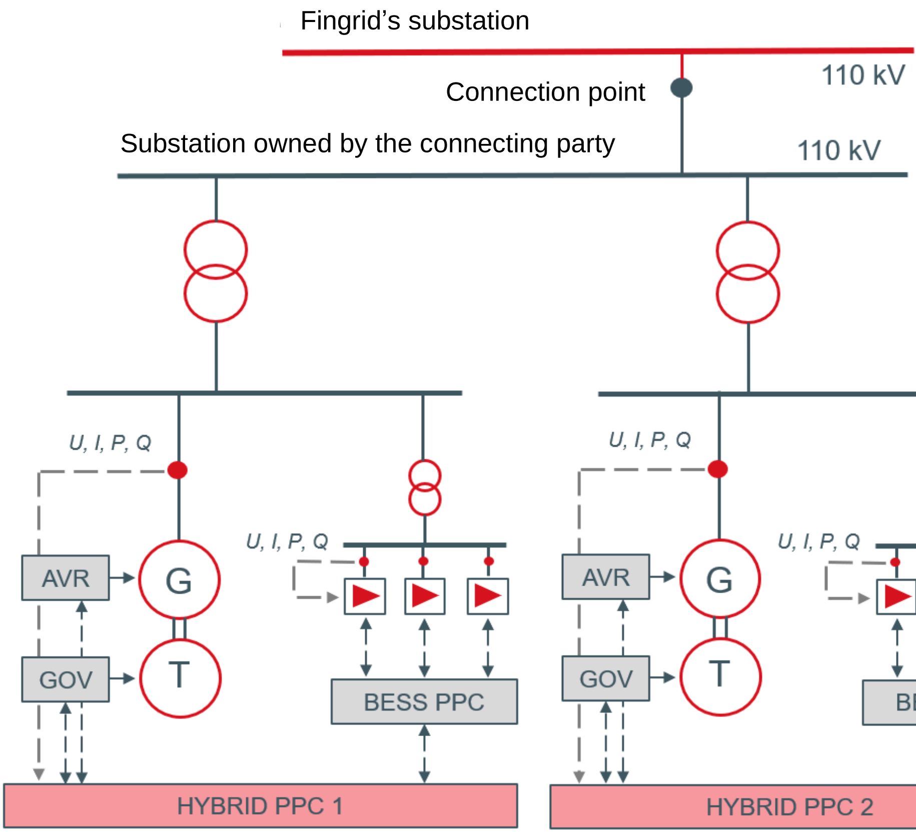
3 Example 3

Hybrid plant: 2 x 1.2 MW grid energy storage systems are added to an existing 2 x 20 MW hydropower plant. Two 25 MVA generator transformers. The connection agreement states that the hybrid power plant's rated capacity (Pmax) to the connection point is 40 MW. The power plant has a 110 kV Fingrid switchgear connection. No connecting line. The purpose of the grid energy storage system is to reduce the mechanical control movement of the water turbine when the hydropower plant operates in the reserve market. It does not increase the power plant's rated capacity.



- Control implementation principle
  - The hydropower plant's 20 MW units (1 and 2) are independent units with dedicated water routes, so they are treated as separate power plants. Therefore, the hybrid power plant consists of a combination of one generator and a battery.
  - A voltage controller controls the hydropower plant's generator and its excitation system, while a turbine controller controls the turbine.

  - The hybrid PPC is responsible for the frequency control offered to the reserve market. The hybrid PPC's active power command to the grid energy storage system is coordinated with the hydropower generator's turbine controller. A hybrid controller limits the power plant's active power to the permitted level of 20 MW.

- The hybrid power plant is a type D plant. In line with the requirements for synchronous machine power plants (VJV2018 section 12.2.2), its reactive power capacity requirement is +/-0.33 x P_{max} at the high-voltage terminals of the power plant's main transformer (taking into account the voltage limits in Figures 1 and 2). In other words, it is +/- 0.33 x 20 MW → +/- 6.7 Mvar.
- The generator is responsible for meeting the reactive power capacity and operates under continuous voltage control.
- The grid energy storage system is incapable of independent operation. It only operates when the hydropower plant supplies power. The grid energy storage system operates under power factor control (with the alignment cos φ ≈ 1) and does not contribute to voltage control.
- The grid energy storage system's fault current injection is parameterised according to SJV2019 section 10.3.3, and the grid energy storage system meets the fault ride-through requirement for a type D plant according to SJV2019 section 10.5.2.