# Time-of-Use settings with Fronius hybrid inverters

Options for optimised battery storage system management for time-dependent electricity tariffs

# Content

# 1. Introduction

Photovoltaic (PV) systems are equipped with electrical storage systems mainly for the purpose of increasing self-consumption and energy independence. High self-consumption means consuming as much of the energy produced as possible at source while autonomy means drawing as little energy as possible from the grid, i.e., being as self-sufficient as possible.

To achieve these goals, a Fronius Smart Meter is installed on the household connection. This device measures how much power is fed into the grid and how much is drawn from the grid. If more power is generated by the PV system than is consumed in the household, this results in surplus PV power. If more power is required than is generated by the PV system, electricity is drawn from the grid.

In the standard configuration, the surplus PV power is stored in the energy storage system. The household is supplied with this stored energy if too little or no PV power is available. The possible energy flows in a household are shown in Figure 1.

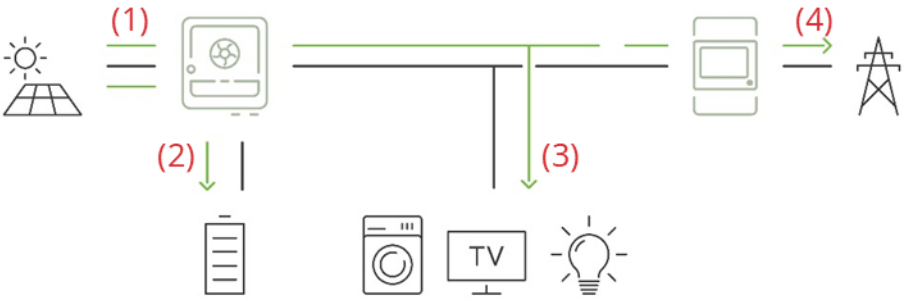


*Figure 1: Energy flows in the household*

(1) PV generator to inverter (PV current)
(2) Inverter to storage system (charging current) or storage system to inverter (discharging current)
(3) Inverter to loads
(4) Inverter to AC grid (feed in) or AC grid to loads or AC grid to inverter and storage system (charging from grid)

If additional framework conditions such as time-dependent electricity tariffs (time-of-use, ToU), variable reserves of emergency power or power limits are to be taken into account, it makes sense to apply additional energy storage system settings. This document explains which settings possible and which applications are covered.

Without additional battery control rules, the device is optimized for maximum self-consumption. The user has to decide the relative importance of self-consumption, costs, and convenience for them depending on the application, as self-consumption may drop when battery control rules are defined.

## 2. Flexible electricity tariffs (Time-of-Use)

With flexible electricity tariffs (also called time-of-use, ToU), customers pay different prices for their energy consumption from the grid at different times of the day. Figure 2 shows typical time-of-use tariffs applied in Australia, as an example. The peak phase, when there is generally also the highest demand for energy, is the most expensive for customers. Customers pay a moderate price during the shoulder phase, while the electricity price is at its lowest during the off-peak phase (typically at night).

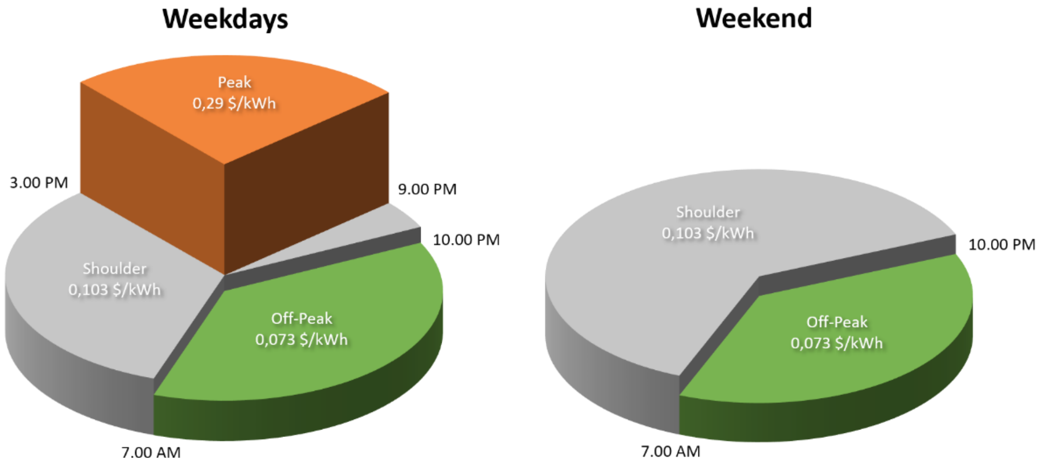


*Figure 2: Typical ToU electricity tariff in Australia*

These time-of-use tariffs often also depend on the time of year (see Figure 3). In winter, more energy tends to be used during the morning and evening, therefore these times are normally the most expensive. In summer, the peak-phase occurs during the day, since there is often increased use of cooling units due to the heat.

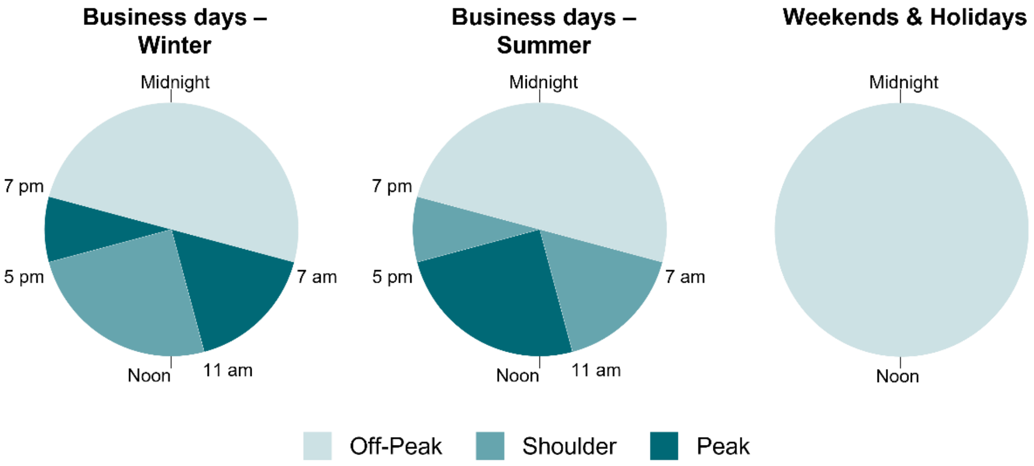


*Figure 3: Possible ToU tariff periods for winter and summer*

Flexible electricity tariffs are intended to give customers an incentive to use energy at times when the general demand is low, and so the electricity price is at its lowest at these times. This enables customers to lower their electricity bills and play a role in load management and reducing the load on the grid infrastructure.

Of course, customers are not always able to shift their energy consumption to the times with the lowest electricity price. However, an energy storage system allows users to store energy either when the electricity price is low or when there is sufficient PV energy. This stored energy can then be used when the electricity price is high. To make best use of this option, Fronius hybrid inverters provides a function that allows users to set time windows for charging and discharging the energy storage system. In this way, the behavior of the Fronius hybrid inverter can be adjusted in line with the time-dependent electricity tariffs.

# 3. Rules for the battery storage system

The Fronius hybrid inverter allows users to set different time-dependent rules for the energy storage system in relation to charging and discharging power for each weekday. This means that the storage system's operating range can be specified, and time-of-use applications covered.

However, there are several external factors which influence these parameters or even render them ineffective. These include permitting charging from the AC grid, power limitations for the inverter, the minimum/maximum permitted state of charge of the storage system or calibration charging/control parameters sent via Modbus.

## 3.1 Storage system power limitations without rules

If no value is entered for a time period, the power is only restricted by the inverter or storage system during this period.

Example discharging power of Fronius inverters and battery storage systems:

Max. AC output power Fronius Symo GEN24 5.0 Plus: 5.0 kW
Max. charging/discharging power BYD Battery-Box Premium HVS 10.2: 5.2 kW

Max. AC output power Fronius Symo GEN24 10.0 Plus: 10.0 kW
Max. charging/discharging power BYD Battery-Box Premium HVS 10.2: 9.01 kW

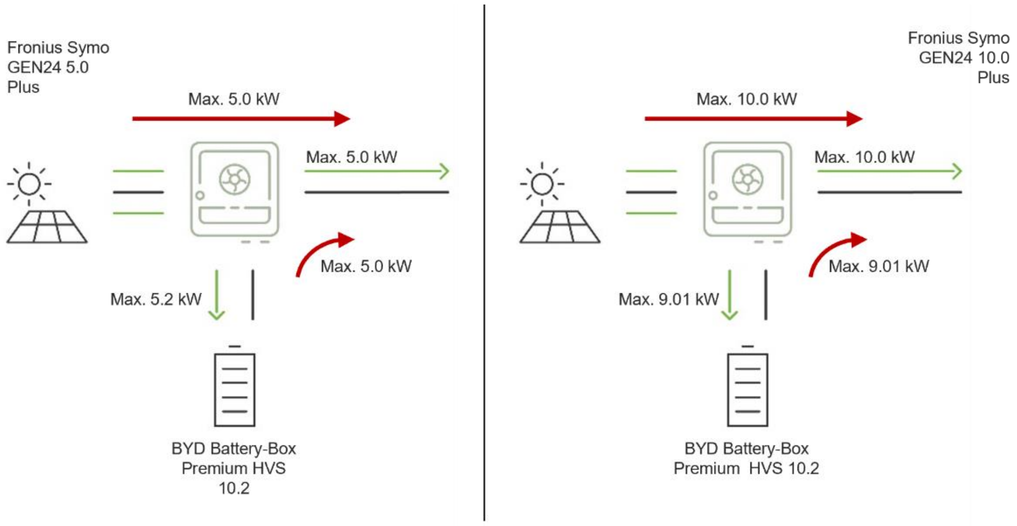


*Figure 4: Maximum system output depending on inverter and storage system*

A maximum of 5.0 kW can be discharged by combining the Fronius Symo GEN24 5.0 Plus and the BYD Battery-Box Premium HVS 10.2. A maximum of 9.01 kW can be discharged by combining the Fronius Symo GEN24 10.0 Plus and the BYD Battery-Box Premium HVS 10.2. In this case, the minimum of both powers is always the limiting factor.

When charging the storage system, note that it is possible to perform charging using energy from the PV system and additional generators at the same time. The PV input power may also be higher than the maximum AC output power of the inverter. In this case, the charging power may be greater than the maximum AC output of the inverter (see Multiflow Technology whitepaper).

## 3.2 Possible parameters for the energy storage system

It is possible to apply four restrictions to the storage system's charging/discharging behavior: maximum and minimum charging/discharging power. The permitted operating range can be pictured as a slide control with two sliders, with the discharging range on the left, neither discharging nor charging in the middle, and the charging range on the right. The operating point of the storage system can be found between the two indicators. Table 1 shows the five permitted configurations for the two restrictions that can be used for time-of-use applications.

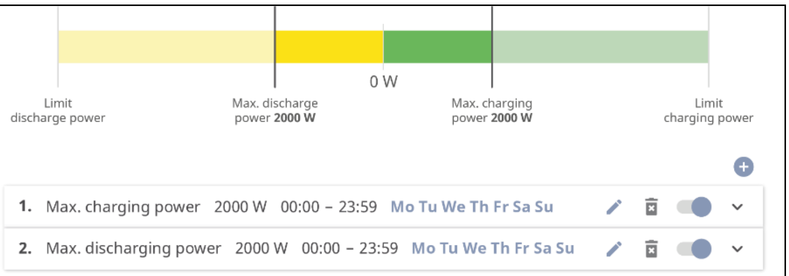
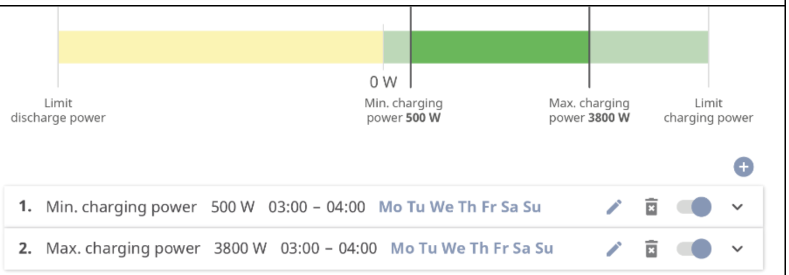
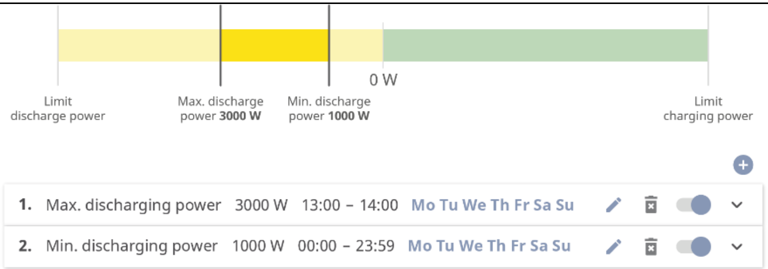
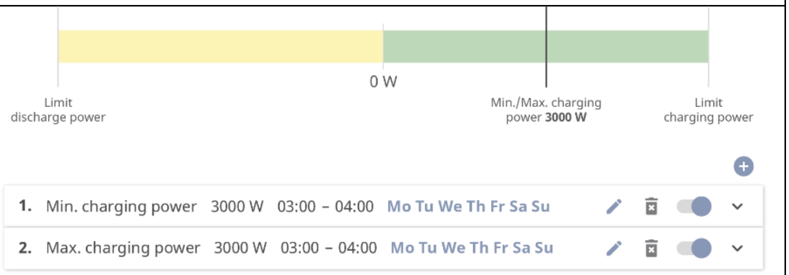
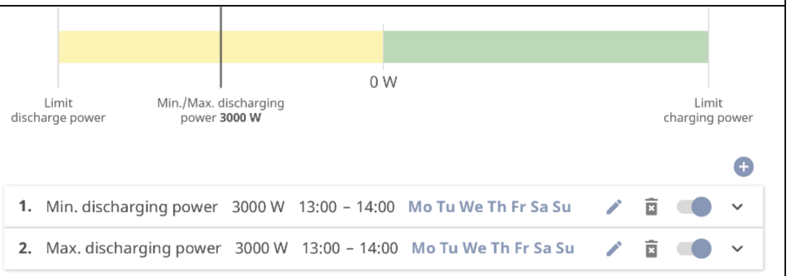
| | |
|---|---|
| **Maximum charging and discharging limits** |  <br>1. Max. charging power 2000 W 00:00 – 23:59 Mo Tu We Th Fr Sa Su<br>2. Max. discharging power 2000 W 00:00 – 23:59 Mo Tu We Th Fr Sa Su |
| **Specifying the charging range** |  <br>1. Min. charging power 500 W 03:00 – 04:00 Mo Tu We Th Fr Sa Su<br>2. Max. charging power 3800 W 03:00 – 04:00 Mo Tu We Th Fr Sa Su |
| **Specifying the discharging range** |  <br>1. Max. discharging power 3000 W 13:00 – 14:00 Mo Tu We Th Fr Sa Su<br>2. Min. discharging power 1000 W 00:00 – 23:59 Mo Tu We Th Fr Sa Su |
| **Specifying a defined charging power** |  <br>1. Min. charging power 3000 W 03:00 – 04:00 Mo Tu We Th Fr Sa Su<br>2. Max. charging power 3000 W 03:00 – 04:00 Mo Tu We Th Fr Sa Su |
| **Specifying a defined discharging power** |  <br>1. Min. discharging power 3000 W 13:00 – 14:00 Mo Tu We Th Fr Sa Su<br>2. Max. discharging power 3000 W 13:00 – 14:00 Mo Tu We Th Fr Sa Su |

*Table 1: Settings for restrictions*

The option of creating parameters for the storage system was developed to ensure the energy produced can be consumed by the user as efficiently as possible. However, situations may arise in which PV energy cannot be fully used due to storage system rules.

For example: A Fronius Symo GEN24 5.0 Plus is configured with a BYD Battery-Box Premium HVS 10.2 with a defined discharge of 3.0 kW. 1.0 kW PV power is produced at the same time.

In this case, the inverter would need to reduce the PV power to 2.0 kW, as the output power of the Fronius Symo GEN24 5.0 Plus is 5.0 kW and the device is already fully utilized through the discharging

Since wasting PV power is not in the interest of the user, the power limitation for the rules is automatically adjusted so that no PV power is wasted. In the above example, this means that the storage system is only discharged with 2.0 kW, so that the 3.0 kW of PV power can be used.

**Caution:** When using external control commands (e.g. via Modbus or control via IOs - ripple control receiver), these parameters are also strictly adhered to even if this means PV energy will be lost.

# 4. Use cases

We will now look at several possible applications for charging/discharging parameters for the energy storage system and the potential savings. Optimal settings and actual savings depend on the consumption behavior, the size of the system and storage system, the tariff difference, and other factors (such as the emergency power function).

It should be noted that certain applications are not permitted in some markets due to the legal situation (e.g., in Germany, charging the storage system from the grid and discharging it back into the grid at a later point).

The examples assume a household with a 10 kWh energy storage system (based on an assumed deep discharge protection of 5% residual capacity, approx. 9.5 kWh is available for full use. To take into account a possibly incomplete discharge overnight, an additional 25% of the available capacity is deducted. This results in a usable capacity of 7 kWh.

## A. Victoria, Australien

ToU tariff rates (in Australian dollars; see Figure 5):

- Peak phase, 3:00 pm to 9:00 pm: 26.53 ct/kWh
- Shoulder phase, 7:00 am to 3:00 pm and 9:00 pm to 10:00 pm: 22.42 ct/kWh
- Off-Peak, 10:00 pm to 7:00 am: 16.71 ct/kWh
- Feed in: 6.7 ct/kWh

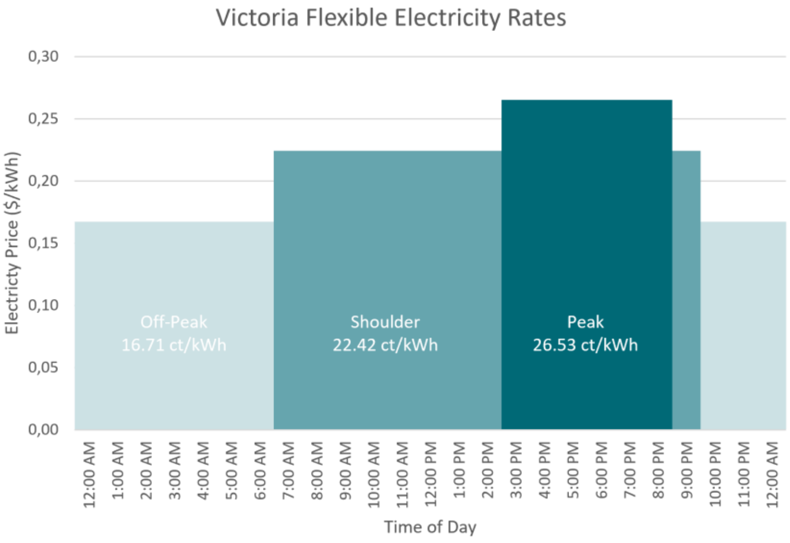


*Figure 5: ToU tariff in Victoria*

## B. Big Island, Hawaii

ToU tariff rates (in US dollars; see Figure 6):

- Peak phase (On-Peak), 5:00 pm to 10:00 pm: 63.10 ct/kWh
- Shoulder phase (Off-Peak), 10:00 pm to 9:00 am: 56.50 ct/kWh
- Off-Peak (Mid-Day), 9:00 am to 5:00 pm: 23.00 ct/kWh
- Feed in: 24.44 ct/kWh

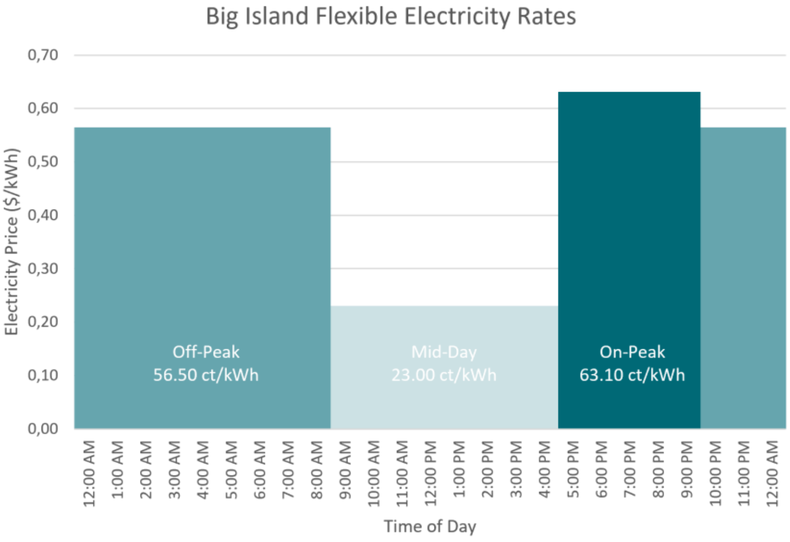


*Figure 6: ToU tariff on Big Island, Hawaii*

One month in this case is assumed to be 22 days, as ToU tariffs do not normally apply at the weekend. To calculate the savings per year, it is assumed that the storage system can actually be fully charged for 7 months per year. This means that the savings could be even higher depending on the number of sunny days.

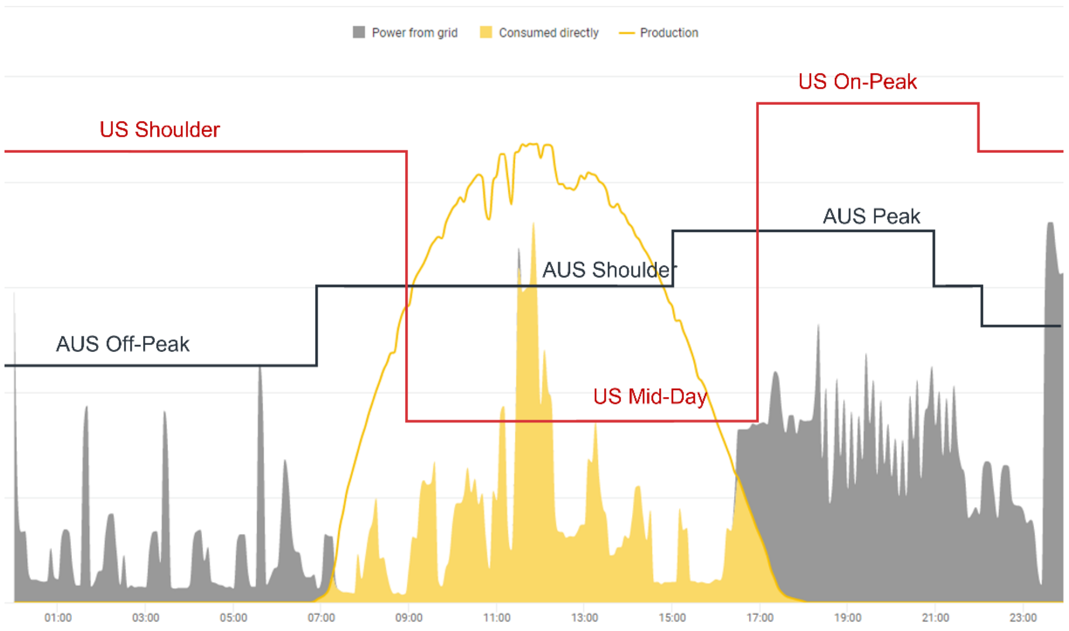


*Figure 7: Energy balance with tariff lines*

For example, Figure 7 shows the energy balance for one day with plotted tariff lines (black: Victoria, Australia; red: Big Island, Hawaii).

## 4.1 Fully charging the storage system only from PV before the peak phase

Probably the simplest use case is having the energy storage system fully charged specifically at the start of the phase with the highest electricity price. In this case – depending on consumption and the size of the storage system – consumption could be fully covered from the storage system. In this case, no expensive electricity will need to be drawn from the grid.

### Example A1

As the PV energy is not fed into the grid during the day but is instead stored for later use, yields from the feed-in tariff are reduced by the following amount:

$$Loss = 7\ kWh * 0.067\frac{\$}{kWh} = 0.47\ \$$$

If the stored energy is fully used during the peak phase, then this results in the following saving per day:

$$Saving_{Total} = 7kWh * 0.2653\frac{\$}{kWh} - Loss = 1.39\ \$$$

Ultimately, this results in savings of AU$30.58 per month/AU$214.06 per year.

### Example B1

As the PV energy is not fed into the grid during the day but is instead stored for later use, yields from the feed-in tariff are reduced by the following amount:

$$Loss = 7\ kWh * 0.2444\frac{\$}{kWh} = 1.71\ \$$$

If the stored energy is fully used during the peak phase, then this results in the following saving per day:

$$Saving_{Total} = 7kWh * 0.631\frac{\$}{kWh} - Verlust = 2.71\ \$$$

Ultimately, this results in savings of US$59.62 per month/US$417.34 per year.

## 4.2 Fully charging the storage system from the grid before the peak phase

The energy storage system should be fully charged specifically at the start of the phase with the highest electricity price, but if there might be insufficient PV energy during the day, due to poor weather for example, users can permit the inverter to also charge the energy storage system from the grid. However, additional parameters should be set here so that this is only permitted at times with a low, ideally the lowest, electricity price. It can also be worth charging from the grid when the electricity price and the feed-in tariff are at similar levels. When on a ToU tariff in summer with a peak phase during the day, users should refrain from additional charging from the grid.

### Example A2

If, for example, the storage system is charged halfway from the grid during the day then the yields from the feed-in tariff are reduced by half due to the lack of feed-in:

$$Loss = 3.5\ kWh * 0.067\frac{\$}{kWh} = 0.23\ \$$$

The remaining energy from the grid for full charging must be paid for (shoulder phase):

$$Costs = 3.5\ kWh * 0.2242\frac{\$}{kWh} = 0.78\ \$$$

This results in the following saving per day:

$$Saving_{Total} = 7kWh * 0.2653\frac{\$}{kWh} - Loss - Costs = 0.85\ \$$$

Ultimately, this results in savings of AU$18.70 per month/AU$130.90 per year.

### Example B2

If, for example, the storage system is charged halfway from the grid during the day then the yields from the feed-in tariff are reduced by half due to the lack of feed-in:

$$Loss = 3.5\ kWh * 0.2444\frac{\$}{kWh} = 0.86\ \$$$

The remaining energy from the grid for full charging must be paid for (Off-Peak phase):

$$Costs = 3.5\ kWh * 0.23\frac{\$}{kWh} = 0.81\ \$$$

This results in the following saving per day:

$$Saving_{Total} = 7kWh * 0.631\frac{\$}{kWh} - Loss - Costs = 2.75\ \$$$

Ultimately, this results in savings of US$60.50 per month/US$423.50 per year.

In this case, there are even slightly more savings than in Example B1, because the feed-in tariff is higher than the mid-day tariff.

## 4.3 Time-dependent battery control and feed-in limitations

Some markets have grid power feed-in restrictions, i.e., users can only feed-in some of the connected PV power (e.g., 70% in Germany) or potentially none (e.g., zero feed-in in Hawaii) into the grid. However, as household consumption can be taken into account, ideally 100% of the PV energy can be used, thereby avoiding a reduction in the output power.

On such systems, it may be the case that PV energy cannot be optimally used at midday, as the energy storage system, which could otherwise take the excess energy, is already fully charged. If there is sufficient capacity available at that time to store the energy that cannot be fed into the grid, then the output power does not need to be reduced and valuable PV energy is not “wasted”. In this case, the storage system must not be charged without limit in the morning, i.e., the maximum charging power of the storage system should be restricted.

### Example A3

If the household is restricted to zero feed-in, energy must not be fed into the grid and therefore there is no feed-in tariff. Due to the zero feed-in obligation, the inverter should have reduced its output power, however the excess energy is moved to the storage system in this example. If the stored energy is now fully used during the peak phase, then this results in the following saving per day:

$$Saving_{Total} = 7kWh * 0.2653\frac{\$}{kWh} = 1.86\ \$$$

Ultimately, this results in savings of AU$40.92 per month/AU$286.44 per year.

### Example B3

If the household is restricted to zero feed-in, energy must not be fed into the grid and therefore there is no feed-in tariff. Due to the zero feed-in obligation, the inverter should have reduced its output power, however the excess energy is moved to the storage system in this example. If the stored energy is now fully used during the peak phase, then this results in the following saving per day:

$$Saving_{Total} = 7kWh * 0.631\frac{\$}{kWh} = 4.42\ \$$$

Ultimately, this results in savings of US$97.24 per month/US$680.68 per year.

## 4.4 Charging the storage system from the grid overnight

The energy storage system that was previously fully discharged during the peak phase can be fully re-charged overnight when the electricity is at its cheapest. This means users can cover their consumption in the morning – during phases with higher electricity prices – from the storage system and only pay the cheapest price.

In this scenario, users may need to ensure that no energy is being fed into the grid, as this could be problematic from a legal perspective (e.g., due to limitations on the discharge power).

### Example A4

The storage system that was previously fully discharged during the peak phase is fully re-charged during the off-peak phase at night. The costs are:

$$Costs = 7\ kWh * 0.1671 \frac{\$}{kWh} = 1.17\ \$$$

If consumption is fully covered by the energy storage system during a peak phase in the morning, then the saving is as follows:

$$Saving_{Morning} = 7\ kWh * 0.2653 \frac{\$}{kWh} = 1.86\ \$$$

The total saving per day, minus the costs for charging, is:

$$Saving_{Total} = Saving_{Morning} - Costs = 0.69\ \$$$

Ultimately, this results in savings of AU$15.18 per month/AU$106.26 per year.

Using the stored energy during a shoulder phase in the morning would result in a saving per day of AU$0.40 which equates to AU$8.80 per month or AU$61.60 per year.

### Example B4

The storage system that was previously fully discharged during the peak phase is fully re-charged during the off-peak phase at night. The costs are:

$$Costs = 7\ kWh * 0.5650 \frac{\$}{kWh} = 3.96\ \$$$

If consumption is fully covered by the energy storage system during a peak phase in the morning, then the saving is as follows:

$$Saving_{Morning} = 7\ kWh * 0.6310 \frac{\$}{kWh} = 4.42\ \$$$

The total saving per day, minus the costs for charging, is:

$$Saving_{Total} = Saving_{Morning} - Costs = 0.46\ \$$$

Ultimately, this results in savings of US$10.12 per month/US$70.84 per year.

## 4.5 Prevent battery from discharging at night

Figure 8 shows the consumption peaks in the evening and morning. If these peaks fall within the peak phases (e.g., from 7:00 am to 8:30 am and from 3:00 pm to 9:00 pm), then users may specifically want to cover these peaks with the stored energy.

In this case, it may make sense to “disable” the storage system after the peak phase in the evening for the rest of the night. This only really makes sense if the stored energy has not already been fully consumed.

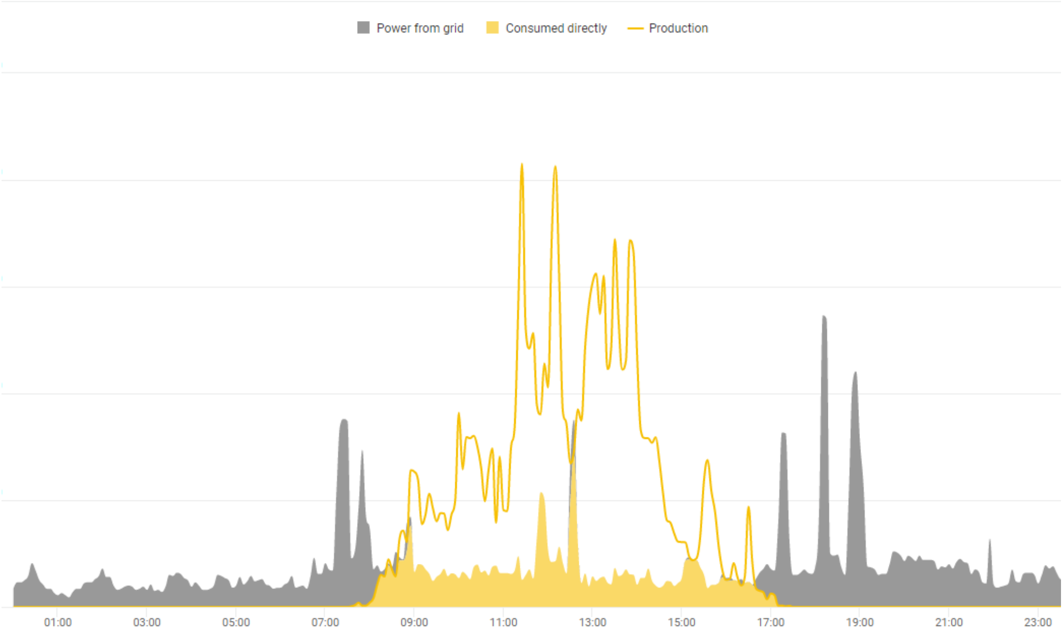


*Figure 8: PV production and consumption with peaks in the morning and evening*

If the storage system is set so that it cannot discharge during the night, then the stored energy can be used specifically when the electricity price rises again.

With the prices presented, this application only makes sense if there is also a peak phase in the morning, otherwise the feed-in could yield more during the day.

## Example A5

The fully charged energy storage system is “disabled” at night, so it does not discharge. Consumption is covered solely by the grid. As the PV energy is not fed into the grid during the day but is instead stored for later use, yields from the feed-in tariff are reduced by the following amount:

$$Loss = 7\ kWh * 0.067\frac{\$}{kWh} = 0.47\ \$$$

If consumption is fully covered by the energy storage system during peak phases, then the saving is as follows:

$$Saving_{Peaks} = 7\ kWh * 0.2653\frac{\$}{kWh} = 1.86\ \$$$

This means that the total saving per day is as follows:

$$Saving_{Total} = Saving_{Peaks} - Loss = 1.39\ \$$$

Ultimately, this results in savings of AU$30.58 per month/AU$214.06 per year.

### Example B5

The fully charged energy storage system is “disabled” at night, so it does not discharge. Consumption is covered solely by the grid. As the PV energy is not fed into the grid during the day but is instead stored for later use, yields from the feed-in tariff are reduced by the following amount:

$$Loss = 7\ kWh * 0.2444 \frac{\$}{kWh} = 1.71\ \$$$

If consumption is fully covered by the energy storage system during peak phases, then the saving is as follows:

$$Saving_{Peaks} = 7\ kWh * 0.6310 \frac{\$}{kWh} = 4.42\ \$$$

This means that the total saving per day is as follows:

$$Saving_{Total} = Saving_{Peaks} - Loss = 2.71\ \$$$

Ultimately, this results in savings of US$59.62 per month/US$417.34 per year.

## 4.6 Limit discharging in the evening/at night

If there is also a peak phase in the morning but not an excessive amount of consumption during the evening peak phase (see Figure 9), then it may make sense to restrict the maximum discharging power in the evening (and afterwards possibly completely prohibit discharging). This enables users to ensure that there is still enough energy in the storage system in the morning to cover the consumption during the peak phase.

Only a defined maximum discharging power is permitted during the night. This means that all consumption in the evening (e.g., 1 kWh) and only a certain amount during the night (e.g., 1 kWh during shoulder phase and 2.5 during the remaining night or 3.5 kWh during the off-peak phase) is covered by the stored energy. The rest (e.g., 2.5 kWh) is used during the peak phase in the morning.

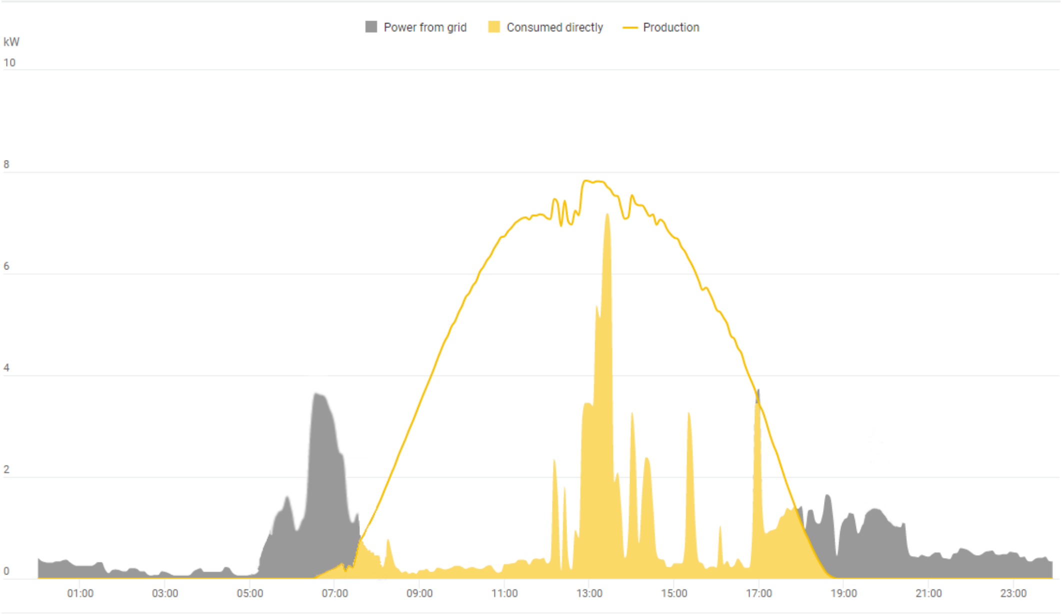


*Figure 9: PV production and consumption with peak in the morning*

## Example A6

As the PV energy is not fed into the grid during the day but is instead stored for later use, yields from the feed-in tariff are reduced by the following amount:

$$Loss = 7\ kWh * 0.067 \frac{\$}{kWh} = 0.47\ \$$$

The saving overnight is:

$$Saving_{Night} = 2.5\ kWh * 0.1671 \frac{\$}{kWh} + 1\ kWh * 0.2242 \frac{\$}{kWh} + 1\ kWh * 0.2653 \frac{\$}{kWh} = \ 0.91\ \$$$

The saving in the morning is:

$$Saving_{Morning} = 2.5\ kWh * 0.2653 \frac{\$}{kWh} = 0.66\ \$$$

The total saving per day is:

$$Saving_{Total} = Saving_{Night} + Saving_{Morning} - Loss = 1.10\ \$$$

Ultimately, this results in savings of AU$24.20 per month/AU$169.40 per year.

## Example B6

As the PV energy is not fed into the grid during the day but is instead stored for later use, yields from the feed-in tariff are reduced by the following amount:

$$Loss = 7\ kWh * 0.2444 \frac{\$}{kWh} = 1.71\ \$$$

The saving overnight is:

$$Saving_{Night} = 1\ kWh * 0.6310 \frac{\$}{kWh} + 3.5\ kWh * 0.5650 \frac{\$}{kWh} = \ 2.61\ \$$$

The saving in the morning is:

$$Saving_{Morning} = 2.5\ kWh * 0.6310 \frac{\$}{kWh} = 1.58\ \$$$

The total saving per day is:

$$Saving_{Total} = Saving_{Night} + Saving_{Morning} - Loss = 2.48\ \$$$

Ultimately, this results in savings of US$54.56 per month/US$381.92 per year.

# 5. Summary

This document illustrates that manually setting the charging and discharging behavior of a PV system’s storage system can be highly advantageous.

With the suitable rules for time-dependent battery control, users can set their Fronius storage solution to suit their personal needs and adjust it in line with time-dependent electricity prices. This means that unnecessarily high costs for additional, and mainly expensive, electricity from the grid can be avoided. The resulting advantages depend primarily on the difference between the time-dependent tariffs. This means that the greater the tariff difference, the greater the benefit from setting one’s energy storage system to work with these conditions. However, if there is only a slight difference between the tariffs, setting rules for the storage system may not be worthwhile. In addition, however, as mentioned above, the battery control rules can also be used to avoid or at least delay a possible legal derating of the PV system, allowing the system to deliver a higher yield.

As the examples show, this free software feature can typically yield a significant financial advantage per year, in addition to increasing self-consumption through the energy storage system.

# 6. Abbreviations

| | |
|---|---|
| AC | Alternating Current |
| AU$ | Australian Dollars |
| kW | Kilowatts |
| kWh | Kilowatt-hours |
| PV | Photovoltaic |
| ToU | Time of Use |
| US$ | US Dollars |