IMPLICATIONS OF DIFFERENT STRING LENGTHS FOR AN MPP TRACKER

Relevance of mismatch losses and effects on the total energy yield for commercial photovoltaic systems

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Solar Energy

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1 INTRODUCTION

It is important to pay attention to general design rules in PV module string design and the planning of PV systems. However, some design rules state that only an equal number of PV modules should be connected to an MPP tracker so that losses can be excluded. Due to advances in modern technology, this guideline no longer applies in some cases.

Local requirements and individual conditions mean that a completely symmetrical string arrangement on roofs is sometimes not possible. As a result, the roof surface often does not permit an equal number of PV modules from strings connected in parallel. In the case of inverters with an MPP tracker, according to the aforementioned design rule, this would mean that the entire string would have to be omitted. However, omitting an entire string can lead to a loss of several kWp in the commercial sector.
It is not only spatial conditions that often hinder symmetrical string arrangement. Due to local conditions or visual expectations, a very specific number of PV modules sometimes need to be implemented.

In this document, the actual effects of a string configuration with unequal lengths is shown. Using the PV*SOL configuration tool, the effects of PV module strings connected in parallel with different lengths are analyzed.
Contrary to the general presumption that "mismatch losses" minimize the total energy yield of a PV system, it can be shown based on calculations that varying string lengths are certainly possible and also useful, as only the additional PV modules would experience any yield losses. However, ultimately the additional PV modules would deliver a higher yield for the installation overall.

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2 OCCURRENCE OF MISMATCH LOSSES

As the name suggests, the Maximum Power Point Tracker (MPPT) in an inverter attempts to continuously find the operating point with the maximum output of the connected PV generator and operate it at this point. If the generator is permanently operated at its MPP, it generates maximum yield.
A PV generator often consists of more than one PV module string. The PV module strings can also have various MPPs due to different alignment, inclination, and number of PV modules. In the case of different MPPs, the MPP tracker attempts to adjust the PV generator to the operating point that delivers the maximum output for all PV modules and strings connected to a tracker. As not every string can be operated at its individual optimum operating point, this can lead to energy losses compared to theoretically recoverable energy. These losses are called mismatch losses.
In general, every PV system exhibits low mismatch losses, as all conditions for two completely identical PV strings can never prevail (for example, the PV modules themselves always differ slightly).

The term mismatch losses is used frequently in the context of different string configurations. Situations in which a deviation in the strings is created deliberately within a PV generator - either through different alignment of the PV modules or a different number of PV modules in the string.

The following figure shows an example of an installation where one string out of a total of 14 strings has intentionally been expanded by a single PV module. In comparison to the other 13 strings, this string consists of 22 instead of 21 PV modules. However, the 14 strings are all connected to one MPPT.
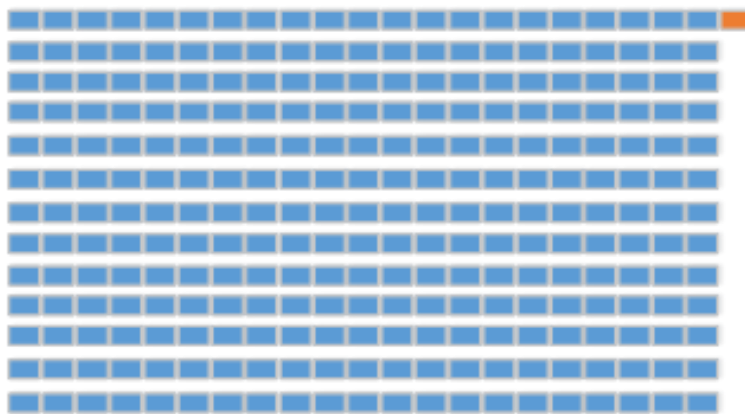
Figure 1: One of a total of 14 strings has 22 instead of 21 PV modules

In the graph below, it can be seen that at full irradiation, the one longer string with 22 PV modules (red curve), has a somewhat higher voltage (904 V) at MPP than the shorter strings (blue curve, 864 V).

If all strings are considered together, this produces the green line. The green line is the curve on which the MPP tracker of an inverter searches for the optimum operating point and finds it at 864 V. This means that all strings are operated at 864 V.

As a result, the short strings (blue curve) are operated at their ideal MPP and the red string, which deviates due to its configuration, is operated slightly outside its MPP. Operating the long string outside its ideal operating point leads to mismatch losses for this individual string. **However, this does not lead to any power reduction for the other strings.**
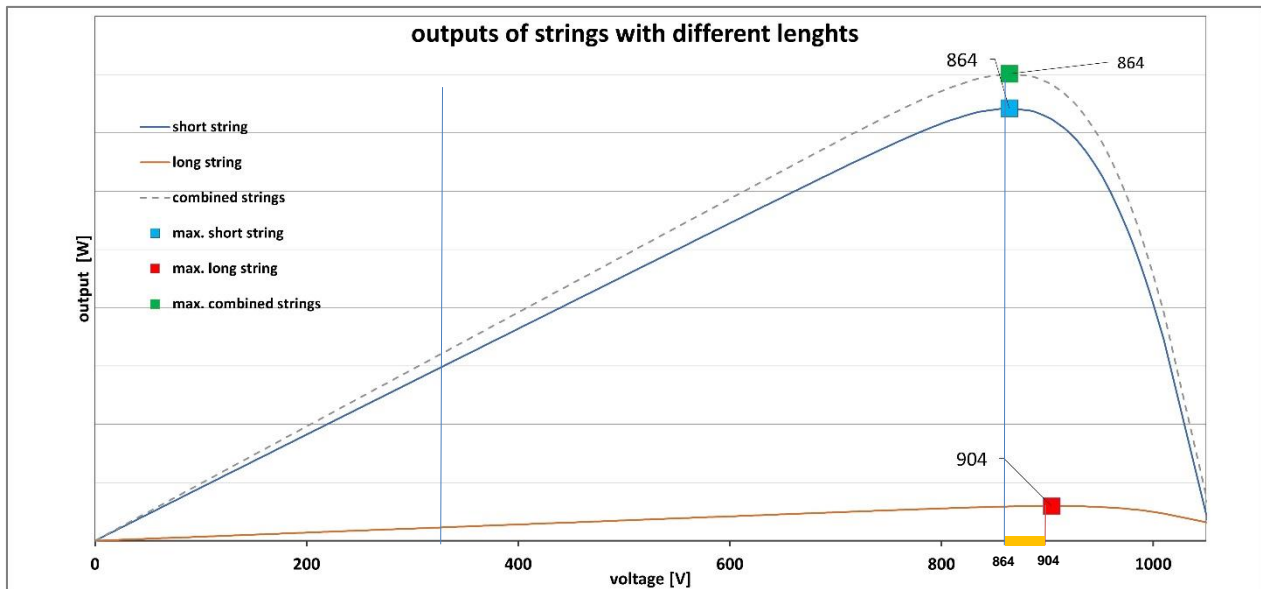
Figure 2: Optimum operating point for strings of different lengths within a PV system

3 SIMULATION

The effects of different string lengths from PV module strings connected in parallel are analyzed using PV*SOL. Targeted analyses are carried out to check whether a configuration with one more or one less PV module in a string is possible and useful with respect to the total energy yield and losses.
In the following chapters, a PV system is simulated which, depending on the example, has a different string configuration. In the simulation example, a Tauro Eco 100-3-D is used with Jinko Tiger Pro JKM440-60HL 4-(V) PV modules, which are arranged in a southerly direction with an inclination of 20°. The assumed geographical location is Kremsmünster in Austria.

Up to 22 strings can be connected in parallel to a Tauro Eco 100-3-D. In this simulation example, a configuration of 14 parallel strings each with 21 PV modules is assumed to be the ideal situation and is compared with deviating string configurations.

3.1 Ideal situation example: 14 strings each with 21 PV modules

In this example, all strings are assumed to each have 21 PV modules. This results in mismatch losses, as expected. The PV system calculated with PV*SOL as an example delivers a total energy yield of **147,482.58 kWh** per year.

As this example 1 corresponds to the ideal situation in the above mentioned design guideline, this example 1 is referred to as a baseline for comparison purposes in the chapters that follow.

3.2 13 strings each with 21 PV modules | 1 string with 22 PV modules
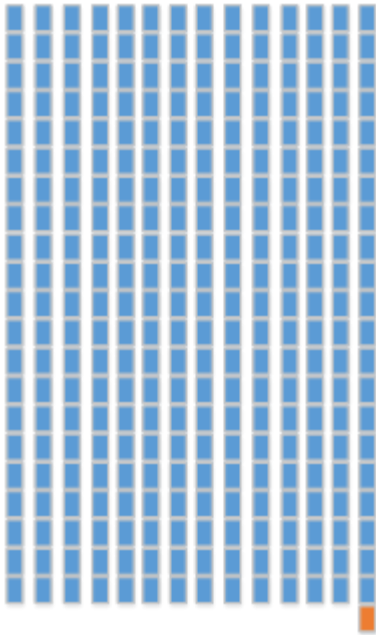
In this example, the same initial situation in the preceding ideal situation example is considered.

The sole difference is that in this situation, an individual string has 22 instead of 21 PV modules. The PV system therefore consists of a total of 14 PV module strings. 13 strings each have 21 PV modules and the last string has 22 PV modules. This means that one of the 14 strings deviates from the general string configuration of the PV system. This additional PV module causes the ideal operating point of this longer string to be different from that of the other strings.

Figure 3: String configuration with a deviating string with 22 PV modules

In this case, according to PV*SOL, mismatch losses amounting to 0.14% of the annual yield occur. The losses result from the longer string being operated outside the ideal MPP. As can be seen in the following graph, the entire system is operated at the MPP voltage level of the main strings.
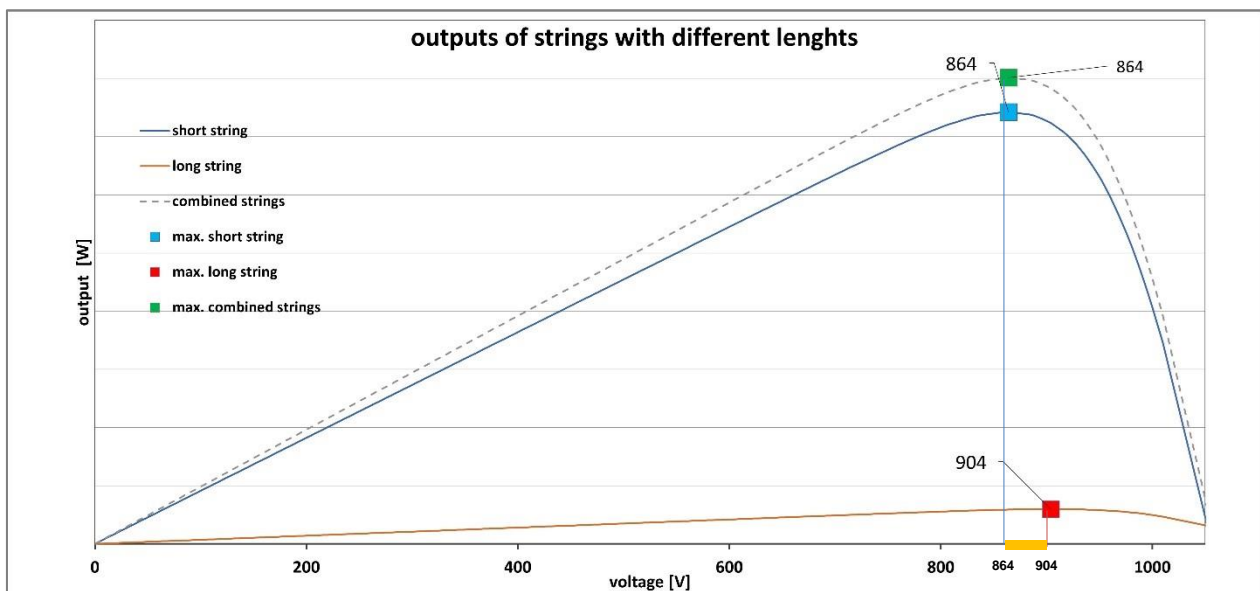
Figure 4: Ideal operating point of the PV system with one longer string

In this string configuration, a total energy yield of 147,721.73 kWh is generated. Due to the additional PV module in the last string, **239.15 kWh more** can be produced per year than in "ideal example 1" despite mismatch losses.

To ascertain the actual influence of the mismatch losses that occur, the yield of the single, additional 440 W PV module must be looked at more closely. In this case, it can be determined that this additional PV module could potentially deliver 501.6 kWh per year. In the calculation example, however, this PV module delivers just 48% of the potential energy.
Thus, 52% of the PV module's potential energy yield cannot be used in this example situation. In this case, it should be carefully assessed whether the additional yield generated by the PV modules can outweigh the additional cost of the PV module.

$$annual\ energy\ yield * electricity\ price = 240\ \frac{kWh}{year} * 0.08\ \frac{€}{kWh} = 19,2\ \frac{€}{year}$$

If you compare the annual yield of the PV module with the feed-in tariff, this PV module generates a profit of €19.20 per year provided that the total yield of the PV system is fed into the grid.

If the yield of the PV system in the example is used for self-consumption within the company, the additional PV module alone would generate a profit of €48.

$$annual\ energy\ yield * electricity\ price = 240\ \frac{kWh}{year} * 0.20\ \frac{€}{kWh} = 48,-\ \frac{€}{year}$$

Depending on the application area, this additional PV module[1] would pay for itself in between 2.5 and 6.25 years.

This clearly shows that even if only 48% of the potential energy generated by an additional PV module can be used in this example situation, investment in this additional PV module is worthwhile. After all, an additional PV module produces an **additional yield of 4800 kWh** over the entire service life of the PV system.

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[1] Assumed PV module price €120

3.3 5 strings each with 21 PV modules | 9 strings each with 22 PV modules
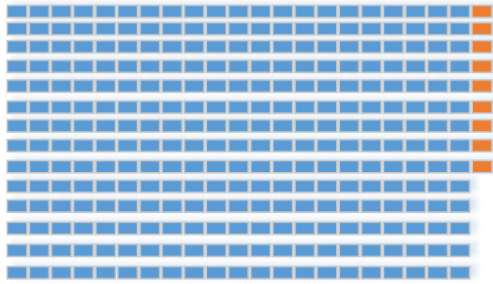
As can be seen from this example, the greater the inequality, the greater the mismatch losses. In the case of 5 strings with 21 PV modules and 9 strings with 22 PV modules, PV*SOL calculates mismatch losses amounting to 0.82% of the annual yield.

Figure 5: String configuration with nine deviating strings each with 22 PV modules

This example shows the string configuration that leads to the highest losses compared with the ideal situation example. However, if you compare the total energy yield of this system with the ideal situation example, you will see that despite the evident mismatch losses, an additional yield of 2560.73 kWh is generated.
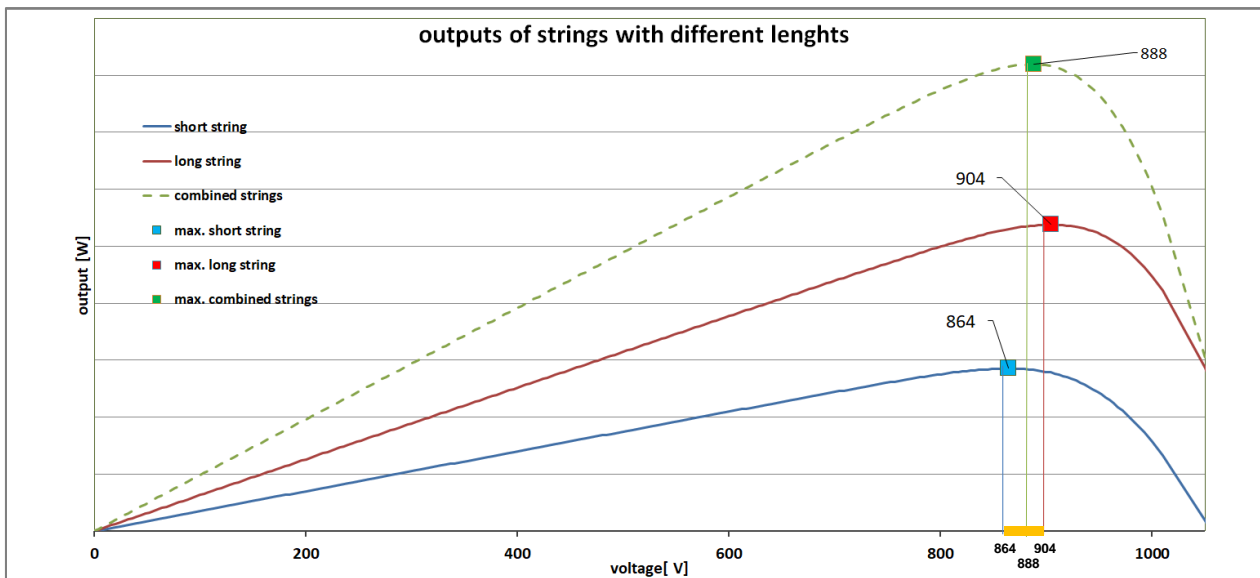
Figure 6: Ideal operating point of the example involving 5 strings each with 21 PV modules and 9 strings each with 22 PV modules

3.4 1 string with 21 PV modules | 13 strings each with 22 PV modules
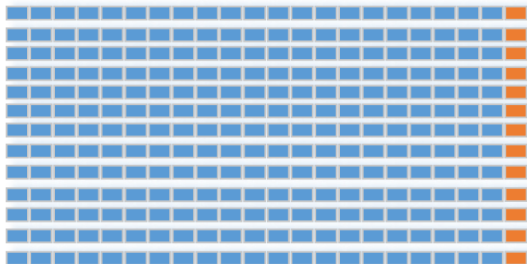
As soon as just 1 string deviates from the other 13 strings, the smallest mismatch losses result compared to the ideal design. These are only at 0.35% of the annual yield.

Figure 7: String configuration with 13 deviating strings each with 22 PV modules

In this situation example, the reverse of example 2 is shown. One string is only one PV module shorter than the 13 other strings. This results in the 13 strings of the same length being operated at their ideal operating point and only the shorter one outside it. The deviation in percent is higher in this case than in the reverse example from chapter 3.2, as the short string is operated at a higher voltage. The PV curve drops faster on the right side (higher voltage) than on the left side of the MPP (lower voltage), therefore the losses are higher when the operating point is at a higher voltage than the MPP.

Despite mismatch losses, the 13 additional PV modules deliver an additional yield of 4693.42 kWh per year.
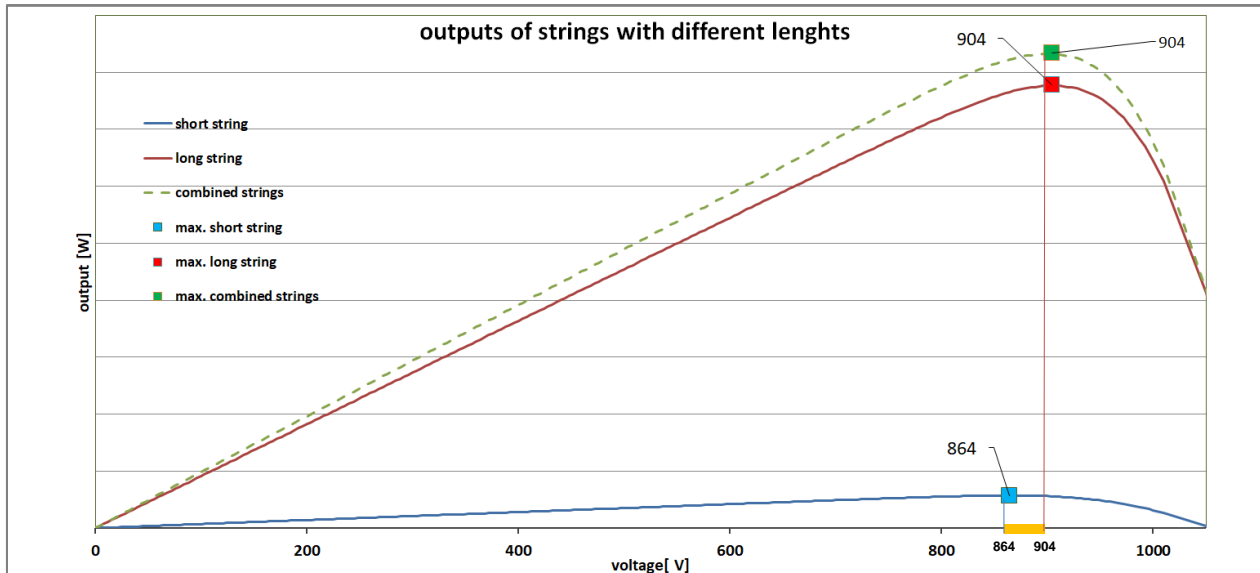
Figure 8: Ideal operating point of the situation example involving 1 string with 21 PV modules and 13 strings each with 22 PV modules

3.5 Overview

In general, the simulation shows that the inequality in the string configuration leads to mismatch losses but at the same to an additional yield. Depending on the severity of the deviation, different levels of mismatch losses result. The following tables show a list of different string configurations and their influence on the total yield of the PV system.
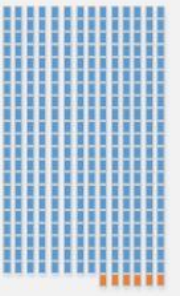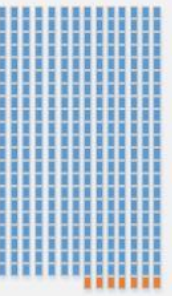
Beispiel	14 Stränge à 21 Module	13 Stränge à 21 Module 1 Strang à 22 Module	12 Stränge à 21 Module 2 Stränge à 22 Module	8 Stränge à 21 Module 6 Stränge à 22 Module	7 Stränge à 21 Module 7 Stränge à 22 Module
Strangkonfiguration					
PV-Gesamtertrag pro Jahr	147.482,58 kWh	147.721,73 kWh	147.960,43 kWh	149.028,16 kWh	149.362,75 kWh
Mismatch-Verluste	0 %	0,14 %	0,28 %	0,70 %	0,75 %
Mehrertrag pro Jahr	0 kWh	239,15 kWh	477,85 kWh	1545,58 kWh	1880,17 kWh

Table 1: Results overview 1 different string configuration
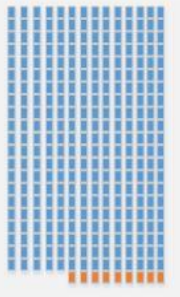
Beispiel	6 Stränge à 21 Module 8 Stränge à 22 Module	5 Stränge à 21 Module 9 Stränge à 22 Module	4 Stränge à 21 Module 10 Stränge à 22 Module	2 Stränge à 21 Module 12 Stränge à 22 Module	1 Strang à 21 Module 13 Stränge à 22 Module
Strangkonfiguration					
PV-Gesamtertrag pro Jahr	149.696,80 kWh	150.043,31 kWh	150.471,66 kWh	151.491,18 kWh	152.176,00 kWh
Mismatch-Verluste	0,80 %	0,82 %	0,78 %	0,58 %	0,35 %
Mehrertrag pro Jahr	2214,22 kWh	2560,73 kWh	2989,08 kWh	4008,60 kWh	4693,42 kWh

Table 2: Results overview 2 different string configurations

4 CONCLUSION

In general, it could be determined from the simulation that the greater the inequality in the string configuration, the greater the losses as a result.
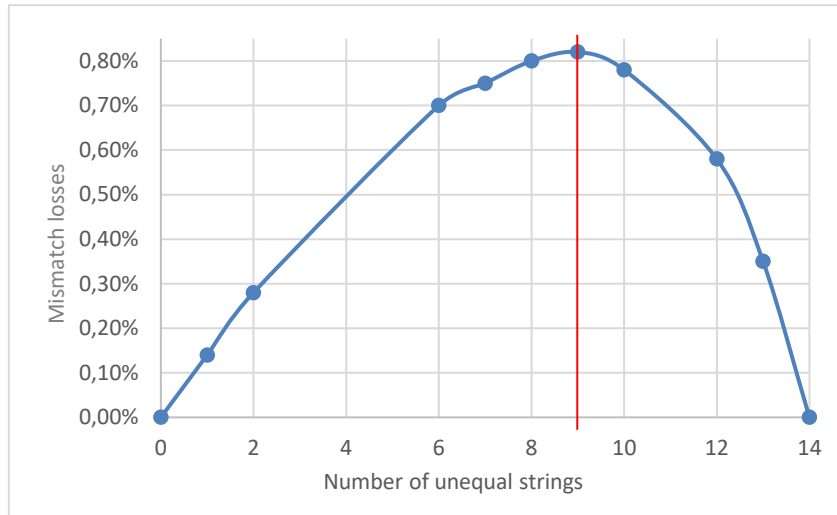
Figure 9: Mismatch losses as a function of the number of unequal strings

The greatest mismatch losses do not result - as might be assumed - from half of the total strings, but at 9 to 5 unequal strings. In this case, this is due to the configuration of the strings and can change depending on the circumstances. In general, **the greater the number of unequal strings, the greater the losses.**

However:

As the examples clearly show, a deviation by a single PV module in a string of a 100 kW inverter, by way of example, **is negligible** in terms of losses. What's more, the total energy yield always increases as soon as a PV module is added.

The general assumption that an additional PV module reduces the total energy yield of the PV system is actually incorrect. The fact is that the deviating strings are not operated at the ideal MPP and this leads to mismatch losses. Therefore, the additional PV modules are only effectively used to a part of the potential power that they would deliver in an optimum string configuration.

As the following chart shows, these additional PV modules (red area) lead to **additional yield** despite mismatch losses.
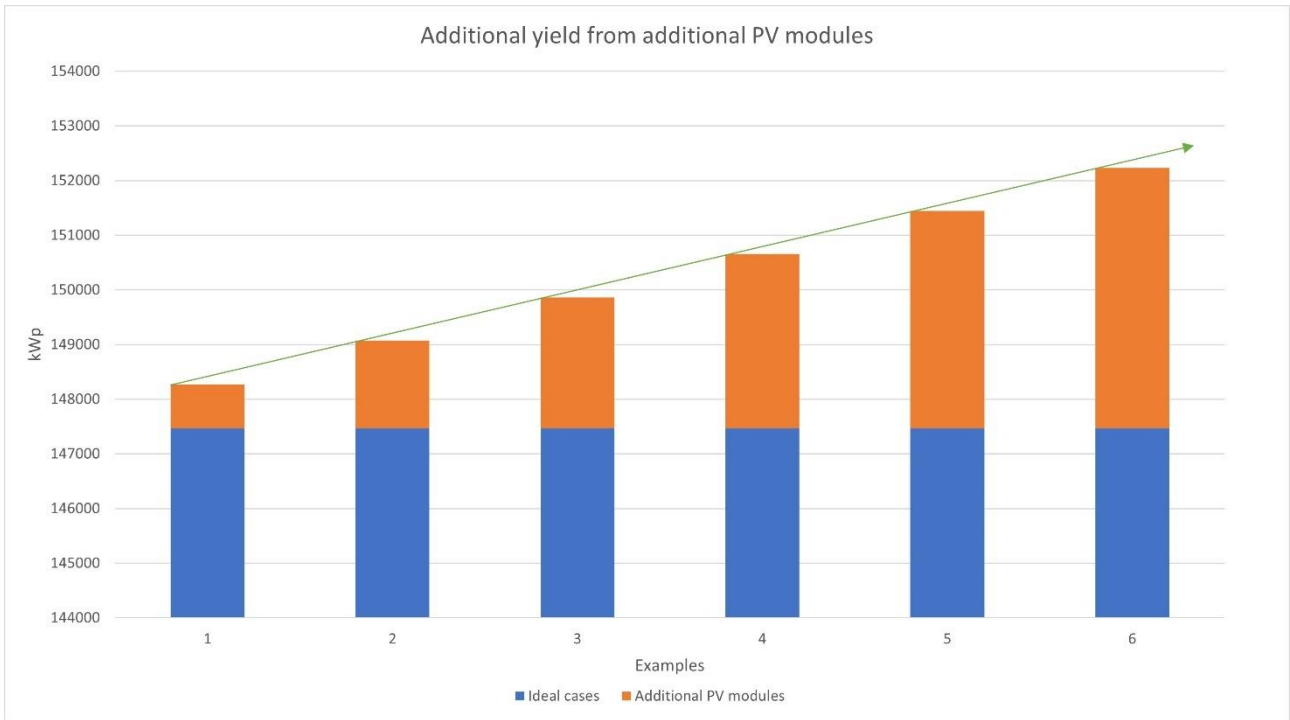
Figure 10: Yield increase from additional PV modules despite mismatch losses

Even with several additional PV modules, the total amount of energy from the system does **not** decrease, only the effectiveness of the additional PV module is reduced. This can be seen in the chart, as the green line flattens out somewhat compared to the blue line (= ideal configuration).

The fewer unequal strings there are, the better this ratio. This explains why the deviation in the amount of energy lessens if more and more strings receive an additional PV module. **However, an additional PV module will always lead to additional PV yield and will not reduce the total yield.**

5 APPENDIX

Example 1: 14 strings each with 21 PV modules

Ergebnisse

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  - Anlagennutzungsgrad (PR) pro Wechselrichter
  - Einstrahlung pro Modulfläche
  - PV Energie über Betrachtungszeitraum
  - Temperatur pro Modulfläche
  - **Energiebilanz PV-Anlage**
- Wirtschaftlichkeit
  - Cashflow Tabelle
  - Kumulierter Cashflow

	Wert	Einheit	%
Globalstrahlung horizontal	1 114,06	kWh/m²	
Abweichung vom Standardspektrum	-11,14	kWh/m²	-1,00 %
Bodenreflexion (Albedo)	6,65	kWh/m²	0,60 %
Ausrichtung und Neigung der Modulebene	145,89	kWh/m²	13,15 %
Abschattung	0,00	kWh/m²	0,00 %
Reflexion an Moduloberfläche	-13,16	kWh/m²	-1,05 %
Globalstrahlung auf Modul	1 242,30	kWh/m²	
	1 242,30	kWh/m²	
	x 634,453	m²	
	= 788 183,18	kWh	
PV Globalstrahlung	788 183,18	kWh	
Verschmutzung	0,00	kWh	0,00 %
STC Konversion (Modul-Nennwirkungsgrad 20,39 %)	-627 461,90	kWh	-79,61 %
PV Nennenergie	160 721,29	kWh	
Schwachlichtverhalten	-207,88	kWh	-0,13 %
Abweichung von der Nenn-Modultemperatur	-2 157,60	kWh	-1,34 %
Dioden	-791,78	kWh	-0,50 %
Mismatch (Herstellerangaben)	-3 151,28	kWh	-2,00 %
Mismatch (Verschaltung/Abschattung)	0,00	kWh	0,00 %
PV-Energie (DC) ohne Wechselrichter-Abregelung	154 412,75	kWh	
Unterschreitung der DC-Startleistung	-10,29	kWh	-0,01 %
Abregelung wegen MPP-Spannungsbereich	-5,60	kWh	0,00 %
Abregelung wegen max. DC-Strom	0,00	kWh	0,00 %
Abregelung wegen max. DC-Leistung	0,00	kWh	0,00 %
Abregelung wegen max. AC-Leistung/cos phi	-3 221,45	kWh	-2,09 %
MPP Anpassung	-45,35	kWh	-0,03 %
PV-Energie (DC)	151 130,05	kWh	
Energie am WR-Eingang	151 130,05	kWh	
Abweichung der Eingangs- von der Nennspannung	-406,52	kWh	-0,27 %
DC/AC-Wandlung	-3 240,95	kWh	-2,15 %
Standby-Verbrauch (Wechselrichter)	-68,28	kWh	-0,05 %
Kabelverluste Gesamt	0,00	kWh	0,00 %
PV-Energie (AC) abzgl. Standby-Verbrauch	147 414,30	kWh	
PV-Generatorenergie (AC-Netz)	147 482,58	kWh	

Projektdaten
Projekttitel
Angebotsnummer
Bearbeiter/in
Inbetriebnahme — 23.08.2021

Anlagenart, Klima und Netz
Anlagenart — Netzgekoppelte PV-Anlage
Klimadaten — Kremsmuenster, AUT
Zeitschritt der Simul... — 1 min
AC-Netz — 230 V, 3-phasig, cos φ = 1
Einspeiseabregelung — Nein

PV-Module
Modulfläche — Süd
Moduldaten — Tiger Pro JKM440M-60HL4-(V)
Hersteller — Jinko Solar
Modulanzahl — 294
PV-Generatorleistung — 129,36 kWp
Neigung — 20°
Ausrichtung — 180°
Einbausituation — Aufgeständert - Dach

Wechselrichter
Gesamtleistung — 100 kW
Modulfläche — Süd
Wechselr. 1 — Tauro Eco 100-3-D
Anzahl — 1
Hersteller — Fronius International
Verschaltung — MPP 1: 14 x 21
Dimensionierungsf... — 129,4 %

Kabel
Gesamtverlust — 0 % (0 W)

Wirtschaftlichkeit
Investitionskosten — 1 500,00 €/kWp
Einspeisetarife — Ökostromgesetz 2012 - Gebäu...

Example 2: 13 strings each with 21 PV modules | 1 string with 22 PV modules

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  - Energiefluss-Grafik
  - Ertragsprognose
  - Ertragsprognose pro Wechselrichter
  - Anlagennutzungsgrad (PR) pro Wechselrichter
  - Einstrahlung pro Modulfläche
  - PV Energie über Betrachtungszeitraum
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  - **Energiebilanz PV-Anlage**
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  - Kumulierter Cashflow

	Wert	Einheit	%
Globalstrahlung horizontal	1 114,06	kWh/m²	
Abweichung vom Standardspektrum	-11,14	kWh/m²	-1,00 %
Bodenreflexion (Albedo)	6,65	kWh/m²	0,60 %
Ausrichtung und Neigung der Modulebene	145,89	kWh/m²	13,15 %
Abschattung	0,00	kWh/m²	0,00 %
Reflexion an Moduloberfläche	-13,16	kWh/m²	-1,05 %
Globalstrahlung auf Modul	1 242,30	kWh/m²	
	1 242,30	kWh/m²	
	x 636,611	m²	
	= 790 864,08	kWh	
PV Globalstrahlung	790 864,08	kWh	
Verschmutzung	0,00	kWh	0,00 %
STC Konversion (Modul-Nennwirkungsgrad 20,39 %)	-629 596,12	kWh	-79,61 %
PV Nennenergie	161 267,96	kWh	
Schwachlichtverhalten	-208,58	kWh	-0,13 %
Abweichung von der Nenn-Modultemperatur	-2 164,93	kWh	-1,34 %
Dioden	-794,47	kWh	-0,50 %
Mismatch (Herstellerangaben)	-3 162,00	kWh	-2,00 %
Mismatch (Verschaltung/Abschattung)	-220,28	kWh	-0,14 %
PV-Energie (DC) ohne Wechselrichter-Abregelung	154 717,69	kWh	
Unterschreitung der DC-Startleistung	-10,11	kWh	-0,01 %
Abregelung wegen MPP-Spannungsbereich	-5,35	kWh	0,00 %
Abregelung wegen max. DC-Strom	0,00	kWh	0,00 %
Abregelung wegen max. DC-Leistung	0,00	kWh	0,00 %
Abregelung wegen max. AC-Leistung/cos phi	-3 280,58	kWh	-2,12 %
MPP Anpassung	-45,43	kWh	-0,03 %
PV-Energie (DC)	151 376,22	kWh	
Energie am WR-Eingang	151 376,22	kWh	
Abweichung der Eingangs- von der Nennspannung	-408,85	kWh	-0,27 %
DC/AC-Wandlung	-3 245,64	kWh	-2,15 %
Standby-Verbrauch (Wechselrichter)	-68,27	kWh	-0,05 %
Kabelverluste Gesamt	0,00	kWh	0,00 %
PV-Energie (AC) abzgl. Standby-Verbrauch	147 653,46	kWh	
PV-Generatorenergie (AC-Netz)	147 721,73	kWh	

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Wechselrichter
Gesamtleistung — 100 kW
Modulfläche — Süd
Wechselr. 1 — Tauro Eco 100-3-D
Anzahl — 1
Hersteller — Fronius International
Verschaltung — MPP 1: 13 x 21 || 1 x 22
Dimensionierungsf... — 129,8 %

Kabel
Gesamtverlust — 0 % (0 W)

Wirtschaftlichkeit
Investitionskosten — 1 500,00 €/kWp
Einspeisetarife — Ökostromgesetz 2012 - Gebäu...

Example 3: 12 strings each with 21 PV modules | 2 strings each with 22 PV modules

Ergebnisse

Globalstrahlung horizontal	**1 114,06 kWh/m²**	
Abweichung vom Standardspektrum	-11,14 kWh/m²	-1,00 %
Bodenreflexion (Albedo)	6,65 kWh/m²	0,60 %
Ausrichtung und Neigung der Modulebene	145,89 kWh/m²	13,15 %
Abschattung	0,00 kWh/m²	0,00 %
Reflexion an Moduloberfläche	-13,16 kWh/m²	-1,05 %
Globalstrahlung auf Modul	**1 242,30 kWh/m²**	
	1 242,30 kWh/m²	
	x 638,769 m²	
	= 793 544,97 kWh	
PV Globalstrahlung	**793 544,97 kWh**	
Verschmutzung	0,00 kWh	0,00 %
STC Konversion (Modul-Nennwirkungsgrad 20,39 %)	-631 730,34 kWh	-79,61 %
PV Nennenergie	**161 814,63 kWh**	
Schwachlichtverhalten	-209,29 kWh	-0,13 %
Abweichung von der Nenn-Modultemperatur	-2 172,27 kWh	-1,34 %
Dioden	-797,17 kWh	-0,50 %
Mismatch (Herstellerangaben)	-3 172,72 kWh	-2,00 %
Mismatch (Verschaltung/Abschattung)	-440,55 kWh	-0,28 %
PV-Energie (DC) ohne Wechselrichter-Abregelung	**155 022,63 kWh**	
Unterschreitung der DC-Startleistung	-9,98 kWh	-0,01 %
Abregelung wegen MPP-Spannungsbereich	-5,09 kWh	0,00 %
Abregelung wegen max. DC-Strom	0,00 kWh	0,00 %
Abregelung wegen max. DC-Leistung	0,00 kWh	0,00 %
Abregelung wegen max. AC-Leistung/cos phi	-3 340,06 kWh	-2,15 %
MPP Anpassung	-45,50 kWh	-0,03 %
PV-Energie (DC)	**151 622,01 kWh**	
Energie am WR-Eingang	**151 622,01 kWh**	
Abweichung der Eingangs- von der Nennspannung	-411,28 kWh	-0,27 %
DC/AC-Wandlung	-3 250,30 kWh	-2,15 %
Standby-Verbrauch (Wechselrichter)	-68,26 kWh	-0,05 %
Kabelverluste Gesamt	0,00 kWh	0,00 %
PV-Energie (AC) abzgl. Standby-Verbrauch	**147 892,17 kWh**	
PV-Generatorenergie (AC-Netz)	**147 960,43 kWh**	

Projektdaten
Projekttitel
Angebotsnummer
Bearbeiter/in
Inbetriebnahme 23.08.2021

Anlagenart, Klima und Netz
Anlagenart — Netzgekoppelte PV-Anlage
Klimadaten — Kremsmuenster, AUT
Zeitschritt der Simul... — 1 min
AC-Netz — 230 V, 3-phasig, cos φ = 1
Einspeiseabregelung — Nein

PV-Module
Modulfläche — Süd
Moduldaten — Tiger Pro JKM440M-60HL4-(V)
Hersteller — Jinko Solar
Modulanzahl — 296
PV-Generatorleistung — 130,24 kWp
Neigung — 20°
Ausrichtung — 180°
Einbausituation — Aufgeständert - Dach

Wechselrichter
Gesamtleistung — 100 kW
Modulfläche — Süd
Wechsel. 1 — Tauro Eco 100-3-D
Anzahl — 1
Hersteller — Fronius International
Verschaltung — MPP 1:
12 x 21 || 2 x 22
Dimensionierungsf... — 130,2 %

Kabel
Gesamtverlust — 0 % (0 W)

Wirtschaftlichkeit
Investitionskosten — 1 500,00 €/kWp
Einspeisetarife — Ökostromgesetz 2012 - Gebäu...

Example 4: 8 strings each with 21 PV modules | 6 strings each with 22 PV modules

Ergebnisse

Globalstrahlung horizontal	**1 114,06 kWh/m²**	
Abweichung vom Standardspektrum	-11,14 kWh/m²	-1,00 %
Bodenreflexion (Albedo)	6,65 kWh/m²	0,60 %
Ausrichtung und Neigung der Modulebene	145,89 kWh/m²	13,15 %
Abschattung	0,00 kWh/m²	0,00 %
Reflexion an Moduloberfläche	-13,16 kWh/m²	-1,05 %
Globalstrahlung auf Modul	**1 242,30 kWh/m²**	
	1 242,30 kWh/m²	
	x 647,401 m²	
	= 804 268,55 kWh	
PV Globalstrahlung	**804 268,55 kWh**	
Verschmutzung	0,00 kWh	0,00 %
STC Konversion (Modul-Nennwirkungsgrad 20,39 %)	-640 267,24 kWh	-79,61 %
PV Nennenergie	**164 001,31 kWh**	
Schwachlichtverhalten	-212,12 kWh	-0,13 %
Abweichung von der Nenn-Modultemperatur	-2 201,63 kWh	-1,34 %
Dioden	-807,94 kWh	-0,50 %
Mismatch (Herstellerangaben)	-3 215,59 kWh	-2,00 %
Mismatch (Verschaltung/Abschattung)	-1 104,72 kWh	-0,70 %
PV-Energie (DC) ohne Wechselrichter-Abregelung	**156 459,31 kWh**	
Unterschreitung der DC-Startleistung	-9,41 kWh	-0,01 %
Abregelung wegen MPP-Spannungsbereich	-4,03 kWh	0,00 %
Abregelung wegen max. DC-Strom	0,00 kWh	0,00 %
Abregelung wegen max. DC-Leistung	0,00 kWh	0,00 %
Abregelung wegen max. AC-Leistung/cos phi	-3 653,08 kWh	-2,34 %
MPP Anpassung	-45,84 kWh	-0,03 %
PV-Energie (DC)	**152 746,96 kWh**	
Energie am WR-Eingang	**152 746,96 kWh**	
Abweichung der Eingangs- von der Nennspannung	-446,43 kWh	-0,29 %
DC/AC-Wandlung	-3 272,36 kWh	-2,15 %
Standby-Verbrauch (Wechselrichter)	-68,22 kWh	-0,05 %
Kabelverluste Gesamt	0,00 kWh	0,00 %
PV-Energie (AC) abzgl. Standby-Verbrauch	**148 959,94 kWh**	
PV-Generatorenergie (AC-Netz)	**149 028,16 kWh**	

Projektdaten
Projekttitel
Angebotsnummer
Bearbeiter/in
Inbetriebnahme 23.08.2021

Anlagenart, Klima und Netz
Anlagenart — Netzgekoppelte PV-Anlage
Klimadaten — Kremsmuenster, AUT
Zeitschritt der Simul... — 1 min
AC-Netz — 230 V, 3-phasig, cos φ = 1
Einspeiseabregelung — Nein

PV-Module
Modulfläche — Süd
Moduldaten — Tiger Pro JKM440M-60HL4-(V)
Hersteller — Jinko Solar
Modulanzahl — 300
PV-Generatorleistung — 132 kWp
Neigung — 20°
Ausrichtung — 180°
Einbausituation — Aufgeständert - Dach

Wechselrichter
Gesamtleistung — 100 kW
Modulfläche — Süd
Wechsel. 1 — Tauro Eco 100-3-D
Anzahl — 1
Hersteller — Fronius International
Verschaltung — MPP 1:
8 x 21 || 6 x 22
Dimensionierungsf... — 132 %

Kabel
Gesamtverlust — 0 % (0 W)

Wirtschaftlichkeit
Investitionskosten — 1 500,00 €/kWp
Einspeisetarife — Ökostromgesetz 2012 - Gebäu...

Example 5: 7 strings each with 21 PV modules | 7 strings each with 22 PV modules

Ergebnisse

Globalstrahlung horizontal	**1 114,06 kWh/m²**	
Abweichung vom Standardspektrum	-11,14 kWh/m²	-1,00 %
Bodenreflexion (Albedo)	6,65 kWh/m²	0,60 %
Ausrichtung und Neigung der Modulebene	145,89 kWh/m²	13,15 %
Abschattung	0,00 kWh/m²	0,00 %
Reflexion an Moduloberfläche	-13,16 kWh/m²	-1,05 %
Globalstrahlung auf Modul	**1 242,30 kWh/m²**	
	1 242,30 kWh/m²	
	x 649,559 m²	
	= 806 949,45 kWh	
PV Globalstrahlung	**806 949,45 kWh**	
Verschmutzung	0,00 kWh	0,00 %
STC Konversion (Modul-Nennwirkungsgrad 20,39 %)	-642 401,46 kWh	-79,61 %
PV Nennenergie	**164 547,98 kWh**	
Schwachlichtverhalten	-212,83 kWh	-0,13 %
Abweichung von der Nenn-Modultemperatur	-2 208,97 kWh	-1,34 %
Dioden	-810,63 kWh	-0,50 %
Mismatch (Herstellerangaben)	-3 226,31 kWh	-2,00 %
Mismatch (Verschaltung/Abschattung)	-1 191,29 kWh	-0,75 %
PV-Energie (DC) ohne Wechselrichter-Abregelung	**156 897,96 kWh**	
Unterschreitung der DC-Startleistung	-9,27 kWh	-0,01 %
Abregelung wegen MPP-Spannungsbereich	-3,78 kWh	0,00 %
Abregelung wegen max. DC-Strom	0,00 kWh	0,00 %
Abregelung wegen max. DC-Leistung	0,00 kWh	0,00 %
Abregelung wegen max. AC-Leistung/cos phi	-3 747,08 kWh	-2,39 %
MPP Anpassung	-45,94 kWh	-0,03 %
PV-Energie (DC)	**153 091,89 kWh**	
Energie am WR-Eingang	**153 091,89 kWh**	
Abweichung der Eingangs- von der Nennspannung	-450,25 kWh	-0,29 %
DC/AC-Wandlung	-3 278,89 kWh	-2,15 %
Standby-Verbrauch (Wechselrichter)	-68,21 kWh	-0,05 %
Kabelverluste Gesamt	0,00 kWh	0,00 %
PV-Energie (AC) abzgl. Standby-Verbrauch	**149 294,54 kWh**	
PV-Generatorenergie (AC-Netz)	**149 362,75 kWh**	

Projektdaten
Projekttitel
Angebotsnummer
Bearbeiter/in
Inbetriebnahme 23.08.2021

Anlagenart, Klima und Netz
Anlagenart — Netzgekoppelte PV-Anlage
Klimadaten — Kremsmuenster, AUT
Zeitschritt der Simul... — 1 min
AC-Netz — 230 V, 3-phasig, cos φ = 1
Einspeiseabregelung — Nein

PV-Module
Modulfläche — Süd
Moduldaten — Tiger Pro JKM440M-60HL4-(V)
Hersteller — Jinko Solar
Modulanzahl — 301
PV-Generatorleistung — 132,44 kWp
Neigung — 20°
Ausrichtung — 180°
Einbausituation — Aufgeständert - Dach

Wechselrichter
Gesamtleistung — 100 kW
Modulfläche — Süd
Wechsel. 1 — Tauro Eco 100-3-D
Anzahl — 1
Hersteller — Fronius International
Verschaltung — MPP 1:
7 x 21 || 7 x 22
Dimensionierungsf... — 132,4 %

Kabel
Gesamtverlust — 0 % (0 W)

Wirtschaftlichkeit
Investitionskosten — 1 500,00 €/kWp
Einspeisetarife — Ökostromgesetz 2012 - Gebäu...

Example 6: 6 strings each with 21 PV modules | 8 strings each with 22 PV modules

Example 7: 5 strings each with 21 PV modules | 9 strings each with 22 PV modules

Example 8: 4 strings each with 21 PV modules | 10 strings each with 22 PV modules

Example 9: 2 strings each with 21 PV modules | 12 strings each with 22 PV modules

Ergebnisse		
Globalstrahlung horizontal	1 114,06 kWh/m²	
Abweichung vom Standardspektrum	-11,14 kWh/m²	-1,00 %
Bodenreflexion (Albedo)	6,65 kWh/m²	0,60 %
Ausrichtung und Neigung der Modulebene	145,89 kWh/m²	13,15 %
Abschattung	0,00 kWh/m²	0,00 %
Reflexion an Moduloberfläche	-13,16 kWh/m²	-1,05 %
Globalstrahlung auf Modul	1 242,30 kWh/m²	
	1 242,30 kWh/m²	
	x 660,349 m²	
	= 820 353,92 kWh	
PV Globalstrahlung	820 353,92 kWh	
Verschmutzung	0,00 kWh	0,00 %
STC Konversion (Modul-Nennwirkungsgrad 20,39 %)	-653 072,59 kWh	-79,61 %
PV Nennenergie	167 281,34 kWh	
Schwachlichtverhalten	-216,36 kWh	-0,13 %
Abweichung von der Nenn-Modultemperatur	-2 245,66 kWh	-1,34 %
Dioden	-824,10 kWh	-0,50 %
Mismatch (Herstellerangaben)	-3 279,90 kWh	-2,00 %
Mismatch (Verschaltung/Abschattung)	-925,24 kWh	-0,58 %
PV-Energie (DC) ohne Wechselrichter-Abregelung	159 790,08 kWh	
Unterschreitung der DC-Startleistung	-8,62 kWh	-0,01 %
Abregelung wegen MPP-Spannungsbereich	-2,67 kWh	0,00 %
Abregelung wegen max. DC-Strom	0,00 kWh	0,00 %
Abregelung wegen max. DC-Leistung	0,00 kWh	0,00 %
Abregelung wegen max. AC-Leistung/cos phi	-4 403,60 kWh	-2,76 %
MPP Anpassung	-46,61 kWh	-0,03 %
PV-Energie (DC)	155 328,56 kWh	
Energie am WR-Eingang	155 328,56 kWh	
Abweichung der Eingangs- von der Nennspannung	-515,16 kWh	-0,33 %
DC/AC-Wandlung	-3 322,23 kWh	-2,15 %
Standby-Verbrauch (Wechselrichter)	-68,16 kWh	-0,04 %
Kabelverluste Gesamt	0,00 kWh	0,00 %
PV-Energie (AC) abzgl. Standby-Verbrauch	151 423,02 kWh	
PV-Generatorenergie (AC-Netz)	151 491,18 kWh	

Example 10: 1 string with 21 PV modules | 13 strings each with 22 PV modules

Ergebnisse		
Globalstrahlung horizontal	1 114,06 kWh/m²	
Abweichung vom Standardspektrum	-11,14 kWh/m²	-1,00 %
Bodenreflexion (Albedo)	6,65 kWh/m²	0,60 %
Ausrichtung und Neigung der Modulebene	145,89 kWh/m²	13,15 %
Abschattung	0,00 kWh/m²	0,00 %
Reflexion an Moduloberfläche	-13,16 kWh/m²	-1,05 %
Globalstrahlung auf Modul	1 242,30 kWh/m²	
	1 242,30 kWh/m²	
	x 662,507 m²	
	= 823 034,82 kWh	
PV Globalstrahlung	823 034,82 kWh	
Verschmutzung	0,00 kWh	0,00 %
STC Konversion (Modul-Nennwirkungsgrad 20,39 %)	-655 206,81 kWh	-79,61 %
PV Nennenergie	167 828,01 kWh	
Schwachlichtverhalten	-217,07 kWh	-0,13 %
Abweichung von der Nenn-Modultemperatur	-2 253,00 kWh	-1,34 %
Dioden	-826,79 kWh	-0,50 %
Mismatch (Herstellerangaben)	-3 290,62 kWh	-2,00 %
Mismatch (Verschaltung/Abschattung)	-567,58 kWh	-0,35 %
PV-Energie (DC) ohne Wechselrichter-Abregelung	160 672,95 kWh	
Unterschreitung der DC-Startleistung	-8,49 kWh	-0,01 %
Abregelung wegen MPP-Spannungsbereich	-2,52 kWh	0,00 %
Abregelung wegen max. DC-Strom	0,00 kWh	0,00 %
Abregelung wegen max. DC-Leistung	0,00 kWh	0,00 %
Abregelung wegen max. AC-Leistung/cos phi	-4 574,36 kWh	-2,85 %
MPP Anpassung	-46,83 kWh	-0,03 %
PV-Energie (DC)	156 040,76 kWh	
Energie am WR-Eingang	156 040,76 kWh	
Abweichung der Eingangs- von der Nennspannung	-529,52 kWh	-0,34 %
DC/AC-Wandlung	-3 335,25 kWh	-2,14 %
Standby-Verbrauch (Wechselrichter)	-68,15 kWh	-0,04 %
Kabelverluste Gesamt	0,00 kWh	0,00 %
PV-Energie (AC) abzgl. Standby-Verbrauch	152 107,85 kWh	
PV-Generatorenergie (AC-Netz)	152 176,00 kWh	

Example 11: 14 strings each with 22 PV modules

Ergebnisse		
Globalstrahlung horizontal	1 114,06 kWh/m²	
Abweichung vom Standardspektrum	-11,14 kWh/m²	-1,00 %
Bodenreflexion (Albedo)	6,65 kWh/m²	0,60 %
Ausrichtung und Neigung der Modulebene	145,89 kWh/m²	13,15 %
Abschattung	0,00 kWh/m²	0,00 %
Reflexion an Moduloberfläche	-13,16 kWh/m²	-1,05 %
Globalstrahlung auf Modul	1 242,30 kWh/m²	
	1 242,30 kWh/m²	
	x 664,665 m²	
	= 825 715,71 kWh	
PV Globalstrahlung	825 715,71 kWh	
Verschmutzung	0,00 kWh	0,00 %
STC Konversion (Modul-Nennwirkungsgrad 20,39 %)	-657 341,03 kWh	-79,61 %
PV Nennenergie	168 374,68 kWh	
Schwachlichtverhalten	-217,78 kWh	-0,13 %
Abweichung von der Nenn-Modultemperatur	-2 260,34 kWh	-1,34 %
Dioden	-829,48 kWh	-0,50 %
Mismatch (Herstellerangaben)	-3 301,34 kWh	-2,00 %
Mismatch (Verschaltung/Abschattung)	0,00 kWh	0,00 %
PV-Energie (DC) ohne Wechselrichter-Abregelung	161 765,74 kWh	
Unterschreitung der DC-Startleistung	-8,36 kWh	-0,01 %
Abregelung wegen MPP-Spannungsbereich	-2,37 kWh	0,00 %
Abregelung wegen max. DC-Strom	0,00 kWh	0,00 %
Abregelung wegen max. DC-Leistung	0,00 kWh	0,00 %
Abregelung wegen max. AC-Leistung/cos phi	-4 784,82 kWh	-2,96 %
MPP Anpassung	-47,09 kWh	-0,03 %
PV-Energie (DC)	156 923,10 kWh	
Energie am WR-Eingang	156 923,10 kWh	
Abweichung der Eingangs- von der Nennspannung	-559,36 kWh	-0,36 %
DC/AC-Wandlung	-3 350,89 kWh	-2,14 %
Standby-Verbrauch (Wechselrichter)	-68,14 kWh	-0,04 %
Kabelverluste Gesamt	0,00 kWh	0,00 %
PV-Energie (AC) abzgl. Standby-Verbrauch	152 944,71 kWh	
PV-Generatorenergie (AC-Netz)	153 012,85 kWh	

6 LIST OF FIGURES

7 LIST OF TABLES

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