SolarMax MT series

Planning and design of decentralized plants with respect to the influence of grid impedance

Technical information

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Contents

1 Introduction

Analysing the electricity production costs plays an increasingly important role with regards to the planning and building of large-scale photovoltaic plants. Along with the investment costs (components, funding, installation, etc.) first and foremost runtime variables such as service and maintenance costs, availability, performance ratio, etc. have an important influence.

Over the past years, the necessity of consistently reducing the electricity production costs, amongst others, resulted in a new approach in planning and installing large-scale plants. Based on central inverters up to that time, large-scale plants have been increasingly planned on the basis of string inverters ever since. Depending on the local circumstances, the benefits such as more specific MPP tracking, good scalability, or simpler handling regarding service and maintenance are clearly obvious. However, on the other hand, decentralized and centralized systems not only differ in regards to the electricity production costs, there are also differing requirements for planning and technical design.

When compared to centralized systems, the quality of the power grid has an increased influence on the operating behaviour of decentralized plants, especially the ratio between grid impedance and plant impedance. In worst cases, undesired dynamic behaviour of the plant may be caused. Therefore, it is necessary to focus on certain system-relevant variables during the planning stage since these have a decisive influence on the operating behaviour. Non-observance may cause subsequent costs for replacements, repairs, retrofitting works, etc. to the plant operator.

This document provides important technical advice to planners and system integrators. It focusses especially on the influence of the grid impedance and the securing of a proper operation of decentralized plants. Since technical design and system cost are closely related it is primary the responsibility of the system planner to find the best compromise between these target figures.

Ideally the following information can already be considered during or even before the planning stage. SolarMax absolutely recommends observing the information, otherwise operating issues with the inverters may occur, generating additional cost and requiring extended measures to be applied. In those cases please get in touch with our local SolarMax office at www.solarmax.com/service in order to receive further information.

2 Grid connection point

Regardless of any planning measures influencing the impedance ratio between grid and plant there is a given capability of the public grid to draw current of a random power generator. This capability can be checked by determining the short-circuit power ($S_{SC,\ grid}$) at the grid connection point (feed-in point). Due to several experiences it is commonly recommended that the short-circuit power is at least 100 times higher than the rated power of the plant when using a transformer for the grid connection. In case of a medium voltage connection the short-circuit power must be at least 30 times higher.

Normally grid operators can provide the short-circuit power value. For a rough check approximate guide values can be used in MV grids:

Medium voltage grid	**$S_{SC,\ grid}$**
10 kV	250 MVA
20 kV	500 MVA

In low voltage grids the short-circuit power can also be calculated by measuring the short-circuit current at the grid connection point and using the formula below:

$$S_{SC,\ grid} = \sqrt{3} \cdot 400\ V \cdot I_{SC,\ grid} \cdot 3$$

$S_{SC,\ grid}$: Short-circuit power at grid connection point
$I_{SC,\ grid}$: Short-circuit current measured at grid connection point

If the extent of the short-circuit power does not comply with the recommendations above it is even more important to observe further measures helping to ensure a failure-free plant operation!

Example:

A PV plant is planned with 150 units of SolarMax 15MT2 inverters. The plant is connected to the medium-voltage grid by a 10kV transformer. The reference value for $S_{SC,\ grid}$ is 250 MVA.

$S_{SC,\ grid} \geq 100 \cdot S_{plant}$
$250\ MVA \geq 100 \cdot (150 \cdot 15\ kVA)$
$250\ MVA \geq 225\ MVA$

The capability of the power grid is sufficient.

3 Plant configuration

In decentralized plants different factors play more or less important roles in their influence on the impedance ratio between grid and plant. As a common rule for every kind of PV plant, the grid impedance must be as low as possible in order to ensure a failure-free operation. For technical questions during the planning stage, please contact our local SolarMax office at www.solarmax.com/service.

3.1 Connecting transformer

The connecting transformer has the greatest impact on the extent of grid impedance! Thus it is important to put a very high priority on sufficient transformer dimensioning in order to avoid future interdependencies with the power grid. Along with this power losses can also be reduced which helps to improve plant efficiency.

It is strongly recommended that the connecting transformer is oversized in relation to the cumulative power of the connected inverters. This is quite important since the grid behavior may change over time and an insufficient dimensioning will cause extended lifecycle cost. As an alternative to oversizing, a high-quality transformer with a short-circuit voltage of $U_k = 4\ \%$ instead of $U_k = 6\ \%$ can be used.

Framework conditions like local installation standards, environmental situations, etc. can influence the plant design in terms of AC wiring, plant topology, etc. This may lead to sub-optimal dimensioning of certain components and thereby to an increase of the grid impedance. These constraints can be partially compensated for by increasing the oversizing of the connecting transformer and therewith lowering the grid impedance.

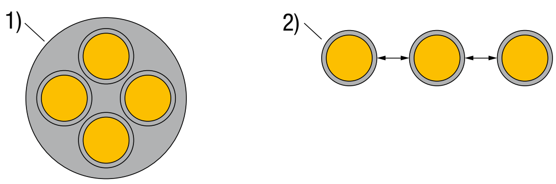
For more detailed information about the configuration of the connecting transformer please refer to the technical information "SolarMax MT series - Requirements for low-voltage and medium-voltage transformers" on www.solarmax.com.

3.2 AC cabling

The AC wiring in decentralized plants is another important factor influencing the grid impedance hence an adequate ratio between DC and AC cable lengths has to be found. Normally longer DC distances must be preferred since power losses on the DC feed-lines are lower. If this design approach cannot be fully applied, special attention has to be paid in the dimensioning of the AC cables. The following measures have proven in practice and are very much recommended for consideration.

3.2.1 Cable type

Multi-conductor rather than single-conductor cables should be used in order to reduce line inductances both for AC feed-lines and especially AC distributing mains.



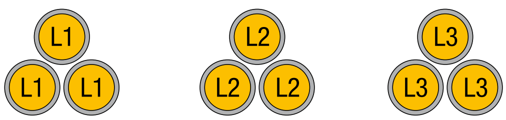
Legend:

1) Multi-conductor cable 2) Single-conductor cables

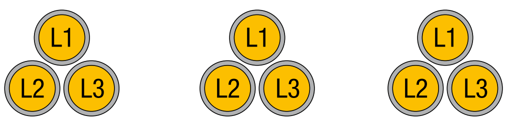
3.2.2 Cable arrangement

Due to cost reduction purposes single-conductor cables often get utilized for the AC distributing mains. In those cases it is very important to arrange the single lines in three-phase systems in order to reduce line inductances. Furthermore loop inductances can be avoided by keeping the cable groups close together.

Conductors grouped by phase –> high line inductance



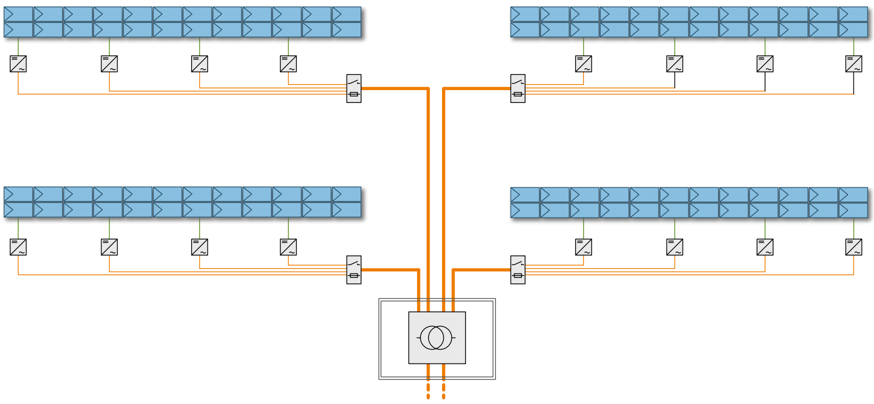
Conductors arranged to 3-phase systems –> low line inductance



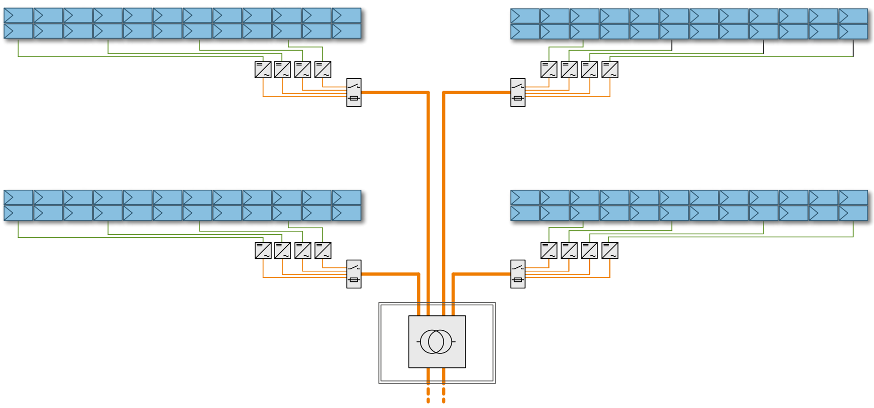
3.2.3 Inverters installation point

Ideally AC cable distances should be kept as short as feasibly possible. A simple but effective measure is to adjust the inverters installation point which can help to lower the grid impedance.

Inverters installation point with shorter DC and longer AC cable distances



Inverters installation point with longer DC and shorter AC cable distances in order to reduce the grid impedance.



Legend:

DC feed-lines
AC feed-lines
AC distributing mains
Inverter
AC terminal box
Transformer
Solar modules

3.2.4 Cable length

Regardless of the cross-section of the AC cables, cable length is the main determining factor for impedance on the AC side of the inverter. As such there is a relation between the number of inverters connected in parallel and the max. length of the AC cable distance. The table below defines the maximum AC cable length depending on the number of SolarMax 15MT2 inverters connected in parallel.

In larger plants inverters already get connected in parallel (compare 4.2) in the field. In those so called cluster topologies, the max. AC cable length is referred to the distributing mains assuming the AC feed-lines do not exceed a length of 20 m and the cross-section is 6 mm².

Number of 15MT2 inverters in parallel	Plant topology	Multi-conductor cable (copper)		Single-conductor cable (copper)	
		Max. AC cable length [m]	Min. cross-section[1] [mm²]	Max. AC cable length [m]	Min. cross-section[1] [mm²]
1	star	1000	185	500	120
2	cluster	500	185	250	120
3	cluster	350	185	175	120
4	cluster	260	185	130	120
5	cluster	200	185	100	120
6	cluster	175	185	85	120
7	cluster	150	185	75	120
8	cluster	130	185	65	120
9	cluster	110	185	55	120
10[2]	cluster	100	185	50	120

1) The cross-section has no impact on the extent of the impedance but on the extent of the cable losses. The values given are the min. cross-sections keeping the losses below 1 %. Dimensioning of the cross-section has to be checked by the system planner separately.

2) When planning to connect more than ten inverters in parallel, please contact our local SolarMax office at www.solarmax.com/service

4 Plant topologies

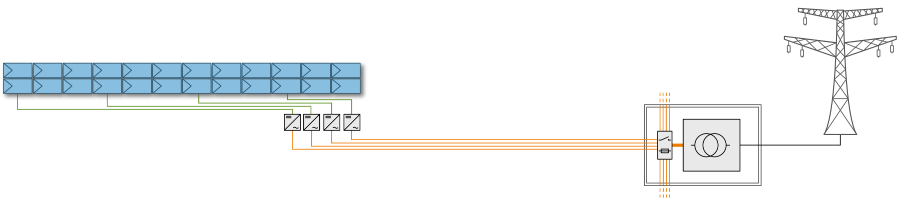
Inverters can be connected to the grid or a connecting transformer in different ways. By changing plant topology it is possible to optimize uptime of the plant and also effect system cost and efficiency in a certain way. The different topologies are more or less suitable for certain applications (roof-top, ground, medium, large, etc.) in terms of their influence on the impedance ratio between grid and plant. So on one hand technical aspects must normally drive the choice of the appropriate topology whilst on the other hand cost for DC and AC cabling, terminal boxes or cable losses might also play a significant role for the technical design. It is the responsibility of the system planner to find the best compromise between a sustainable technical design and system cost.

Following several experiences it has been found that some topologies require special attention on certain system components. Following are listed two typical topologies applied in decentralized plants and the measures that need to be strongly considered in order to keep the grid impedance as low as possible.

4.1 Star topology

Description:

All string inverters get directly connected to an AC terminal box close to the connecting transformer or the grid connection point.



Application:

Preferably applied in small decentralized plants. Distance from the inverters to the connecting transformer or grid connection point must be kept as short as possible.

Cabling:

Multi-conductor cables should be preferred with a maximum length of 1000 m (compare 3.2.4). When using single-conductor cables extended measures are required (compare 3.2.2).

Transformer:

Provided there is a sufficient short-circuit power at the grid connection point the grid impedance will only slightly raise due to the low currents on the single AC feed-lines. For the connecting transformer an oversizing of 10 % is recommended.

Benefits:

- Due to longer DC feed-lines with higher voltages the cable losses can be reduced.
- Due to lower currents on single AC feed-lines the grid impedance is greatly minimized.
- With the direct connection to transformer or grid connection point AC terminal boxes can be saved.

Example 1:

A PV plant is planned with six units of SolarMax 15MT2 inverters. They all get connected separately to an AC terminal box close to the LV grid connection point.
For the AC cabling multi-conductor cables are utilized with a cross-section of 6 mm² per phase.

What is the max. AC cable length from one inverter to the AC terminal box considering impedance and cable losses?

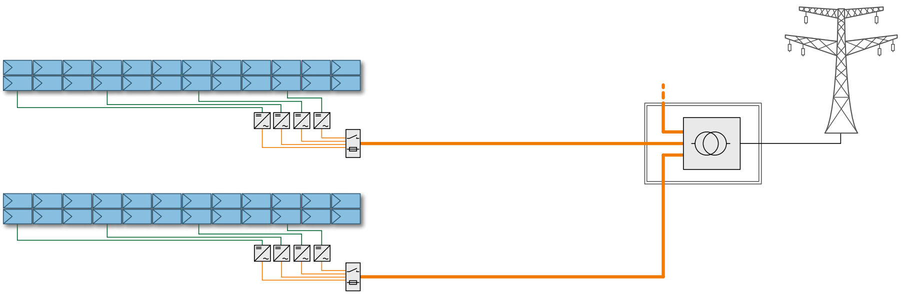
Low cable losses (1 %) –> max. AC cable length 70 m
Low impedance –> max. AC cable length 1000 m

The max. AC cable length is limited by the cable losses and should not exceed 70 m.

4.2 Cluster topology

Description:

A certain number of string inverters get connected in parallel to an AC terminal box in the field. The power transmission to the connecting transformer is realized cluster-wise with AC distributing mains.



Application:

Preferably applied in medium to large decentralized plants. Both in ground mounted and flat-roof installations a mounting rack is typically used to hold the solar modules. The AC terminal boxes should be installed at the end of a row with as short a distance as possible to the connecting transformer. The same is true for the inverters which should be installed close to the AC terminal box in order to reduce distances of the AC feed-lines. The maximum number of inverters connected in parallel is recommended at ten otherwise please contact our local SolarMax office at www.solarmax.com/service.

Cabling:

Multi-conductor cables are strongly recommended. Furthermore the AC cable distances must be carefully considered (compare 3.2.4). This is especially true for the AC distributing mains since on longer distances the impact of the line inductances gets higher. When utilizing single-conductor cables extended measures are required (compare 3.2.2).

Transformer:

Provided there is sufficient short-circuit power at the grid connection point the grid impedance will potentially be increased due to the higher currents on the AC distributing mains. In order to compensate this effect an oversizing of 15–20 % is recommended for the connecting transformer.

Benefits:

- Due to longer DC feed-lines with higher voltages the cable losses can be reduced.
- AC cable cost can be reduced when utilizing distributing mains from the AC terminal boxes to the transformer.

Example 2:

A PV plant is planned with 120 units of SolarMax 15MT2 inverters. Five devices get connected in parallel to a closely (max. 30 m) located AC terminal box. The multi-conductor feed-lines have a cross section of 6 mm². In total there are 24 clusters respectively 24 AC terminal boxes. A distributing main is transmitting the current from each terminal box to a 10kV transformer.
For the AC distributing mains multi-conductor cables are utilized with a cross-section of 185 mm² per phase.

What is the max. cable length of one AC distributing main from an AC terminal box to the transformer considering impedance and cable losses?

Low cable losses (1 %) –> max. AC cable length 215 m
Low impedance –> max. AC cable length 200 m

The max. cable length of the distributing main is limited by the impedance and should not exceed 200 m.

Example 3:

A PV plant is planned with 120 units of SolarMax 15MT2 inverters. Five devices get connected in parallel to a closely (max. 30 m) located AC terminal box. The multi-conductor feed-lines have a cross section of 6 mm². In total there are 24 clusters respectively 24 AC terminal boxes. A distributing main is transmitting the current from each terminal box to a 10kV transformer.
For the AC distributing main single-conductor cables are utilized with a cross-section of 120 mm² per phase.

What is the max. cable length of one distributing main from an AC terminal box to the transformer considering impedance and cable losses?

Low cable losses (1 %) –> max. AC cable length 140 m
Low impedance –> max. AC cable length 100 m

The max. cable length of the distributing main is limited by the impedance and should not exceed 100 m.

5 Conclusion

There are different measures which can be taken during the planning stage in order to keep the grid impedance as low as possible. On one hand it ensures proper operation for the future and thereby reduces the probability of further cost for reworks and troubleshooting. On the other hand it also makes the plant less sensitive against environmental changes like the installation of a further PV plant or large industrial loads in close vicinity which may influence the impedance of the power grid.

- In advance check the capability of the power grid at the connection point (compare 2).
- Consider an adequate oversizing of the transformer in order to keep the grid impedance as low as possible (compare 3.1).
- Utilize multi-conductor cables (compare 3.2.1 et seq).
- Consider the AC cable length by keeping the distances between inverters and connecting transformer as short as possible (compare 3.2.3 et seq).
- Check the relevance of the previous measures according to the deployed plant topology (compare 4).

The very important measures mentioned above are fundamental for a maximum uptime of the plant. Since the possibility of unpredictable influences in the future exists, trouble-shooting measures like retrofitting capacitors or switches might be necessary. Due to our extensive experience with planning larger PV plants SolarMax is able to provide individual solutions on request. Please contact your local SolarMax office at www.solarmax.com/service.

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