Advisory Guide

String inverters

Decentralized Inverter Technology in Large-Scale PV Plants

Technical Information | Edition1.1 | BL-DezWT-UEN103511

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1 Introduction

With the development of the Sunny Mini Central and Sunny Tripower transformerless inverters, string technology asserts itself into the megawatt range, particularly due to the improved specific price and the high efficiency. By now, decentralized inverter configuration represents a technically sensible and cost-effective system solution, even in large plants, and it stands out in comparison with centralized structures due to key advantages.

- Flexible and optimal string configuration for each inverter.
- Local MPP-Tracking for a limited number of PV modules.
  This way the number of mismatches is minimized, and losses due to shading are reduced.
- Simplified installation (reduced DC cabling)
- Successive commissioning of small generator blocks
- Low system and maintenance costs
- Replacement of inverters takes place rapidly and can be carried out by local personnel.
- Modular expandability
- Important functions are already integrated (string fuses, communication, overvoltage protection, etc.)

This guide addresses various issues which must be taken into account in the planning and implementation of a decentralized large-scale plant. Solution approaches are sketched and background technical information is given in the areas of PV connection, inverter configuration, AC structures, decoupling protection, medium-voltage connection and grid management which provide aid for the planner in the layout of larger decentralized PV plants. The different sections point the reader to applicable standards and directives.
The technical information and cross references of this document are subjected to a continuous further development and therefore the right to any changes as may be technically or legally required is reserved.

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Further information: www.sma.de → Service → Downloads → Technical Information → Application notes

2 PV Generator

When planning and designing a PV plant there are specific criteria which have to be taken into account in the areas of inverter topology, module technology, and module configuration in order to avoid negative interactions.
With help from the "Sunny Design" layout program, an optimal plant configuration can be put together rapidly and simply. The software delivers data for an economic evaluation of the plant[1] along with a technical inspection of the various components. Comprehensive data bases for actual PV modules and worldwide weather data are made available for the calculations.
The physical and electrotechnical requirements described in the following chapters must also be taken into account for the plant configurations, in order to ensure optimal and fault-free functioning.

2.1 Insulation Resistance

When using transformerless inverters[2], certain threshold values for the insulating resistance (R_{iso}) of the entire plant must be observed[3]. Every PV plant exhibits a different potential with respect to the ground. The leakage currents formed here under certain circumstances - caused by bad insulation - cannot be allowed to be a hazard, and for this reason transformerless inverters measure the R_{iso} before every grid connection. Continuous measurement (during operation) is not possible with this type of inverter due to the lack of galvanic isolation.

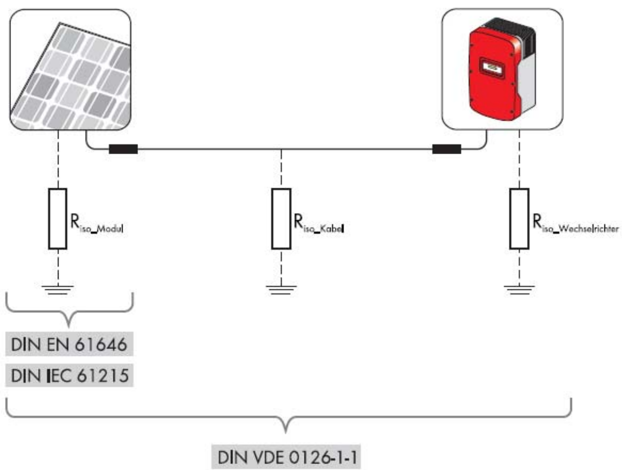


Figure 1: Insulation resistance of the PV plant

[1] Yield calculations are estimates based on mathematical models.

[2] For inverters with galvanic isolation there are no DIN requirements with respect to this

[3] R_{iso} – module/-cable/-inverter in accordance with DIN EN 61646; DIN IEC 61215 und DIN VDE 0126-1-1

According to the standards, the following threshold values apply:

- For modules: per m^2 of area: $R_{iso} > 40\ M\Omega m^2$
  Since the insulation resistance of all modules represent a parallel connection against ground, the simplified equation results:

$$R_{iso} = \frac{R_{modul}}{Modulequantity}$$

  it follows that R_{iso} decreases with increasing module numbers.

- For transformerless inverters:
  The prescribed R_{iso} depends on the maximum input voltage of the inverter.
  The following applies: $R_{iso} > 1k\Omega/V$, but at least 500 $k\Omega$
  (as at May 2010 – please pay attention to new standards and regulations)

When planning a PV plant and the configuration of the number of modules per inverter, it is important to observe the interrelations with respect to the insulation resistance, otherwise there is the danger that the inverters could refuse the grid connection because of a R_{iso} that is too low.
In the Sunny Mini Central SMC 9000TL, SMC 10000TL and SMC 11000TL the threshold R_{iso} is set at 900 kΩ (according to the standard, at 700V input voltage at least 700kΩ are required - SMA has provided the threshold value with a security margin of 200kΩ). Transformerless inverters require a TN grid with a PE connection in accordance with the standards. Since the insulation resistance is dependent on the module surface, special attention must be paid to the configuration of large plants with thin-film modules in order not to exceed the threshold values mentioned.

One example
Thin-film module: P_{MPP} = 70 Watts, surface of module (0.6 m x 1.2 m) = 0.72 m^2
Inverter: SMC11000TL with 6 modules/strings and 25 strings per inverter
Number of modules: 150; PV power: 10.5 kW_p

According to the standard, there must be an insulation resistance of at least 40 $M\Omega m^2$. The 150 modules per inverter cover an area of 108 m^2. It follows that this configuration may have an insulation resistance of only 370kΩ under certain circumstances (perhaps occurring more acutely due to humidity, a dirty installation, or external components on the DC side like DC fuses, overvoltage protectors or string collectors). In this case, the inverter would not start.

>> Further information: SMA Technical Information (TI) - Insulation Resistance

2.2 Capacitive Discharge Currents

Due to its construction - because it is not galvanically isolated - the transformerless inverter mixes in an AC voltage on the DC side which is generated by a pole reversal of the solar generator during the change between the positive and the negative halves of the grid voltage wave of the grid. If this AC voltage present at the solar generator connections exceeds one capacitance, capacitive discharge currents are the result. The magnitude of the discharge current is determined by the size of the capacitances and the harmonic content of the voltage. In a PV plant, capacitances generally occur through the ground capacitance of the solar generator (module frame capacitance), through Y condensers at the inverter, or maybe through the contact capacitance between the insulated module surface and the ground.

In transformerless inverters, half of the grid amplitude is coupled into the PV module connection. The arrangement oscillates with 115 V and 50 Hz.

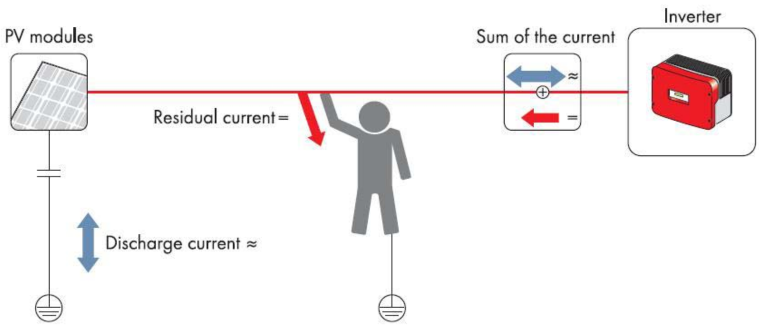


Figure 2: Capacitances of a PV plant

If glas/film modules are used, greater discharge currents appear on the back side than if one uses glas/glas modules. The discharge currents measured at the solar generator are between a few and several hundred milliamperes, depending on the inverter. For this reason, if there is a rupture in the generator grounding, there is a high potential for hazard.[1]

The magnitude of the discharge current is proportional to the capacitance and amplitude of the voltage connected. Since for inverters with transformer, only a few volts are mixed into the voltage at the generator, observation of the discharge current can be neglected.

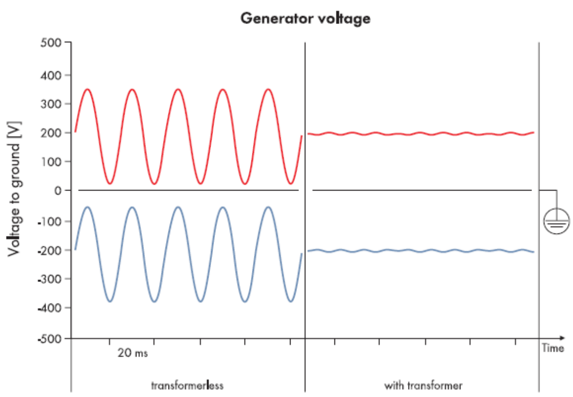


Figure 3: Mixing in of voltage at the generator[2]

[1] see J. Kirchhof, 21. Symposium Photovoltaische Solarenergie, March 2006, Staffelstein

[2] see SMA-TI module technique

The capacitance of the PV modules is proportional to the surface and inversely proportional to the thickness. High capacitances - and with them increased discharge currents - occur in modules with flexible substrates but also in some crystalline modules with metallic back sides. If such modules are connected extensively to transformerless inverters, such high discharge currents can appear during operation that the inverter's residual current monitoring is triggered and the device is disconnected from the grid. This effect is favored by a small distance between module and grounded substrate, like, for example:

- The module is placed directly on the grounded roof sheeting.
- The module is laid as a laminate directly onto an aluminum roof.
- The module is mounted onto a metal holder

For transformerless inverters there arises a borderline capacitance of 1400nF past which one can count with fault-prone operation. Here, the valid approximation formula for the capacitance is:

$$\mathbf{C[nF] = 50 \times A[m^2] / d[mm]}$$

A: effective module surface
d: distance between the plates

(as at May 2010 – please pay attention to new standards and regulations)

>> Further information: SMA TI - Capacitive discharge currents

2.3 PV Generator Grounding

When thin-film modules or modules with contacts in the back are used, it is essential to use galvanically isolated inverters in order to be able to implement the necessary grounding of the generator.

- Thin-film modules
  With these modules there is danger of TCO corrosion, i.e., the electrically-conducting layer (TCO: Transparent Conductive Oxide) on the inside of the glass cover is destroyed by a chemical reaction (Na^+ and humidity). This corrosion is avoided by using a galvanically isolating inverter with negative grounding set from SMA.
- Modules with contacts in the back
  With this module type a polarization effect can occur which causes a progressive diminution of the module efficiency. This effect can be avoided with the use of a galvanically isolating inverter with a positive grounding set.

Whether transformerless inverters can be used with the PV generators mentioned above must be consulted with and confirmed by the respective module manufacturer.

Cell technology / Module design	transformerless inverters		Inverters with transformers		
	SB xxxxTL SMC xxxxTL	SB xxxxTL-HC	Series devices SB xxxx SMC xxxx		
			without grounding kit	with neg. grounding set	with pos. grounding set
monocrystalline Si	●	●	●	○	○
polycrystalline Si	●	●	●	○	○
CdTe	–	–	–	●	–
amorphous Si (superstrate design)	–	–	–	●	–
amorphous Si (substrate design)	●	●	●	○	○
CIS	●	●	●	○	○
monocrystalline Si (A-300)	–	–	–	–	●
Metal foil as substrate or in module design	–	●	●	●	●
Caption: ● recommended; ○ recommended to a limited extent; – not recommended					

Table 1: Overview of inverter cell technology recommendations

>> Further information: SMA TI - Module Technology

2.4 Use of String Fuses

Most of the time more than 3 strings are connected in parallel at the inverter when designing large PV plants and where Sunny Mini Central inverters are used. If there is a short circuit in one of the strings or if there is a defect in one or more modules, the open terminal voltage of this string (especially if there are only few modules per string) will be significantly lower than the terminal voltage of the remaining strings parallel to it. A reverse current by the faulty generator string is the result, which, depending on the intensity of the current, can lead to a strong heating which can go as far as the destruction of the modules of this string. One cannot rule out secondary damage due to the local overheating.

If a reverse current exceeds the reverse current rating quoted by the module manufacturer, the individual strings can be protected with fuses. The DC inputs in the SMC9000TL/10000TL/11000TL inverter generation are prepared for retrofitting with string fuses (melting) which must be specially dimensioned.

The fuse value depends on the module manufacturer data sheet quotes and the number of strings connected in parallel[1].

[1] Examples of calculation of the value and possible fuse values in: "Stringsicherungen_SMC-UNE083420.pdf".

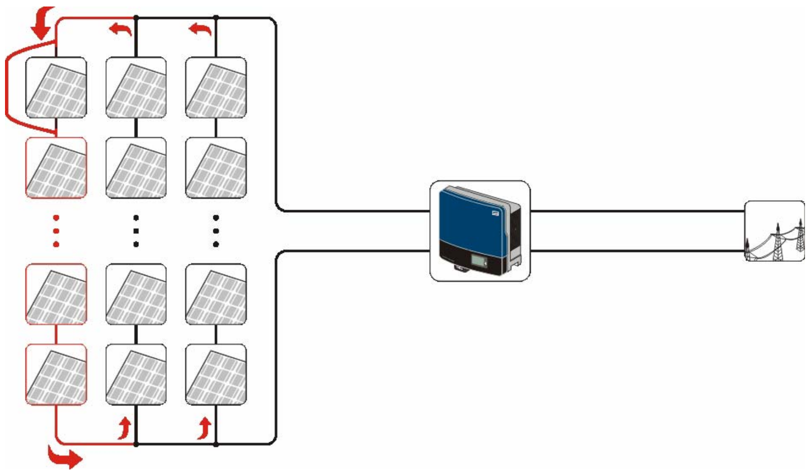


Figure 4: Reverse current into the faulty string = total current oft the remaining string

The STP 1000TL/12000TL/15000TL/17000TL 3-phase inverters monitor the DC inputs by means of electronic fuses which do not need to be dimensioned and work without any losses. In case of string faults, the corresponding input is short-circuited, avoiding a reverse current.

>> Further information: SMA TI - Reverse Current
SMA TI - Application of string fuses of Sunny Mini Central

2.5 Laying DC current cables

When carrying out the cabling for the DC side, a few rules should be observed for optimal and fault-free operation, both with roof-mounted and free-standing devices.

- Use cables with connectors which are contact-proof and designed to avoid confusion.
- Cables should run through protective tubes or mounting frames to protect them from weathering and UV radiation. Cables which are hanging freely or which lie on stone or in water (-> flat roof) are not allowed.
- It is advisable to carry out insulation and resistance measurements after every cable installation in order to locate any possible faults in this partial string, which is harder to do later in the whole system.
- The connection cables for all strings should be numbered to facilitate later fault location.
- In a large PV array the cross-section variants of the cables must be as few as possible in order to facilitate mounting and to avoid faulty installations due to confusion of cables. Here, cable losses should always remain under 1% (e.g. in Germany in accordance with DIN VDE 0100-712).

With large plants it is often necessary to bundle together the strings from the solar generators in generator connection boxes (GCB) which are then led to DC inputs of the individual inverters. In addition, string fuses, overvoltage protection devices and maybe an additional DC disconnection point, if desired, can be integrated. When using GCBs, it must be ensured that the necessary insulation resistance (R_{iso}) for the inverters is guaranteed through proper installation (mounting, humidity avoidance). In addition, the following points must be observed:

- The generator connection box must be mounted to be short-circuit- and ground-fault free.
- The positive and negative parts must be separated clearly
- The GCB should have at least IP54 protection rating
- The maximal current rating of the connection plugs should not be exceeded.
- Avoid large conductor loops into which overvoltage could be coupled
- Mount the GCB as close as possible to the modules, to keep the string cables short. In the case of integrated overvoltage protection, the modules are also optimally protected this way.

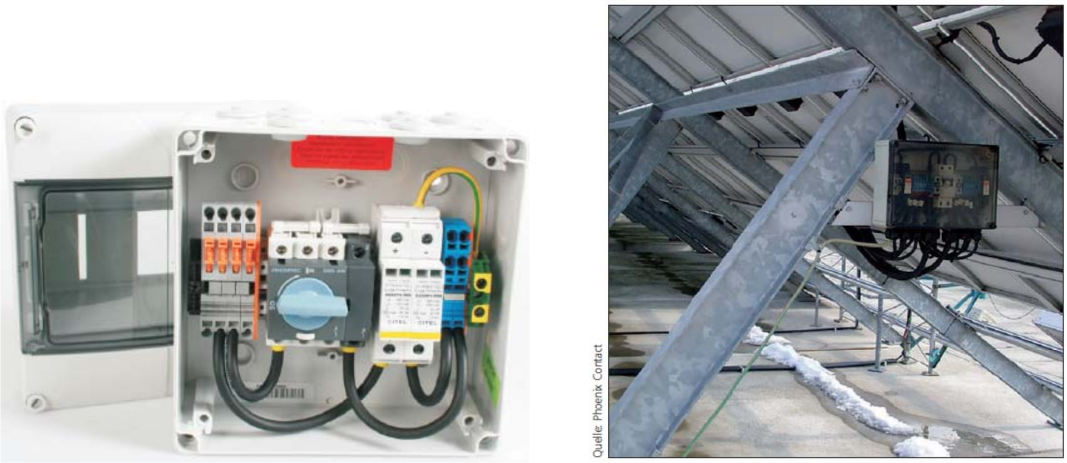


Figure 5: Example of a generator connection box with main switch and overvoltage protection by the manufacturer ENWI (left) and mounting in a plant (Phoenix).

Tripower inverters can be optional equipped with overvoltage protection devices from typ 2 on the DC – side to protect the string-inputs A and B. An external solution is therefore not necessary.

For the fixed laying of conductors and cables from the GCB to the inverter, wet room cabling (NYM-O) or underground cables (NYY-O) are suitable as individual insulated conductors; the cross-section should be chosen to correspond to the generator short-circuit current. The Connection system "Sunclix" allows cable cross-sections from 2.5 mm^2 up t o 6 mm^2 and a current rating of 40 A.

The main DC conductor arriving at the inverter can be separated into individual strings again with the aid of a GCB, in order not to exceed the current rating of the connection plug.

3 Low-Voltage Side Connection Concept

3.1 Types of Grid Structure and Connection Compatibility

(as at May 2010 – please pay attention to current information and Installation manuals)

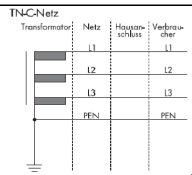
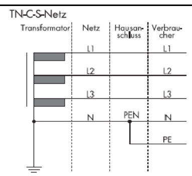
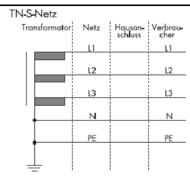
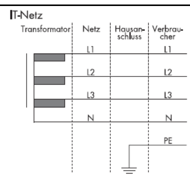
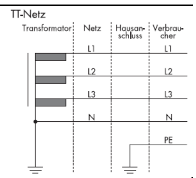
Grid structure / Inverter	 TN-C-Grid	 TN-C-S-Grid	 TN-S-Grid	 IT-Grid	 TT-Grid
Single phase, with transformer					
SMC 6000A	yes	yes	yes	yes	yes
SMC 7000HV	yes	yes	yes	yes	yes
SMC 7000HV-11	yes	yes	yes	yes	yes
Single phase, without transformer					
SMC 6000TL	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
SMC 7000TL	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
SMC 8000TL	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
SMC 9000TL	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
SMC 10000TL	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
SMC 11000TL	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
SMC 9000TLRP	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
SMC 10000TLRP	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
SMC 11000TLRP	yes	yes	yes	no	yes, if $U_{N-PE} < 30V$
Three phase, without transformer					
STP 10000TL-10	yes	yes	yes	no	yes
STP 12000TL-10	yes	yes	yes	no	yes
STP 15000TL-10	yes	yes	yes	no	yes
STP 17000TL-10	yes	yes	yes	no	yes

Table 1: Compatibility of selected inverters with particular grid structures

Observe that IT grids are often used in areas with special requirements like, for example, personnel or supply security. For these grids one should weigh whether the installation of a photovoltaic inverter is sensible. Through the normal operating behavior of the inverter (e.g., possible connection and disconnection processes based on irradiation conditions) unwanted effects on other devices (e.g., medical devices) could occur.
The use of transformerless inverters in a TT grid cannot be recommended, since the voltage relationship U_{N-PE} is dependent on external influences which change (humidity, soil conditions, types of grounding, etc.) and can therefore also change.

3.2 General Plant Design

In order for the advantages of a decentralized PV plant to come to fruition it is helpful to observe a few planning principles.

- The entire PV generator can be put together from partial generators with the same power, connections and dimensions, to each of which an inverter is assigned. These base generators then only need to be duplicated, prepared and interconnected.
- In the case of inverters which are feeding-in in single phase (SMC) groups of three are built in order to assemble a three-phase system. The feed-in power has to be distributed as evenly as possible throughout the phases, and the difference in apparent feed-in power between two phases should not exceed 4.6 kVA. If the Power Balancer[1] is to be used, the inverters in a group should be mounted in a way that will allow the necessary cabling between them.
- Optimal placement of the inverter is determined by local conditions. The goal is to minimize the sum of the cable losses and costs on the DC and the AC sides. If the plant design allows it, the inverters should be installed as closely as possible to the modules in order to save DC cabling. Here, the individual inverters can be mounted directly onto their partial generator, or they can be grouped so as to use a common AC distribution placed within cabling range.
- Depending on the placement of the feed-in point in the generator field and of the number of inverters, a specific number of AC subdistributors and AC main distributors must be used to make a stepwise AC bundling toward the transformer. Cables must be dimensioned according to the occurring currents (losses < 1%). The cross-section versions of the cables should be kept as small as possible here as well. To calculate the cable dimensions one can use the Excel tool "Leitungsberechnung_13_20081016 _DE.xls", (to be found at

[1]By means of the Power Balancer - available in all Sunny Mini Centrals - a coupling of three single-phase inverters into a three-phase unit is made, which can react to breakdown of a phase or of a device, to avoid an unbalanced load.

www.sma.de/de/service/downloads -> Software The individual subdistributors are to be equipped with line circuit breakers and, if needed, with overvoltage protection (more information in 3.2 and 3.3).

Figure 6: Rack-mounted Inverter assembly in groups of six in a ground-mounted system

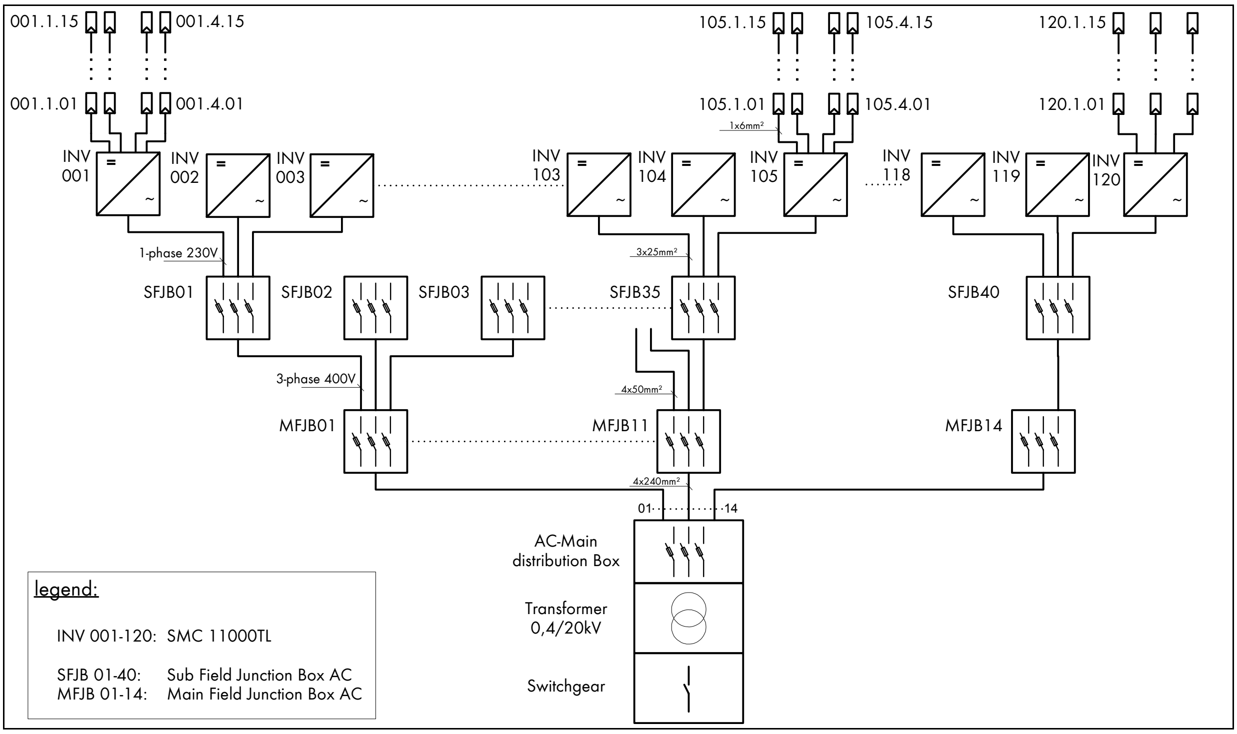


Figure 7: Block diagram of a decentralized 1.2MW plant with SMC

- In Germany e.g. in plants with an added nominal apparent power of more than 30 kVA, a switching device with disconnection point which is accessible at all times is always required. This can be implemented on the low-voltage side in the main distributor by means of a fuse-switch-disconnector. If a decoupling protector is required for the low-voltage side, a combination of grid monitoring relays and load-disconnecting-switches must be provided (the exact requirements must be discussed with the local electric power company).

3.3 Use of single-phase SMC Devices

Due to the decentralized installation, close to the module, of the single-phase SMC inverter in large-scale plants, one must cover greater distances between the inverter and AC distributors or feed-in points. For optimal cabling, the following rules should be observed:

- Grouping of three SMC devices with equal power into one three-phase system.
- The single-phase connections of the individual devices are grouped into one triple-phase cable routing by means of a subdistributor. The distances between the inverters and subdistributor should be kept short in order to minimize line losses and the cable cross section of each single-phase cable.
- From the subdistributor onward, longer cable paths with small line losses can be implemented by choosing appropriate cables to the next connection point (e.g., standard 4 x 50 mm^2 cable). If there is a symmetric feed-in, there is no load on the neutral conductor and the cable losses are cut in half. Thus, the maximum possible cable length is doubled.
- When choosing the cable type, both the environmental influences (temperature, type of cabling, UV resistance) and the inverter-specific data (max. AC current) must be observed.

The maximum cable lengths relative to the conductor cross-section are shown in the following table (copper at 1% loss). Do not exceed the maximum cable length.

Conductor cross-section	Maximum wire length		
	SMC 9000TL-10 / SMC 9000TLRP-10	SMC 10000TL-10 / SMC 10000TLRP-10	SMC 11000TL-10 / SMC 11000TLRP-10
16.0 mm^2	27 m	24 m	22 m
25,0 mm^2 [a]	43 m	38 m	35 m
[a] Only use flexible cables!			

Table 2: Maximal cable lengths between the SMC inverter and the subdistributor.

For Example are in German PV plants larger than 30 kVA, a switchgear with disconnection point accessible at all times, triple-phase voltage monitoring, with protection against voltage increases and decreases, and section switches required according to the German VDEW Directive "Eigenerzeugungsanlagen am Niederspannungsnetz" (Power-Generating Systems on the Low-Voltage Grid). Triple-phase voltage monitoring, and with it grid-symmetric operation can be implemented by means of the electric coupling of three single-phase inverters to form a triple-phase feed-in unit and of the activation of the Power Balancer function present in every SMC. In this, the Power Balancer recognizes different operation modes with which one can determine the reaction of each feed-in unit to grid or device faults:

- Operation mode "OFF"
  Feed-in continues in the non-affected phases if there is a failure. Unbalanced load possible.
- Operation mode "Power Guard"
  In the non-affected phases, feed in continues at max. 5 kVA if there is a grid failure or device fault.
- Operation mode "Phase Guard"
  If there is a grid failure, the feed-in unit is disconnected.
- Operation mode "Fault Guard"
  If there is a grid or device failure, the feed-in unit is disconnected. The advantage of this operating mode in comparison with external voltage monitoring is that there is also disconnection if there is a device fault.

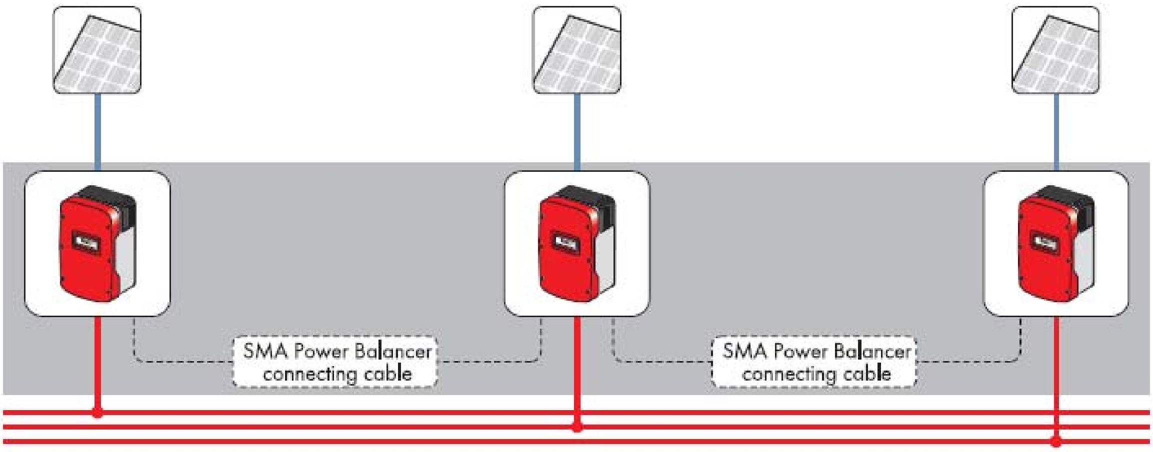


Figure 8: Three-phase feeding-in unit with electrical connection through the Power Balancer

>> Further information: SMA TI - Three phase connection

3.4 Use of 3-phase Tripower Devices

When the Tripower inverter is used, grouping to form feed-in units is not done, because every inverter is connected to the low-voltage grid in 3-phase. Depending on the possible number of line circuit breakers in the main distributor, the inverters can be connected directly to the low-voltage main distributor or they can be bundled by means of an AC subdistributor and led to the main distributor. The maximum cable lengths between inverter and distributor must be observed here again.

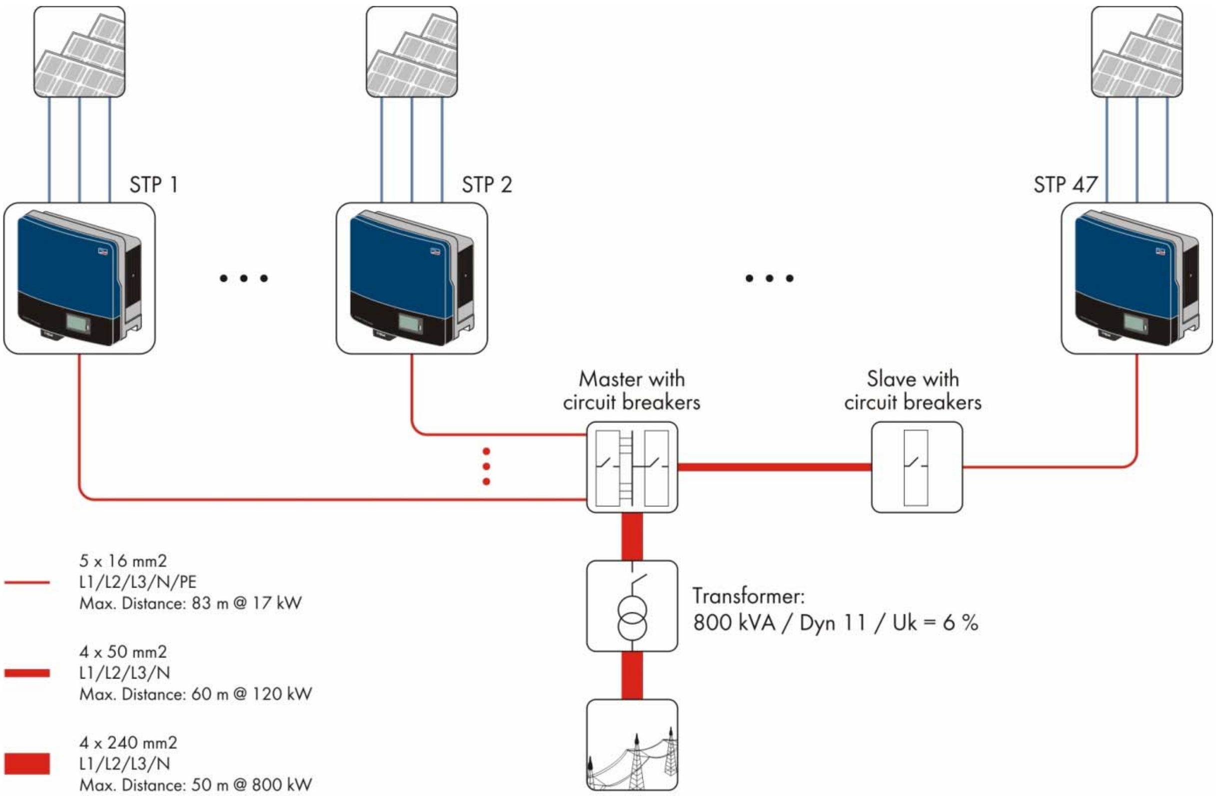


Figure 9: Example of plant, 800 kW with Sunny Tripower

The grid impedance of the AC cable must not exceed 1 Ohm. Otherwise, the Sunny Tripower will disconnect at full feed capacity due to excessive voltage at the feed-in point.
The maximum cable lengths relative to the conductor cross-section are shown in the following table. Do not exceed the maximum cable length.

Conductor cross section	Max. cable length			
	STP 10000TL-10	STP 12000TL-10	STP 15000TL-10	STP 17000TL-10
6.0 mm²	53 m	43 m	35 m	31 m
8.0 mm²	70 m	58 m	46 m	41 m
10.0 mm²	88 m	73 m	58 m	52 m
16.0 mm²	141 m	116 m	93 m	83 m

Table 3: Maximal cable lengths between the STP inverter and the subdistributor.

A multi-MW plant can be formed modularly from low-voltage blocks made up of the same configuration of solar modules, DC and AC cabling, Tripower devices and medium-voltage transformers. The individual low-voltage blocks are led together to the medium-voltage grid and from there they are connected to the the power supply grid.

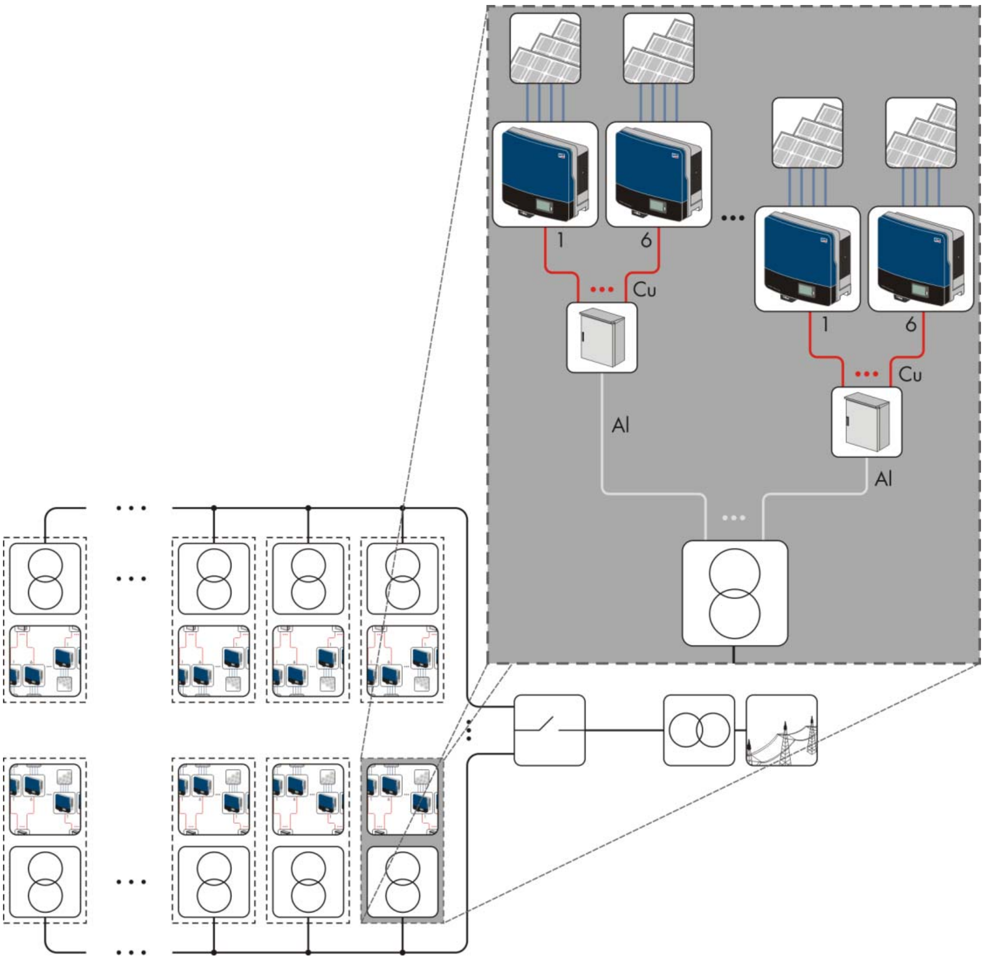


Figure 10: Block wiring diagram for a multi-MW pant with Sunny Tripower[1]

[1] From: Multi-Megawatt PV-Großkraftwerke mit modularer Anlagentopologie (Large-scale PV plants with modular plant topology) [M. Sporleder, M. Breede, J. Reekers]

An optimal structure for the low-voltage blocks can result by using economical, standardized (non walk-in) compact transformer stations, inverters in the 10 - 17 kW power class and block sizes of between 400 kVA and 1250 kVA . The following cost-optimal solutions stand out here:

- Low-voltage blocks of up to 630 kVA. In this case the inverters distributed in a decentralized fashion in the PV array can be connected directly to the compact station. Installation advantages are achieved here, because there is no need for AC distributors.
- Low-voltage blocks as of 630 kVA. The inverters distributed in the PV array in a non-centralized way are bundled in groups of six in an AC distributor and they are connected with an aluminum cable to the medium voltage transformer (compact station).

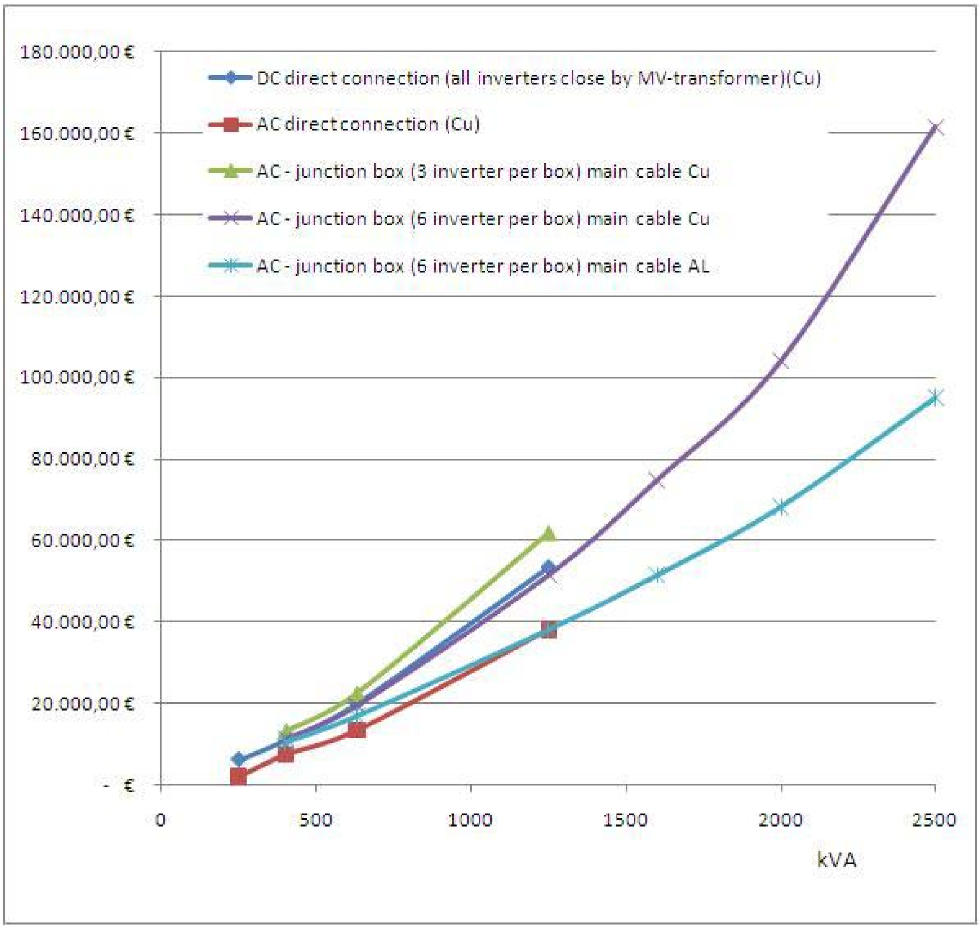


Figure 11: Material costs for low-voltage cables and distributors in the connection of 17 kW Tripower devices to various MS transformer sizes[1].
[Price assumptions: Cu 4.28 €/kg; Al 1.87 €/kg – cable-loss power (AC-DC) approx. 1.5% of nominal power]

[1] From: Multi-Megawatt PV-Großkraftwerke mit modularer Anlagentopologie [M. Sporleder, M. Breede, J. Reekers]

The outcome of this is the following possible configuration:

- Inverter mounted near the PV-Modules using junction boxes
- Inverter mounted near the PV-Modules with direct AC-connection
- Inverter mounted near the MV-station with DC direct connection

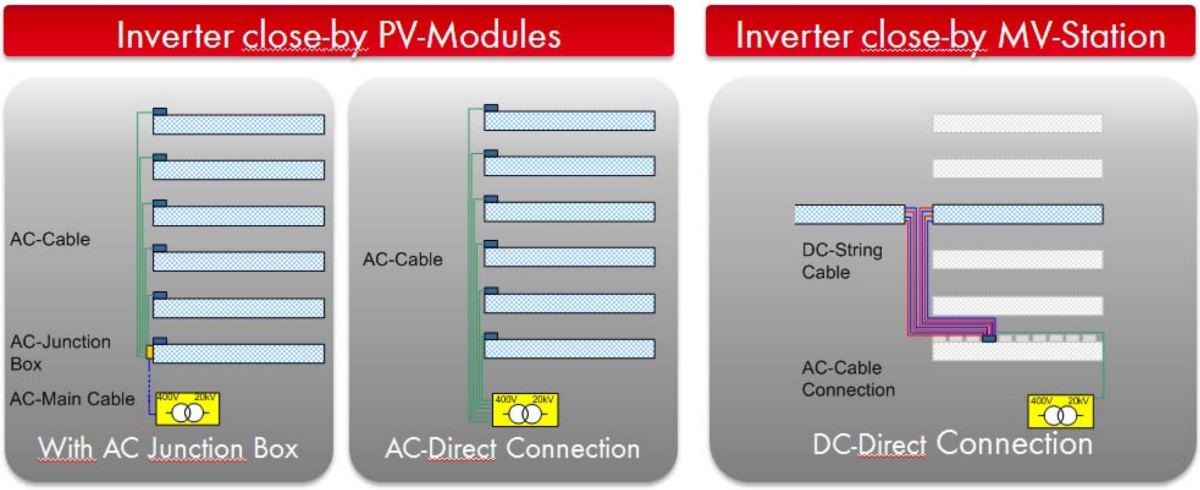


Figure 12: Possible decentralized configurations[1]

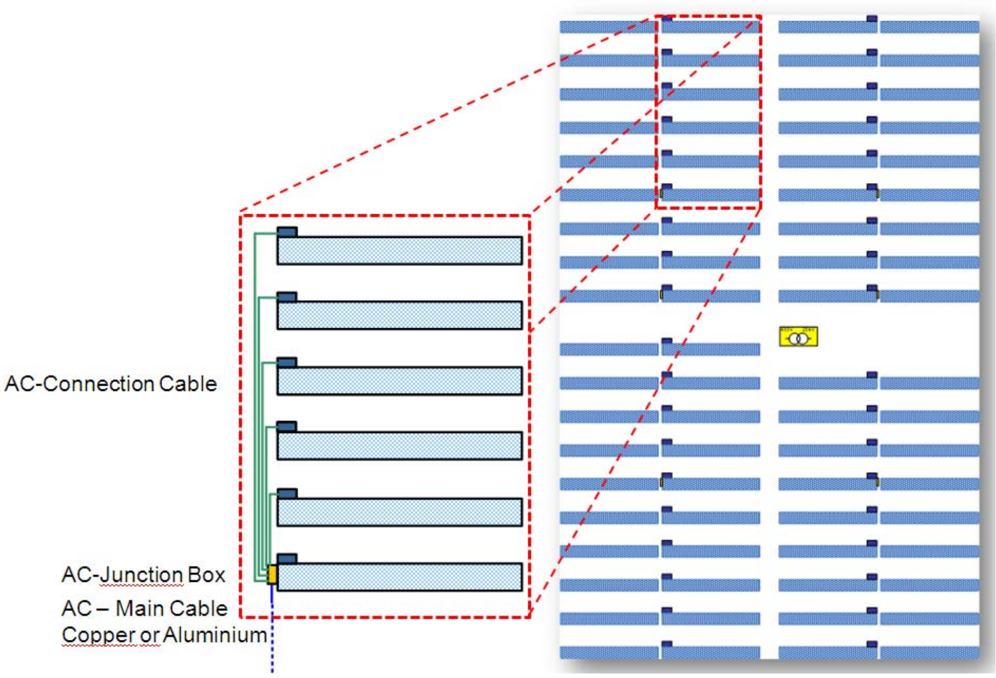


Figure 13: Inverter close-by PV-Modules whereat 6 Tripower are connected to one junction box

[1] From: Multi-Megawatt PV-Großkraftwerke mit modularer Anlagentopologie [J. Reekers, Bad Staffelstein 03/2010]

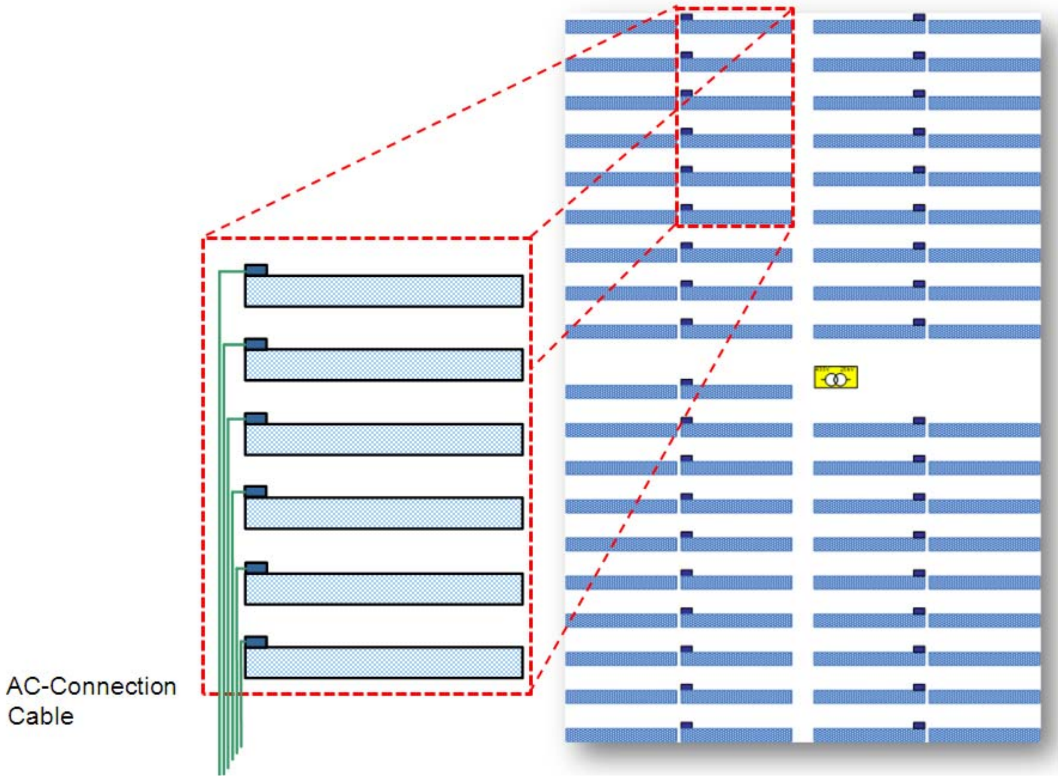


Figure 14: Inverter close-by PV-Modules with AC direct connection to MV-Station

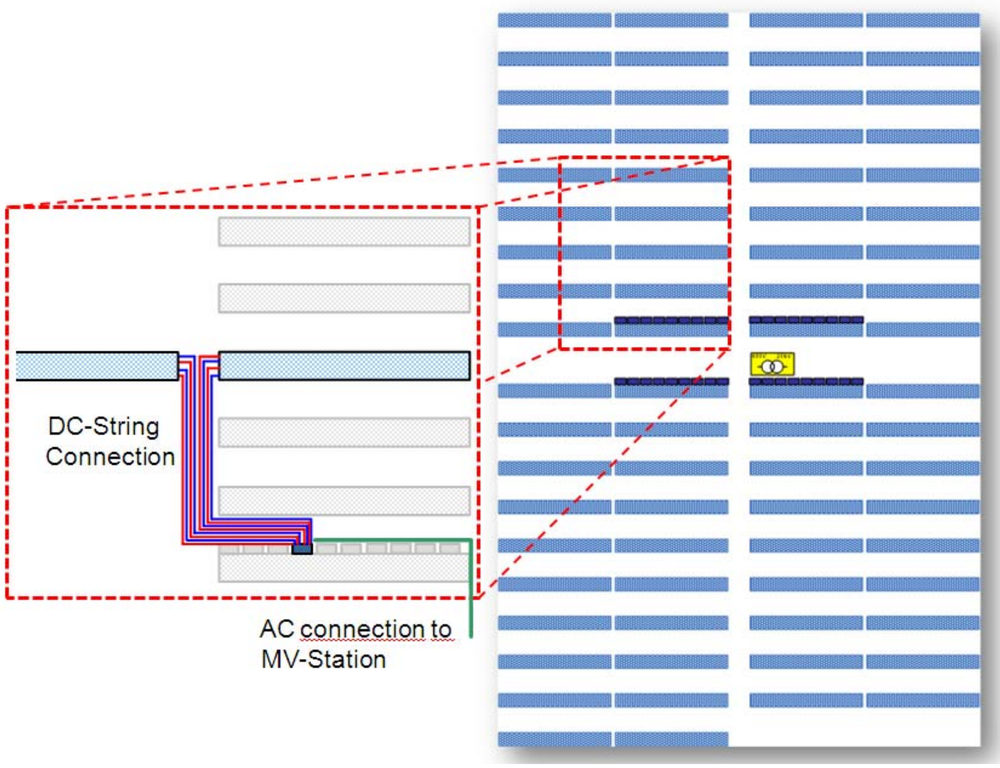


Figure 15: Inverter mounted close-by MV-Station with direct DC connection

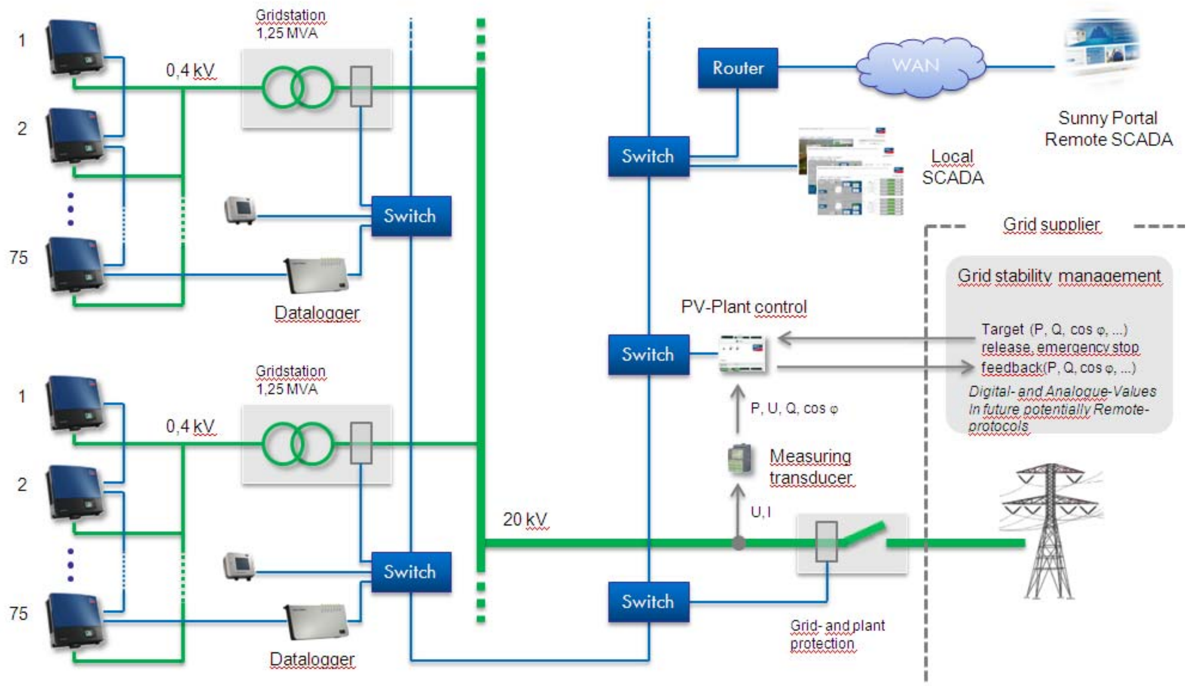


Figure 16: Example of a 100 MW PV-Plant consisting of 80 MV-Blocks with 75 Tripower STP 17000TL-10 per block.

3.5 Protection and Switchgears

3.5.1 Line circuit breaker

You must install a separate line circuit breaker for each inverter and every cable, respectively, in order to ensure that the inverter can be securely disconnected under load. Local standards and regulations must be observed when selecting the line circuit breakers.
Both the cables to be protected as well as the line circuit breakers themselves are subject to influencing factors which must be taken into account when selecting and dimensioning these. The line circuit breakers must be adapted to the ampacity of the connected cables, so they can be activated when the admissible current has been exceeded. The ampacity of a cable depends on:

- Cross-section, material (copper, aluminum) and type of cable (insulation, number of insulated conductors, etc.)
- Ambient temperature around the cable. As temperature increases, the ampacity decreases.
- Routing method for the cables. Due to the temperature dependency just mentioned, the ampacity drops when the cables cannot dissipate generated heat (routing in insulating material) or when the cables transfer heat to one another (dense routing). In outdoors routing (PV ground mounting systems, flat-roof plants) the increased environmental temperature can influence the ampacity of the cables.

When dimensioning and installing the line circuit breakers, one must observe that

- The loop impedance limits the current in case of a failure and can therefore influence the triggering time of the line circuit breaker. If the disconnection times specified in the standards cannot be maintained, an RCD must be provided as an alternative for the disconnection of the power supply.
- The line circuit breakers can warm one another up due to close placement, and this can affect their triggering behavior in such a way that they are triggered below their nominal currents. Inverters feed in their maximal current simultaneously and so they can cause faster heating of line circuit breakers lying next to each other. To avoid premature triggering, provide more space between the line circuit breakers (observe the adding factor).
- As ambient temperature increases, the triggering current in case of overload decreases. For this reason, the subdistributors in the open field should not be exposed to direct sunlight. Installation in strongly heated rooms should also be avoided.
- That fuses connected one after the other behave selectively. That means that, if there is a short-circuit, the fuse closest to it blows significantly sooner than one farther away.

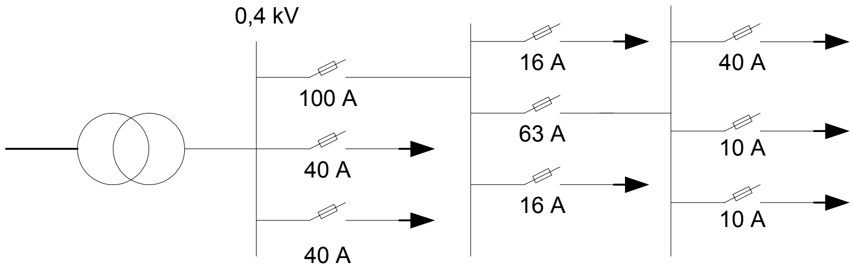


Figure 17: Protection of a low-voltage grid through staggering.

- Depending on the start behavior of the connected devices, different line circuit breaker characteristics are used (e.g., B-Characteristic: I_{Nom} x 5 = triggering current; C-Characteristic: I_{Nom} x 10 = triggering current)

A screw type fuse element, e.g., D system (Diazed) or D0 system (Neozed) is not a switch disconnector, and thus can be used as cable protection but not as a load disconnection unit. The element can be destroyed during disconnection under load. An exception are Linocur switching devices for Neozed fuses.

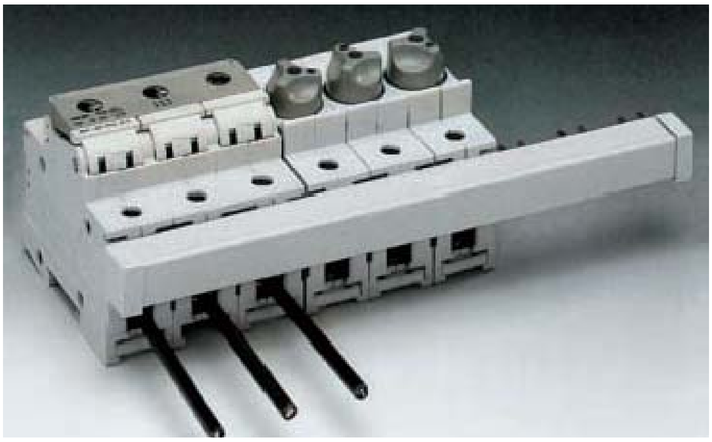


Figure 18: Linocur switching device (left, 3-pole) with interchangeable Neozed fuses.
Source: Ferraz Shawmut

Maximum permissible fuse protection for SMC and STP inverters.
(as at May 2010 – please pay attention to current information and Installation manuals)

Inverter	Maximum fuse protection (current strength)
Sunny Mini Central 4600A	40 A
Sunny Mini Central 5000A	40 A
Sunny Mini Central 6000A	40 A
Sunny Mini Central 7000HV	50 A
Sunny Mini Central 6000TL	50 A
Sunny Mini Central 7000TL	50 A
Sunny Mini Central 8000TL	50 A
Sunny Mini Central 9000TL	80 A
Sunny Mini Central 10000TL	80 A
Sunny Mini Central 11000TL	80 A
Sunny Tripower 10000TL	40 A
Sunny Tripower 12000TL	40 A
Sunny Tripower 15000TL	40 A
Sunny Tripower 17000TL	40 A

Table 4: Maximum permissible fuse protection per phase for SMC and STP devices

>> Further information: SMA TI - Line Circuit Breaker with calculation examples

3.5.2 Residual current device

All transformerless Sunny Mini Centrals and Sunny Tripower devices are equipped with an integrated residual current monitoring unit (RCMU). For clarification as to whether an additional residual current device (RCD) is necessary, one must consult the applicable local standards which deal with the protection against indirect contact.

Reasons for the use of an RCD:

- The line circuit breakers cannot fulfill the disconnection conditions for protection through automatic disconnection of the current supply (e.g., in case of excessive loop impedance).
- The utility operator requires the use of an RCD in his technical connection conditions.
- Place of installation or local conditions make the use of an RCD necessary due to other standards. For example, in installations in barns or wooden houses in Germany, an RCD with a rated differential current of at most 300 mA is prescribed for fire protection reasons, in accordance with DIN VDE 0100-482.

In accordance with country-specific standards, protection devices for disconnection are required on the AC voltage side. If the DC and AC voltage sides of the PV power supply system do not at least have a simple disconnector, residual current protector devices of type B, sensitive to both AC and DC current must be used. If it can be assured that no direct residual current can arise, other types of protection devices, e.g., of type A, are admissible.

All SMA inverters with transformers and all transformerless inverters with a residual current monitoring unit (RCMU) cannot feed in direct residual currents into the grid due to their circuit design. Therefore, the use of an RCE of type B is not required. If a residual current circuit breaker is connected in front of the inverters, a device of type A suffices.

Due to the fact that direct differential currents can appear in transformerless inverters (see 2.1 and 2.2), the rated differential current ($I\Delta_f$) of an upstream RCD must be at least 100 mA in order to avoid premature triggering during operation. In this case one must allow for a rated differential current of 100 mA for each inverter connected (e.g., with 3 inverters, the $I\Delta_f$ of the RCD is 300 mA).

>> Further information: SMA TI - Criteria for Selecting an RCD with examples

3.5.3 Overvoltage Protection

The Sunny Tripower and Sunny Mini Centrals fulfill the requirements of the overvoltage category 3 on the AC side, which corresponds to a voltage rating of protection class III (4 kV voltage pulse). However, neither measure fulfills the requirements of a comprehensive overvoltage and lightning protection. For plants in which this is required or desired, it must be accomplished through the use of external components. The inverters, being a part of the fixed installation, are operational resources and should be protected by surge protectors of type 2, or also 1 and 2, according to use. Which overvoltage protector should be used is to be determined separately by a specialist/specialist company for lightning and overvoltage protection.

Private clients (no public buildings):

In plants of up to 10 kWp a lightning protector is not mandatory. In this case, the private individual can decide whether he wants to install lightning protection.

In plants greater or equal to 10 kWp in size, the union of property insurers requires an internal and an external lightning protector. If no lightning protector is installed here, it can lead to problems with the insurer.

Public buildings (schools, hospitals, public authorities, etc.):

The corresponding building ordinance in the land in question regulates the installation of lightning protection to the required standard. The installer must dimension and carry out the lightning protection measures, or let them be carried out by a lightning protection company. The installer is liable for carrying out the installation of the lightning protection. The land's corresponding standard describes general regulations for the construction of the lightning protection installation and/or how it is integrated.

3.6 AC Distribution

AC Subdistributors

AC subdistributors combine the inverters' AC outputs by phases, include line circuit breakers and can be expanded by adding overvoltage protection if needed.

With a connection box (e.g., from Wieland), SMC inverters can be combined in groups of 3 or 6. Depending on the size of the plant, one can use several levels of subdistribution to gather all AC strings and lead them to the low-voltage main distribution.

Figure 19: Wieland connection box

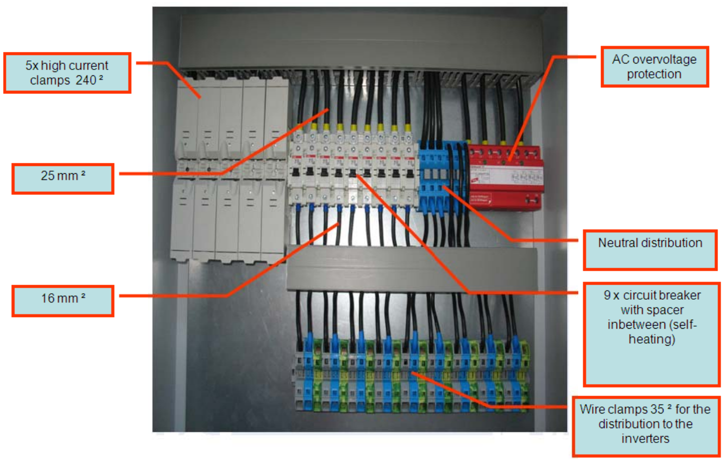


Figure 20: Possible assembly of a master distributor for 9 SMC inverters to be connected to a TNC-S grid

Low-voltage main distributor

The low-voltage main distributor (LVMD) links the inverter to the transformer station. The LVMD can be built in the following way:

- For a direct connection of the inverters, the corresponding number or line circuit breakers should be used.
- Optionally, instead of line circuit breakers you can use fuse-switch-disconnectors on copper busbars. The connection to the NH fuse switches is realized with cross sections of up to 240 mm^2.
- As additional protection, a primary NH fuse-switch-disconnector including fuse is planned for.
- If decoupling protection is required on the low-voltage side, a combination of grid monitoring relays and load-disconnecting switches are to be included according to the local regulations and standards.
- Alternatively, one can integrate a motor-driven circuit breaker with definite-time overcurrent protection and grid decoupling protection.

4 Medium-Voltage Connection

4.1 Directives

The Sunny Tripower and Sunny Mini Central classes of inverters are able to adhere to valid laws, standards and directives which apply to grid security management and grid support for medium-voltage connection. For this, the following functions are provided:

- Active power limitation
- Frequency-dependent active power limitation
- Reactive power provision
- Dynamic grid support

4.1.1 Active power limitation

In order to counter an excessive supply of energy in the grid, the supply grid operator has the right to carry out a remote reduction of the power fed into the grid. This remote control can be implemented by means of ripple control technology (via radio or the grid). By means of the SMA Power Reducer, the switching states of the potential-free relay outputs of the ripple control receiver are passed on to the inverter to limit the active power in steps (e.g., 100%, 60%, 30%, 0%).

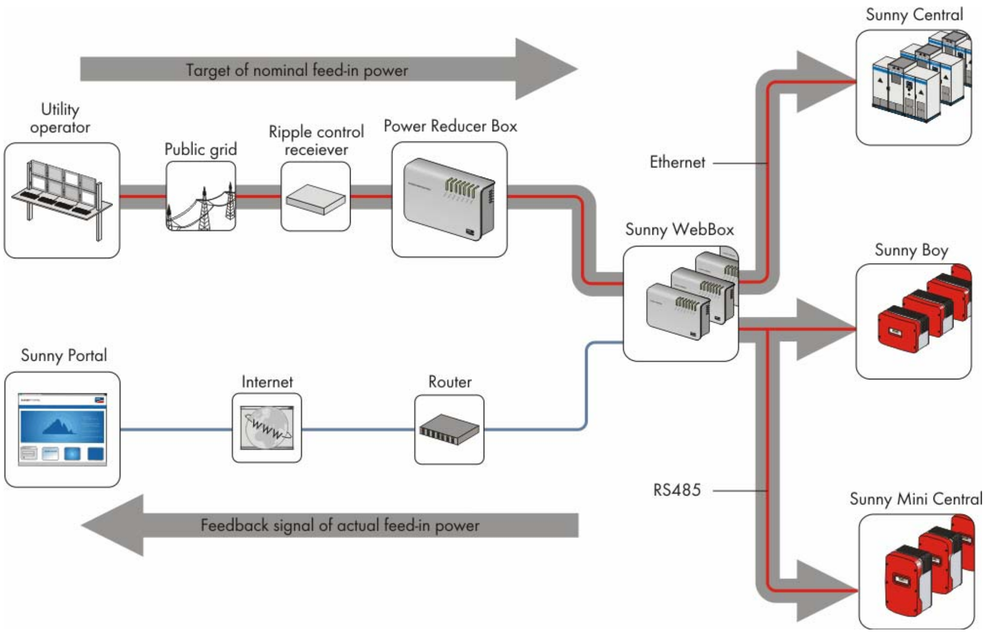


Figure 21: Active power reduction by means of the Power Reducer Box

4.1.2 Frequency-Dependent Active Power Limitation

In order to be able to react more quickly to suddenly-appearing changes/faults in the grid, in addition to the relatively slow reduction through ripple signal (reaction in minutes), frequency-dependent active power limitation is needed. The basis for this is that an oversupply in the grid can be recognized by an increasing frequency. If the frequency increases past a certain threshold value, e.g., 50.2 Hz, the active power must be reduced as a function of the frequency increase. The frequency must drop below a certain value again (50.05 Hz) before the power can increase again (drag pointer function).

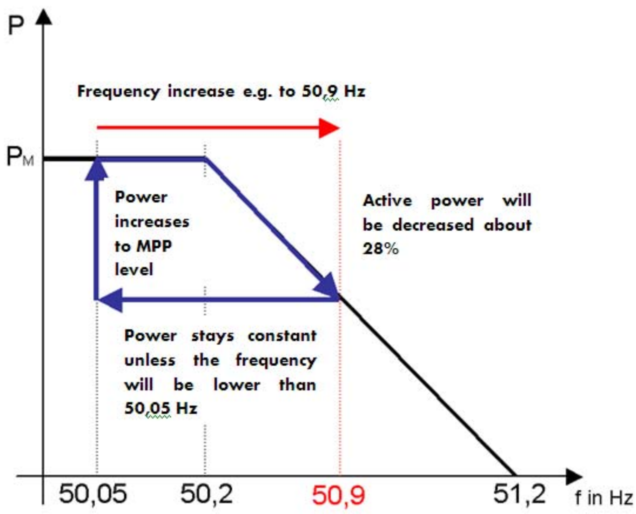


Figure 22: Example of a frequency increase to 50.9 Hz

SMA inverters reduce the current active power automatically (at the moment in which the limit value is reached) as a function of the continuing frequency increase. The corresponding parameters can be configured.

4.1.3 Reactive Power Provision

The required provision of reactive power contributes to the stabilization of the grid voltage at the interconnection point. A resistive-capacitive feed-in results in an increase in the grid voltage at the interconnection point and a resistive-inductive one does the opposite, and this can contribute to grid support in a limited way.
Here one can define different setpoints:

- **Fixed setpoint - e.g., cos φ**
  . The utility operator assigns a fixed value for cos φ or Q. The values can be set directly via the inverter parameters or via the Power Reducer Box - WebBox communication.
- **Setpoint varying in time - e.g., cos φ (t)**
  The utility operator puts out a schedule (e.g., covering a day or a year) according to which variously staggered values for cos φ or Q are to be realized. In addition one can also establish a setpoint using a communications device, e.g., ripple control, and therefore possibly by means of the Power Reducer Box.
- **Setpoint for the reactive power according to a characteristic curve, e.g., cos φ (P) or Q (U)**

  The release of capacitive or inductive reactive power is controlled as a function of the measured active power or voltage. The characteristic values of this control can be set using parameters in the inverter. This way one can, for example, avoid an increase in voltage in the presence of a high measured active power by feeding in inductive reactive power.

4.1.4 Dynamic Grid Support

Dynamic grid support requires that, if there is a critical grid situation, the plant does not disconnect itself from the grid, but that it stays on the grid under certain conditions. In addition, in fully dynamic grid support one can require that during the grid fault a reactive power is fed in. The requirements for dynamic grid support are defined by means of limit curves in the voltage / time diagram (see figure 18). It can be specified there whether a generator plant must keep feeding in, or whether it can or must disconnect if the voltage collapses down to a certain percentage of the nominal voltage during a time x. This way one can avoid, on the one hand, that a great number of generators disconnect during the grid fault, further weakening the grid, and on the other, that the voltage is supported by a reactive current during the grid fault.

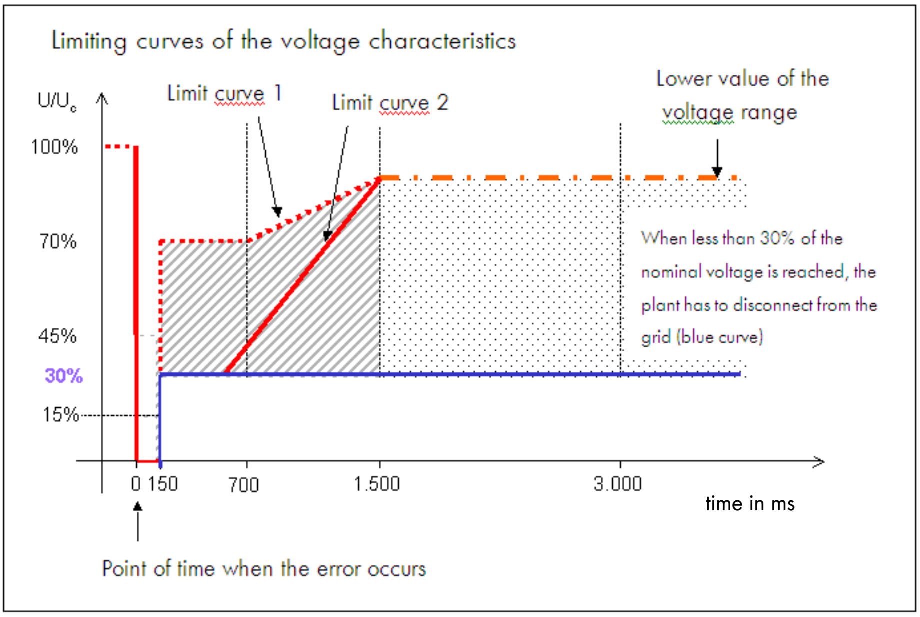


Figure 23: Limit curve shape of dynamic grid support

If a voltage collapse is corrected within less than 150 ms, the generator plant must remain on the grid and continue to feed-in. If the voltage dip is between the limit lines 1 and 2, the plant can disconnect or it can continue feeding in. In the case of grid faults which run underneath the limit curve 2 or when less than 30% of the nominal voltage is reached, the plant has to disconnect from the grid.

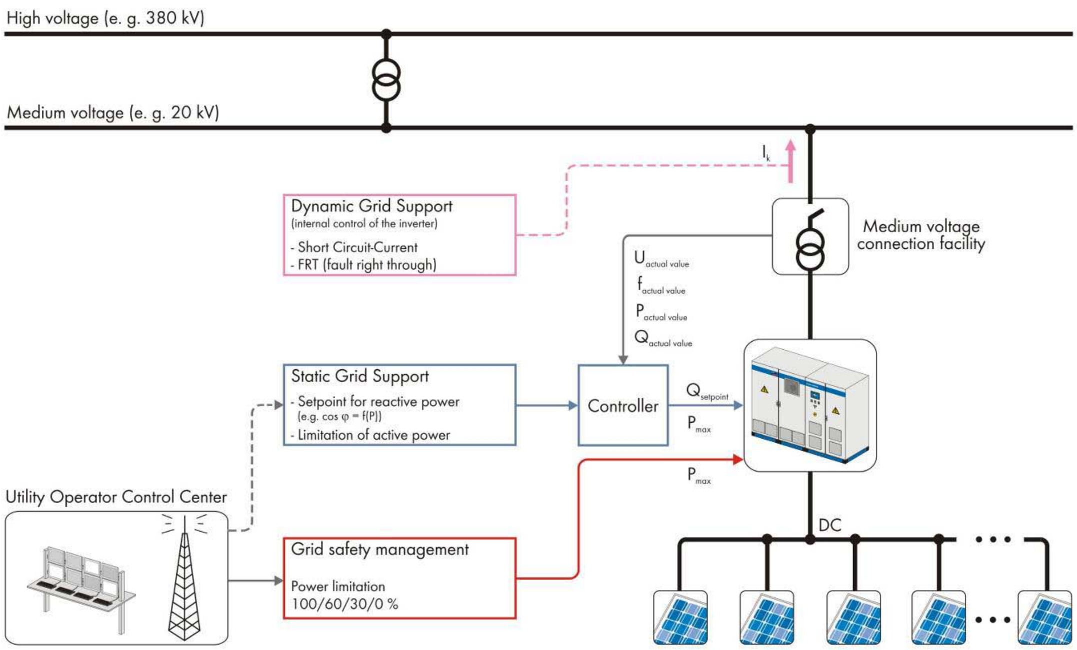


Figure 24: Graphic overview of grid security management

4.2 Plant Layout

For the construction of the connection plant the country-specific directives, the connection conditions of the utility operator and the generally valid regulations for medium-voltage plants must be observed.

The plant is to be dimensioned in order to achieve short-circuit resistance. The information needed for this, like

- initial short-circuit AC current from the utility operator's grid at the grid connection point (without the contribution of the generator plant).
- the utility operator makes available the error correction time of the main protection in the utility operator's grid at the grid connection point.

is provided by the utility operator.

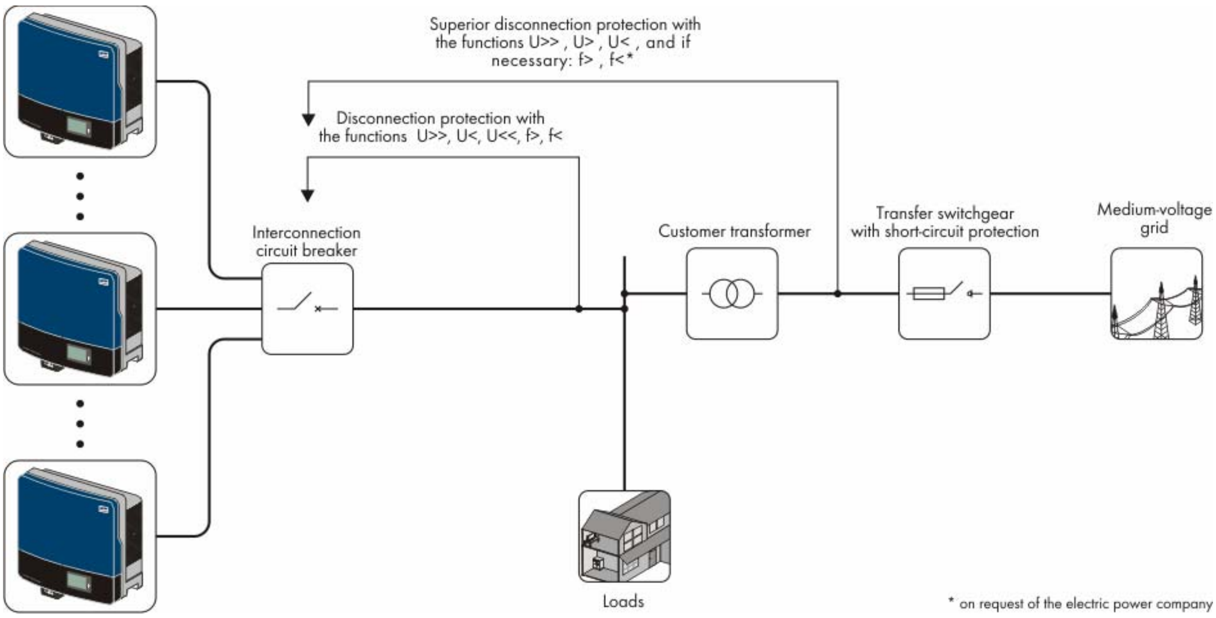


Figure 25: Schematic circuit diagram of a generating plant with a switch-disconnector

The connection of the generator plant to the medium-voltage grid takes place by means of a switchgear at the connection point which has to be accessible for the utility operator at all times and which must be equipped as a switching device with at least load switching capacity and a disconnection point. Protection devices must be provided in the transmission station which could disconnect a faulty grid or the entire station. In plants with great power (> 1MVA) a line power switch is required.

4.2.1 Switchgears

Due to the high transmission power, the switchgears in the medium-voltage and high-voltage range are exposed to particularly high stress. Therefore the requirements for the switches are high. The standards pertaining to the high-voltage switching devices must be observed. According to the requirements, one distinguishes between the following switching devices:

- **Disconnector** to create a visible separation between the disconnected plant portions and those under tension.
- **Switch-disconnector** to switch operational currents on and off during normal operation at a power factor of cos $\varphi \geq 0.65$.
- **Power switch** for switching on and off operational and short-circuit currents.
- **High tension / high capacity fuses** (HH-fuses) purely as protective devices against the effects of short-circuits.

To dimension the switching devices you can use rated dimensions like rated voltage, rated current, rated power frequency withstand voltage and rated short-time withstand current (usually with 3 s as reference). When dimensioning the switchgear at the connection point, short-circuit currents from both the grid and the generator plant have to be taken into account.

The generator plant is connected to the grid or to the rest of the client's plant (transformer) with a section switch. The prescribed protection devices (see chapter 4.2.2) act on the section switch, which must at least have circuit-breaking capacity, in order to be able to disconnect the plant from the grid manually in case of a fault. The section switch must ensure 3-pole galvanic isolation. Suitable for this are, for example:

- Power switch
- fuse-switch-disconnector
- motor overload switch
- Weld-proof contactor with load-switching capability and upstream short-circuit protection

4.2.2 Protection Devices

The required protection devices have the purpose of disconnecting the plant from the grid automatically as soon as the prescribed grid-compliant limits have been exceeded. Decoupling protection equipment is installed at the generator units and/or at the interconnection point. The required parameters are measured using transducers on the low-voltage and/or the medium-voltage side and they are evaluated by means of decoupling protection relays.

The following functions are to be realized at the generator units:

- Voltage increase protection U>>
- Voltage decrease protection U< and U<<
- Frequency increase protection f>
- Frequency loss protection f<

The following setting values are recommended by, for example, BDEW (Federal Association of German Energy and Water Industries)[1]:

Function	Setting range of the protection relay	Recommended protection relay settings	
Rise-in-voltage protection U>>	1.00 – 1.30 U_n	1.15 U_{NS}	≤ 100 ms
Under-voltage protection U<	0.10 – 1.00 U_n	0.80 U_{NS}	1 s
Under-voltage protection U<<	0.10 – 1.00 U_n	0.45 U_{NS}	300 ms
Rise-in-frequency protection f>	50.0 – 52.0 Hz	51.5 Hz	≤ 100 ms
Under-frequency protection f<	47.5 – 50 Hz	47.5 Hz	≤ 100 ms

Table 5: Recommended settings for protection at the generator units[2]

The protection relay influences the section switch.

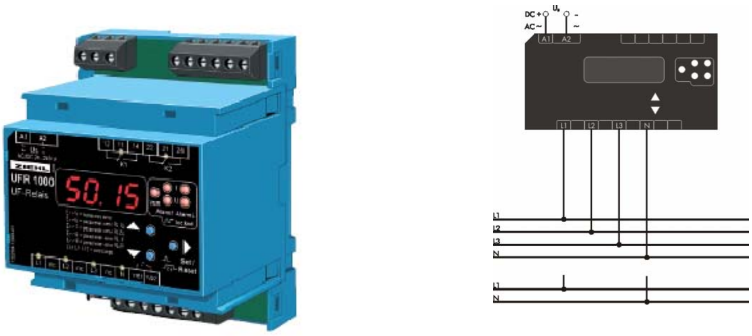


Figure 26: Example of a voltage/frequency relay by Ziehl (UFR1000)

[1]Bundesverband der Energie- und Wasserwirtschaft in Deutschland (Federal Association for Energy and Water in Germany)

[2]See Technical Directive "Generating Plants Connected to the Medium-Voltage Network" BDEW (Federal Association of German Energy and Water Industries) 2008 chapter 3.2.3.3

If a decoupling protection device is required at the transfer point by the utility operator, the following functions are to be implemented:

- Voltage decrease protection U<
- Voltage increase protection U> and U>>
- Reactive power / undervoltage protection $Q_{>}$ & U<

The following setting values are recommended by, for example, BDEW:

Function	***Setting range of the protection relay***	***recommended settings of protection relays***	
rise-in-voltage protection U>>	1.00 – 1.30 U_n	1.15 U_c	≤ 100 ms
rise-in-voltage protection U>	1.00 – 1.30 U_n	1.08 U_c	1 min
under-voltage protection U<	0.10 – 1.00 U_n	0.8 U_c	2.7 s
reactive power / under-voltage protection *($Q_{\rightarrow}$ & U<)*	0.70 – 1.00 U_n	0.85 U_c	t = 0.5 s

Table 6: Recommended settings for protection at the interconnection point[1]

The decoupling protection devices have an effect on the power switch at the transfer point or on the section switch.
The voltage protection devices must generally be implemented in triple-phase versions and the voltage should be measured between the phase conductors. Protection devices for frequency reduction and increase can be implemented single-phase. The quantity to be measured should be the voltage between two outer cables.

4.2.3 Remote Control

The generator plant is to be integrated into the utility operator's remote control system upon his request. This includes among others:

- Remote control of the power switch in case of critical grid situations
- Active power limitation
- Reactive power provision

The information used to analyze the plant status through the control systems is to be made available by the grid subscriber.

[1]See Technical Directive ""Generating Plants Connected to the Medium-Voltage Network" BDEW (Federal Association of German Energy and Water Industries) Chapter 3.2.3.3

4.2.4 Transformers

The transformers used must comply with country-specific standards and can be of the following types:

- Oil-filled distributor transformers[1]
- Dry-type transformers[2]

For the supply voltage and the transformation ratio consult the utility operator. In a decentralized plant, the voltage on the low-voltage side is 3 x 230/400V. The neutral conductor on the low-voltage side should be lead outward at the transformer. On the following table you can find recommended transformers in standard versions.

Power	400 kVA	630 kVA	800 kVA	1000 kVA	1250 kVA	1600 kVA
Type	Distributor transformer					
Vector group	Dyn11					
Short-circuit impedance	4%	4%	6%	6%	6%	6%
Load losses (These values correspond to C_k)	4600 W	6500 W	8400 W	10500 W	13500 W	17000 W
Open-circuit losses (These values correspond to C_0)	610 W	860 W	930 W	1100 W	1350 W	1700 W
Loss class (standard)	C_kC_0					
Loss class (optional)	C_kC_0 -30%					
Voltage on high voltage side	20kV					
Tap area on high voltage side	± 2 x 2.5%					
Voltage on undervoltage side	3AC 230/400V					
Connection on high voltage side	Outer cone plug sockets					
Connection on undervoltage side	Threaded bolts with terminal links					
Installation altitude	≤ 1000m					
Maximum medium ambient temperature	40°C					
Permissible overtemperatures (winding/ oil)	65°C / 60°C					
Ambient temperature	-20°C .. +55°C					
Frequency	50 HZ					
Accessories	Dial thermometer for warning and disconnection					

Table 7: Transformer specifications for different power levels

[1]Germany/Europe: DIN EN 50464-1 /40/
[2]Germany: DIN 42523-1 /41/

4.3 Compact Station

A non walk-in compact station offers the connection possibility for string inverters (SMC and Tripower) to the medium-voltage grid. The station is divided into three areas: low-voltage, transformer and medium-voltage. The low-voltage area houses the AC connection of the inverter in the form of a low-voltage main distributor, a communication enclosure for monitoring equipment (COM-B) and a decoupling protection relay with a corresponding fuse-switch-disconnector. In the transformer area there are distribution transformers provided in the following eligible power classes: 400 kVA, 630 kVA, 800 kVA, 1000 kVA, 1250 kVA and 1600 kVA. The medium-voltage area can be equipped optionally with a medium-voltage switchgear in a string or a ring version.

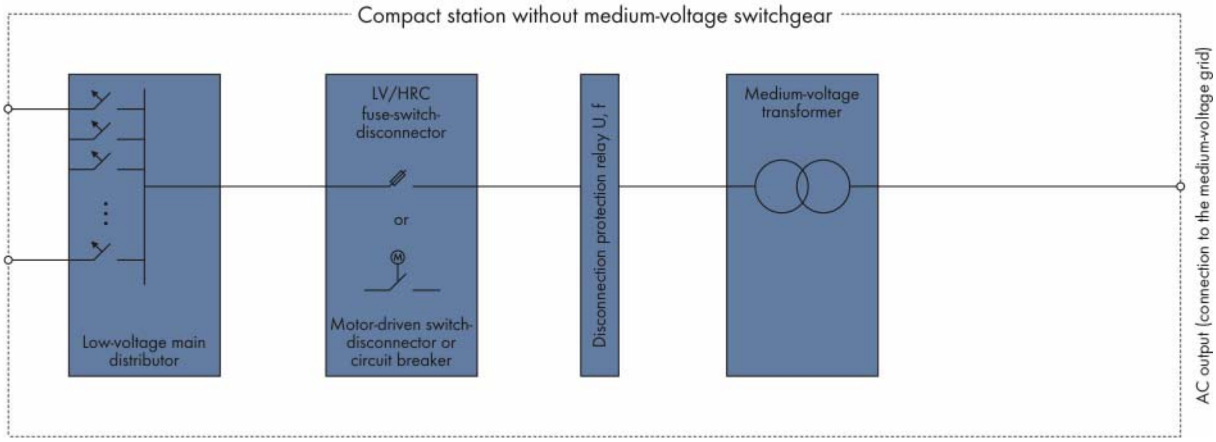


Figure 27: Block circuit diagram of the compact station without medium-voltage switchgear

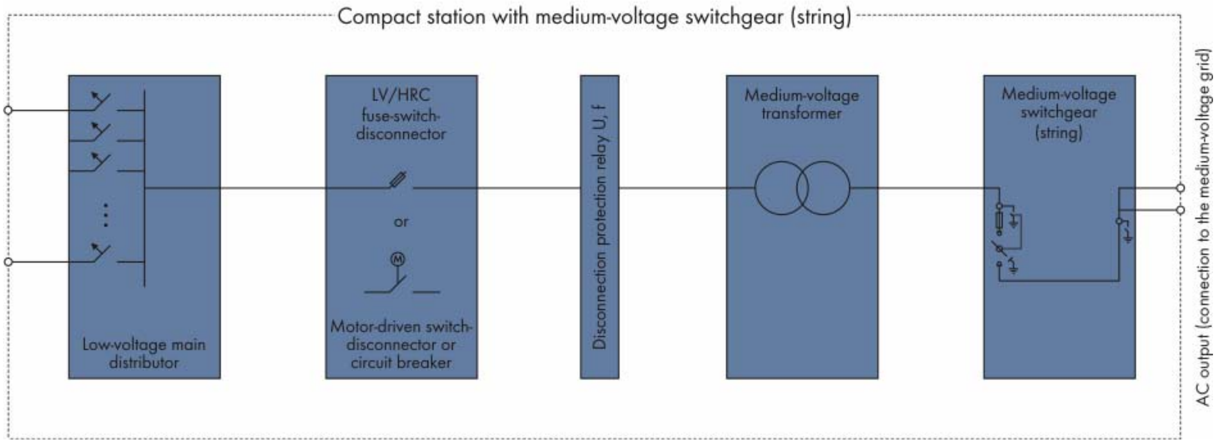


Figure 28: Block circuit diagram of the compact station with medium-voltage switchgear (string)

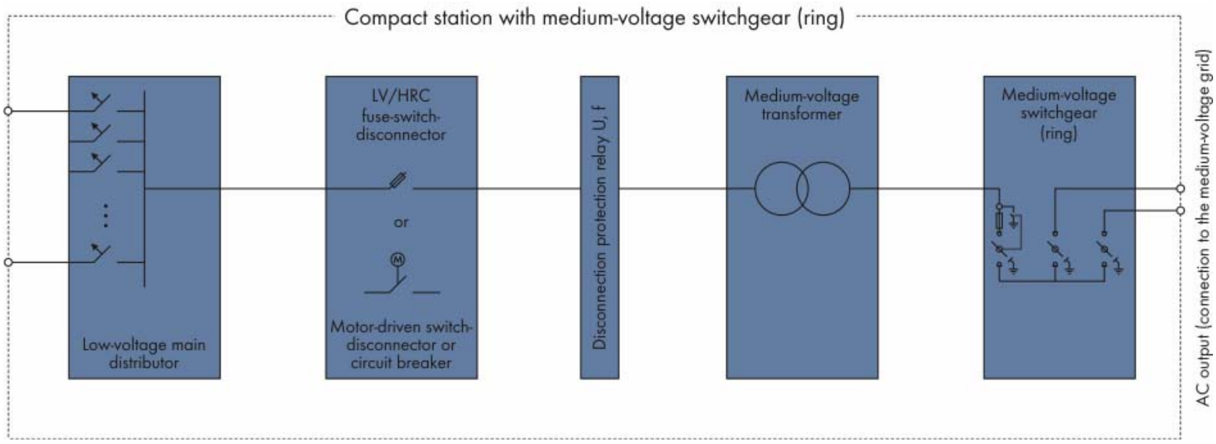


Figure 29: Block circuit diagram of the compact station with medium-voltage switchgear (ring)

Depending on the requirements, the connection of the individual stations with medium-voltage switchgears should be done in 2 (string) or 3 (ring) sections.

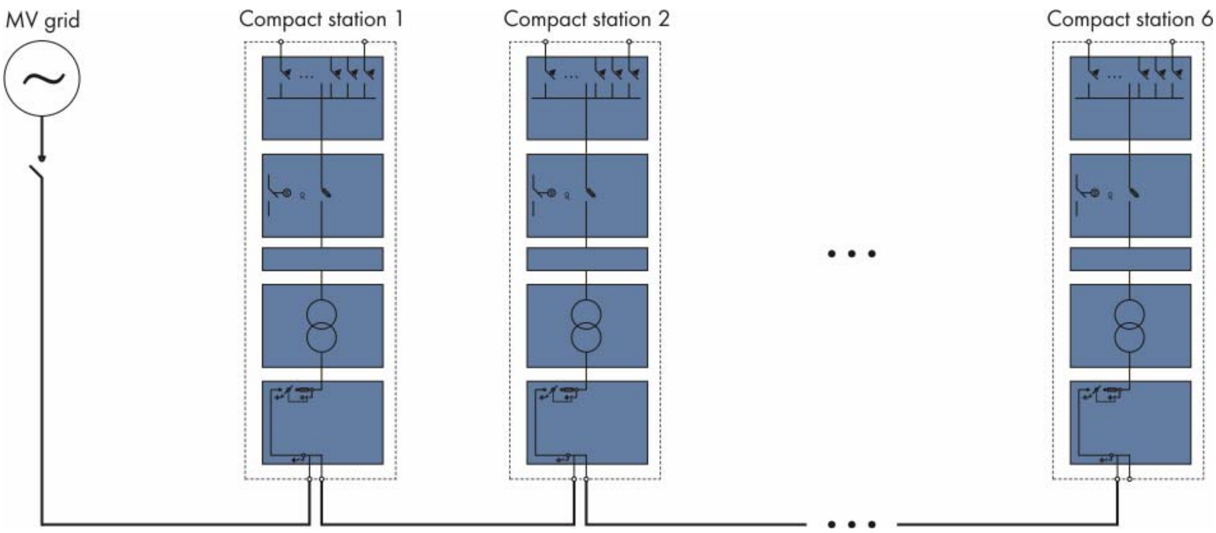


Figure 30: String connection (2-section) of 6 compact stations

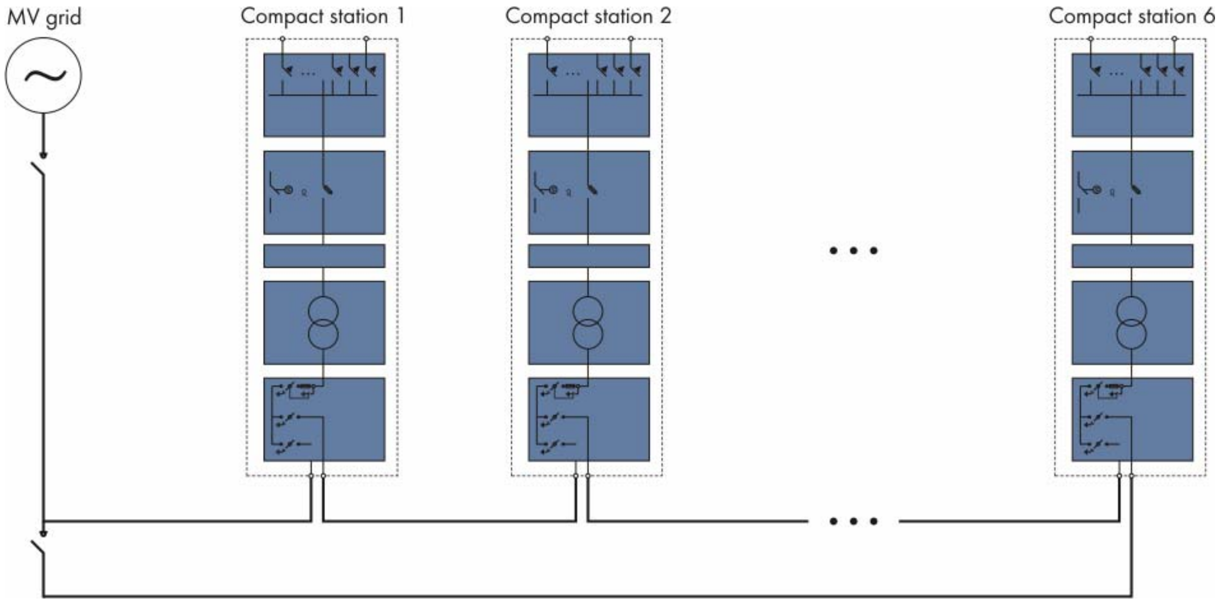


Figure 31: Ring connection (3-section) of 6 compact stations.

The string connection stands out due to low investment costs. However, if a station is disconnected from the string, all stations behind it are disconnected from the grid too. With the ring connection there is greater plant availability, since each station can be separated from the medium-voltage grid individually.

If the inverters are directly connected to the compact station, a corresponding number of line circuit breakers or, optionally, of fuse switches, is required in the low-voltage main distributor. The connection is made with a NYY-J 5 x 16 mm² cable.

Station 400 kVA		27 Line circuit breakers, 3-pole B 40 A
	or	5 x NH1, 3-pole, on Cu-busbar ≥ 40 x 10 mm
Station 630 kVA		42 Line circuit breakers, 3-pole B 40 A
	or	8 x NH1, 3-pole, on Cu-busbar ≥ 60 x 10 mm
Station 800 kVA		54 Line circuit breakers, 3-pole B 40 A
	or	10 x NH1, 3-pole, on Cu-busbar ≥ 80 x 10 mm
Station 1000 kVA		67 Line circuit breakers, 3-pole B 40 A
	or	12 x NH1, 3-pole, on Cu-busbar ≥ 100 x 10 mm

Table 8: Example of low-voltage distribution with connection of Sunny Tripower 15000TL

5 Grid Stability Management

5.1 Plant Control

The following grid management functions are possible with the aid of the Power Reducer Box:

- Reduction of the feed-in power upon request. The 4 digital voltage-free inputs available can activate up to 16 states. The necessary input signals are transmitted using ripple control signals (via radio or cable) by the energy provider. This way, a stepwise reduction of the active power is possible.
- Reactive power setpoint by setting a fixed cos φ or a fixed reactive power value (as a percentage of the maximum possible reactive power) Control takes place via a signal to the 4 digital inputs.

Function Overview of the Power Reducer Box

- integrated web server (for configuration of the Power Reducer Box).
- Log book in which every event is saved along with a time stamp.
- HTTP download of the events in csv format.
- Support of up to 50 Sunny WebBox devices.
- Saving of events onto SD card.

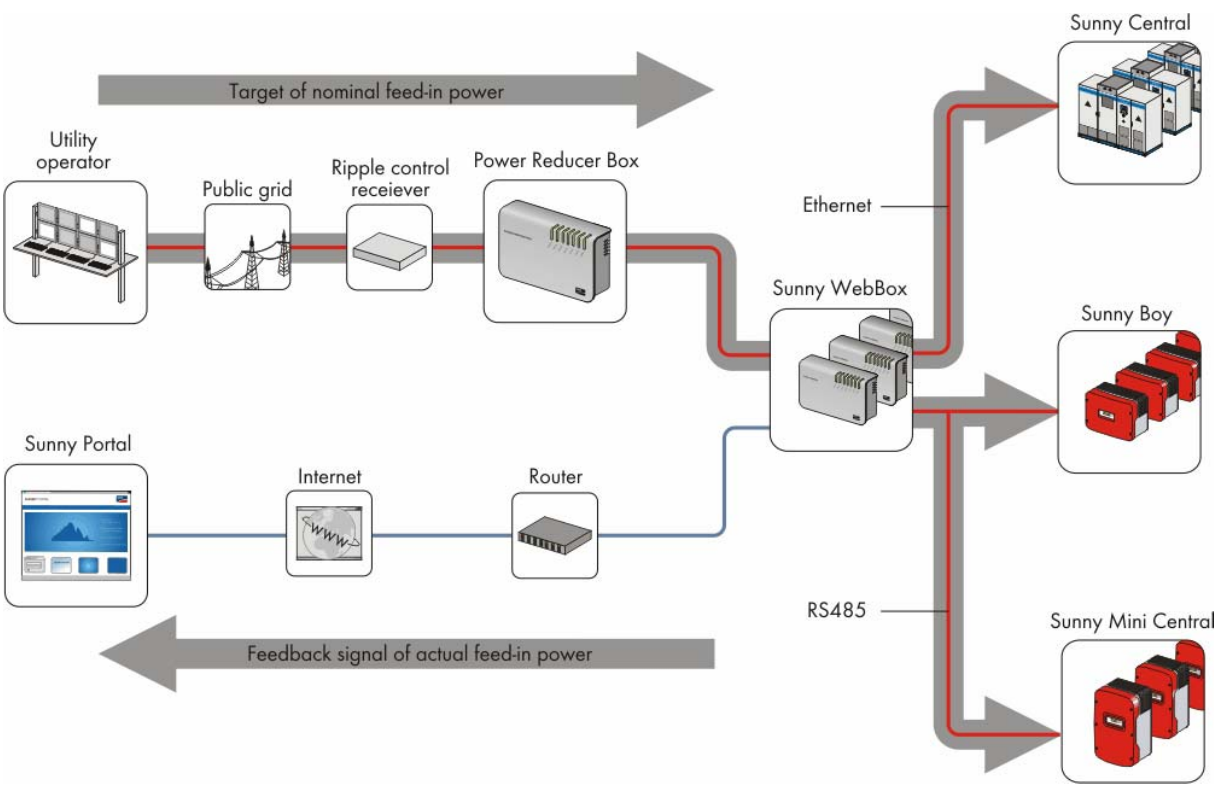


Figure 32: System configuration with Power Reducer Box

Data cable specifications:

RS485 for SB, SMC and STP	Twisted cable LiYCY 2 x 2 x 0.25 mm2
Cable Power Reducer Box - signal circuit	Twisted cable Li-2YCYv 4 x 2 x 0.5 mm²
Ethernet	< 100 m CAT 5/6 > 100 m < 2 km fiber optical cable (multi mode) > 2 km < 15 km fiber optical cable (single mode)

Other grid security management functions are installed directly in the inverter.
(as at May 2010 – please pay attention to current information and Installation manuals)

Inverters without transformer		SMC 9000TL-10 SMC 10000TL-10 SMC 11000TL-10	SMC 9000TLRP-10 SMC 10000TLRP-10 SMC 11000TLRP-10	STP 10000TL-10 STP 12000TL-10 STP 15000TL-10 STP 17000TL-10
Inverters with transformer			SMC 7000HV-11	
Reduction of feed-in power as required (with Power Reducer Box)		✓	✓	✓
Active power reduction via overfrequency		✓	✓	✓
Reactive power: fixed setting	cos φ	✗	✓	✓
	Q	✗	✗	✓
Reactive power: set point via Power Reducer Box		✗	✓	✓
Reactive power: characteristic curve(s) in the device Cos φ (P), Q(U)		✗	✗	✓
Limited Dynamic Grid Support		✗	✓	✓
Complete dynamic grid support		✗	✗	✓

Table 9: Overview of the grid management possibilities of selected SMC and STP devices

Especially in larger plants it is often desired to detect and control the PV power plant by means of a higher-level control system (SCADA, CRM). With the aid of the SMA OPC server there is the possibility of establishing a standardized OPC connection between the control center and the SMA devices.

Communication via Sunny WebBox	Ethernet, TCP/IP
Max. number of Sunny WebBox units	50
Communication with the control station client	Ethernet, TCP/IP
Communication standard	OPC-DA (Windows), OPC-XML-DA (Linux)
Approved clients	National Instruments LabView; Siemens WinCC; Wonderware Intouch
Two-way data exchange	Parameter; Measured values

Table 10: Specifications of the OPC server

The OPC server acts as an interface only Data queries, data recording and control commands must be activated activelly by the OPC client.

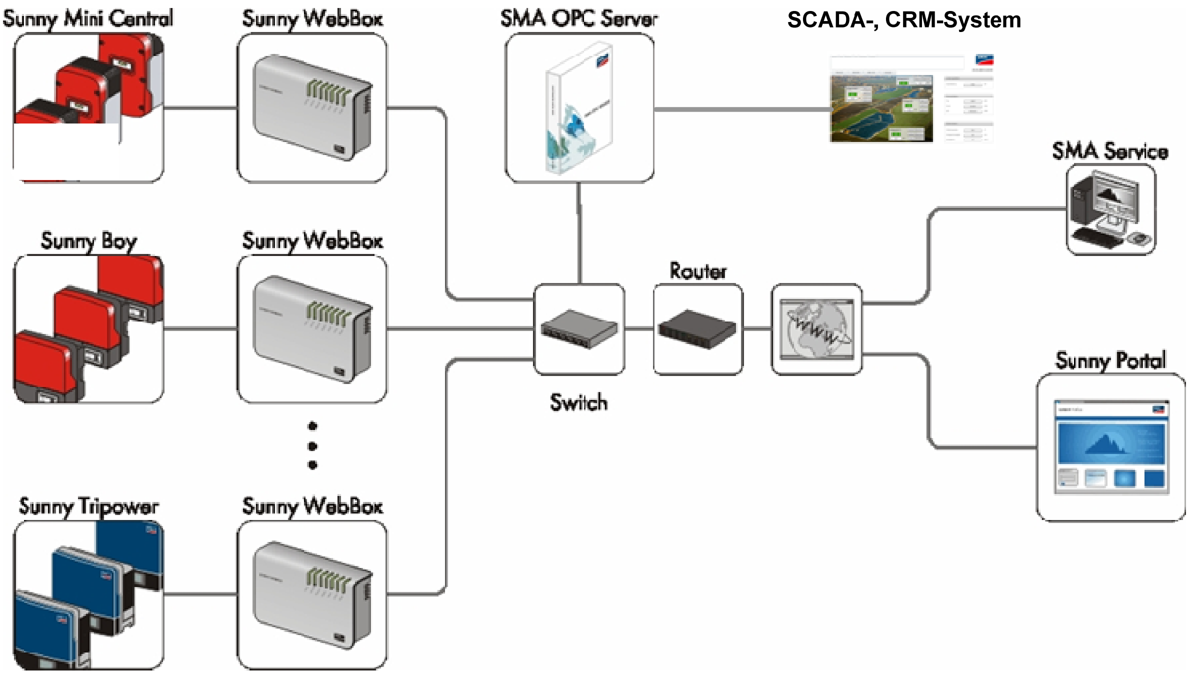


Figure 33: Plant monitoring with an OPC server interface

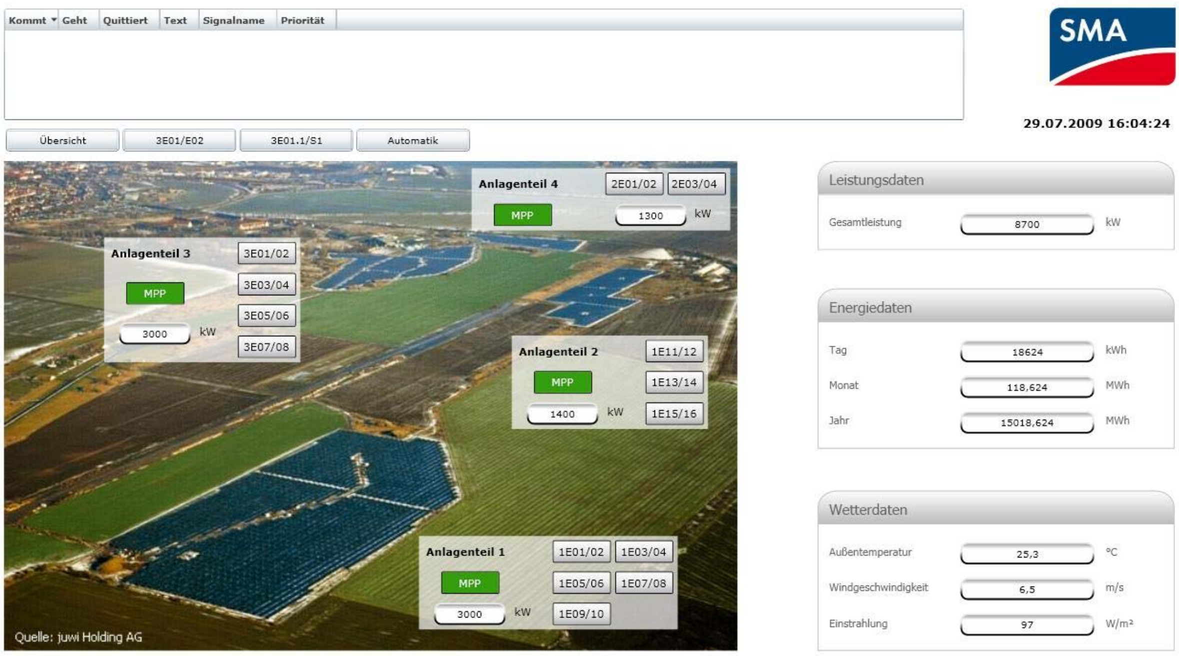


Figure 34: Example of an OPC client for plant monitoring

5.2 Plant Examples

Specifications for Control Systems in Plant A

- NSM (Grid stability management) in accordance with EEG §6
- Interfaces to the utility operator:
  - o Digital IN: NSM (grid stability management) in accordance with EEG (K1 - K4 for 0, 30, 60, 100% P_{AV})
- Setting of new NSM (grid stability management) setpoints within one minute
- Feed-in management for Q(U) regulation at the grid connection point
- Voltage measurement at the feed-in point
- 15 min averaging via U to avoid fluctuations
- Analog/Digital conversion via SPS solution (e.g., by OLTEC)
- Cos φ setpoints are sent from the Power Reducer Box through the Sunny WebBox to the corresponding inverters
- 14 cos φ values between 0.9 $_{lagging}$ and 0.9 $_{leading}$ are configurable in the Power Reducer Box
- Deadband: 20 kV +/- 1 % (cosj = 1)

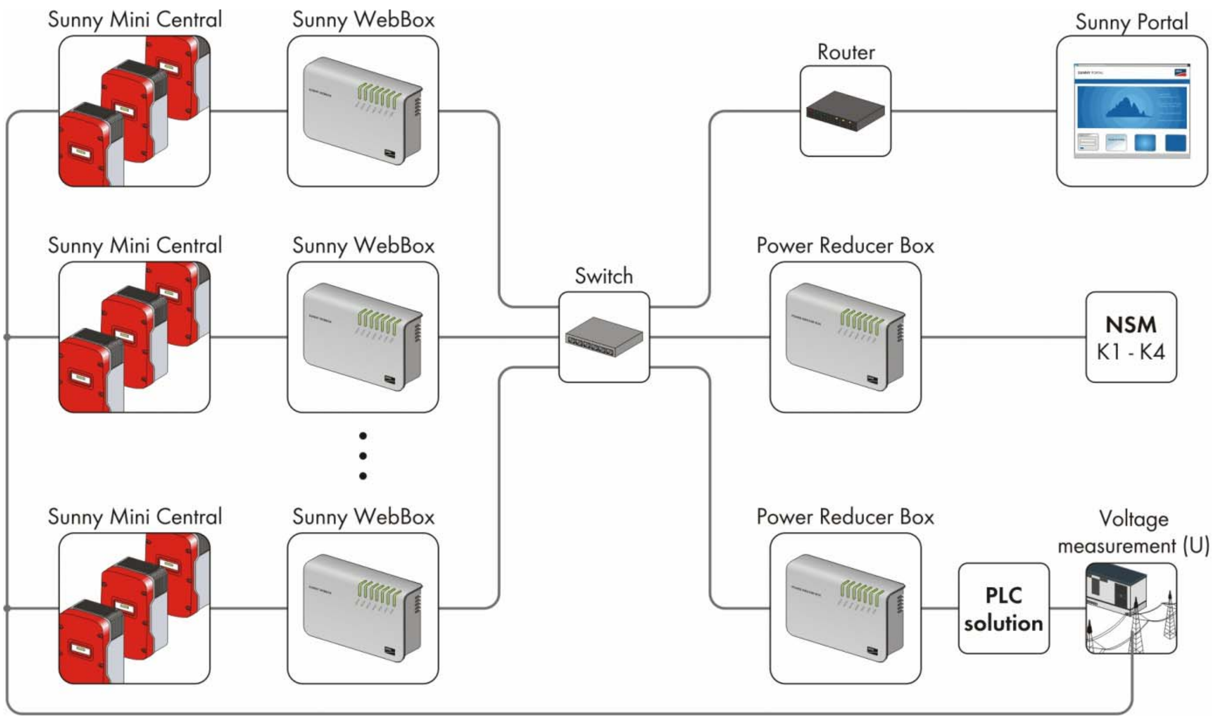


Figure 35: Process control systems Plant A

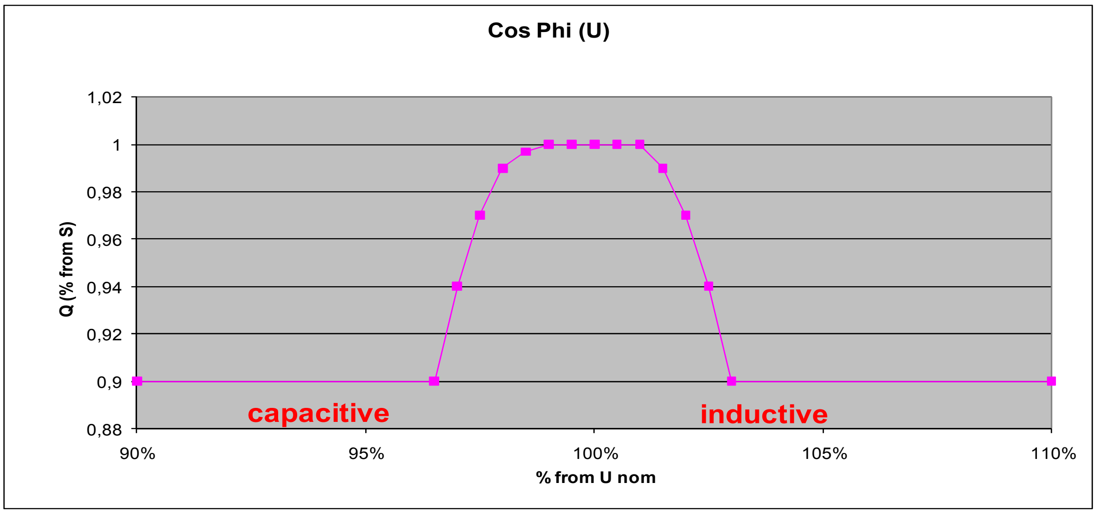


Figure 36: Linear allocation of grid voltage to cos φ of plant A

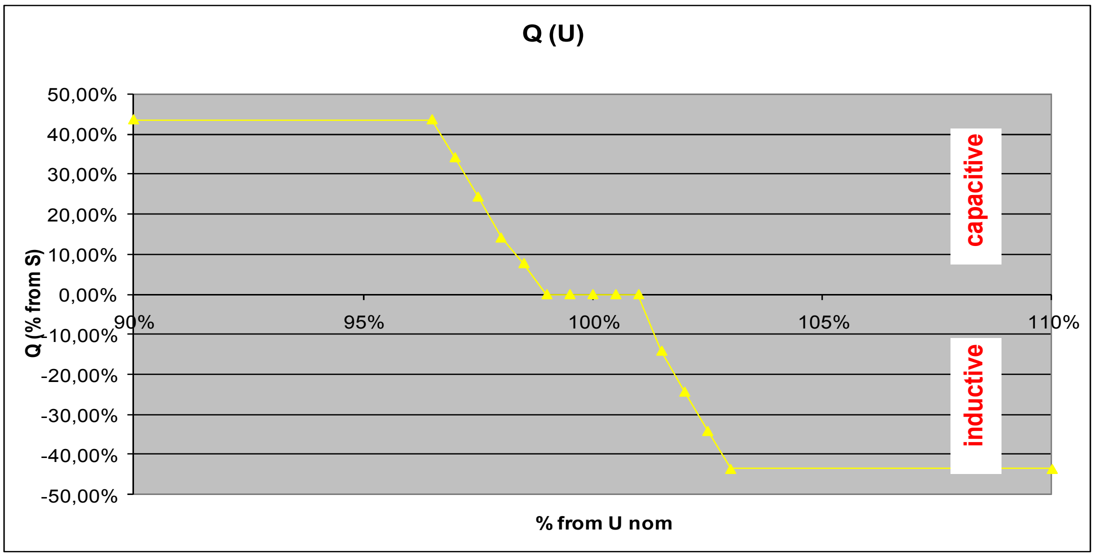


Figure 37: Linear allocation of grid voltage to Q(U) of plant A

Requirements for Control Systems in Plant B

- Feed-in management for PV plants > 100 kW P_{AV}
  - Limitation of active power (§6 EEG)
  - Setpoints for cos φ
  - EMERGENCY-STOP
  - Confirmation of all commands
- Transformer station and PV plant are connected via an fibre-optic path
- Process data interfaces:
  - 4 digital inputs active power limitation at: 0%, 30%, 60%, 100% P_{AV}
  - 3 digital inputs reactive power operation cos φ: 0.9 leading./0.9 lagging./dyn. con φ (U)
  - 1 digital input EMERGENCY-STOP
  - 8 digital outputs response to all commands
- Pulse duration of all signals and responses: 500 ms

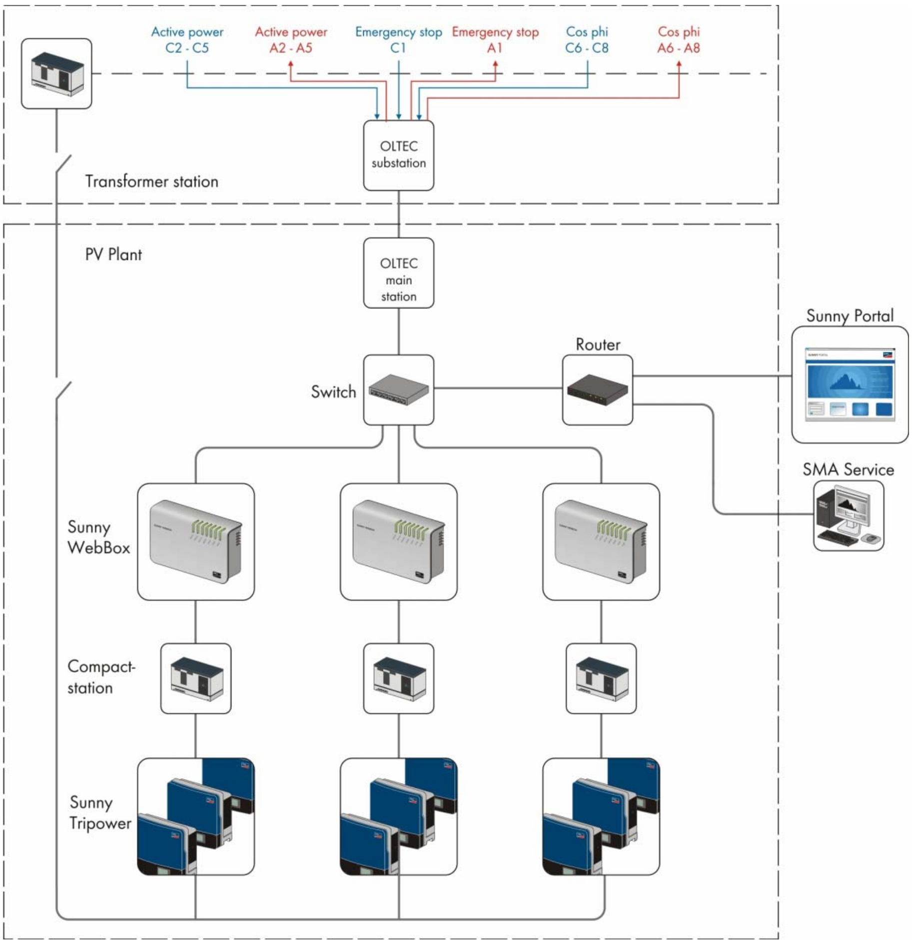


Figure 38: Process control systems Plant B

Communications Concept for the OLTEC PV Control Systems Plant B

- Command processing
  Commands are read through the digital inputs of the substation (SS), transmitted to the main station (MS), they are processed and they are released again.
  - The command "EMERGENCY-STOP" is transmitted immediately and simultaneously to all inverter stations through a copper wire used solely for this purpose.
  - All other commands are transmitted to the Sunny WebBoxes as an RPC command
  - Max. time delay for "EMERGENCY-STOP": 50 ms
  - Max. time delay for the remaining commands: < 1 s
  - The sampling rates of the digital inputs can be different.
  - Fast grid disconnection (< 1 s) of the inverter in case of "EMERGENCY-STOP".
  - Setting of the required operational values on the grid -connection point within 1 minute
- Command response:
  - Execution of the command "EMERGENCY STOP" is immediately signalized (after switching the relay in the MS) through a relay in the SS
  - The execution of the RPC command is signalized at the corresponding output of the SS after the "OK" of all WebBoxes has been carried out
- The MS must have two Ethernet controllers to keep traffic which comes up after rapid sampling of the inputs away
- The MS must offer the possibility of remote maintenance

6 Applicable Standards

(as at May 2010 – please pay attention to current/local standards and regulations)

Standard	Name
IEC 62271-100	High-voltage alternating current circuit breakers
IEC 62271-200	AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV
IEC 62271-202	High voltage/low voltage prefabricated substation
IEC 60694	Common specifications for high-voltage switching device standards
IEC 60529	Degrees of protection provided by enclosures (IP code)
IEC 60364-4-41	Installing low-voltage plants - Electric shock protection measures
DIN VED 100-712 IEC 60364-7-712	Requirements for special installations or locations Solar photovoltaic (PV) power supply systems
IEC 60439	Low-voltage switchgear and controlgear assemblies
EN 50178	Electronic equipment for use in power installations
IEC 60270	High-voltage test techniques – Partial discharge measurements
IEC 60076	Power transformers
EN 60721	Classification of environmental conditions
DIN VDE 0126-1-1	Automatic disconnection device between a grid parallel power-generating system and the public low voltage grid.
DIN VDE 0100-410	Construction of electric power installations with nominal voltages of up to 1000 V
DIN EN 61646	Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval
DIN IEC 61215	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval
IEC 60417	Symbols for identification of protection ratings
IEC 60309	Plugs, socket-outlets and couplers for industrial purposes