MAKING MODERN LIVING POSSIBLE

Concept Paper

String inverters for PV power plants

Crystalline Modules

May 2009

SOLAR INVERTERS

Table of Contents

Concept paper - String inverters for PV power plants

1 Introduction – Executive Summary

This concept paper will present new ideas of how to utilise string inverters in large PV plants.

It is well known that there is a coupling between inverter size and specific cost in €/kW. Therefore, when creating state of the art PV plants in the multi MW range the norm has been to utilise as large inverters as possible in the effort to drive down the investment cost. Today, central inverters are available up to a power level between 1 and 2 MW. However, this development trend towards larger and larger inverters is driving external costs higher.

The inherent modular nature of PV modules (largest module is still below 500W) means that a PV plant of any size is modular. Hence, it makes sense to look at alternative ways to structure a PV plant.

By using string inverters as a modular element in the plant, the built-in functionalities of the string inverters make many of the additional functions that are needed when applying a central inverter station superfluous.

String inverters of today offer the major advantages of central inverters such as high DC system voltage range and three-phased output while still maintaining the high efficiencies. This leads to reduced losses in both AC and DC cabling assuring higher yield. A large number of maximum power point trackers ensure that more power from the panels is utilised. Additionally, string combiners and external string monitoring are not required thus making simple cabling possible.

Using compact transformer stations to connect the string inverters to the Medium Voltage grid means that both transformer stations and inverters can be placed amongst the PV module substructures with little influence. Furthermore compact transformer stations and string inverters are easy to install and have short lead times as they are commonly used.

Special training is not required to install, maintain or exchange string inverters, whereby service contracts known from central inverters can be avoided. By omitting junction boxes, service on the DC side is also avoided.

This paper will highlight why string inverters are an attractive alternative to central inverters in power plants. This is done by means of an example of a 10 MWp plant in central Europe with 15 identical quadratic PV fields, 15 individual 630 kVA transformer stations and 15x42 TripleLynx inverters.

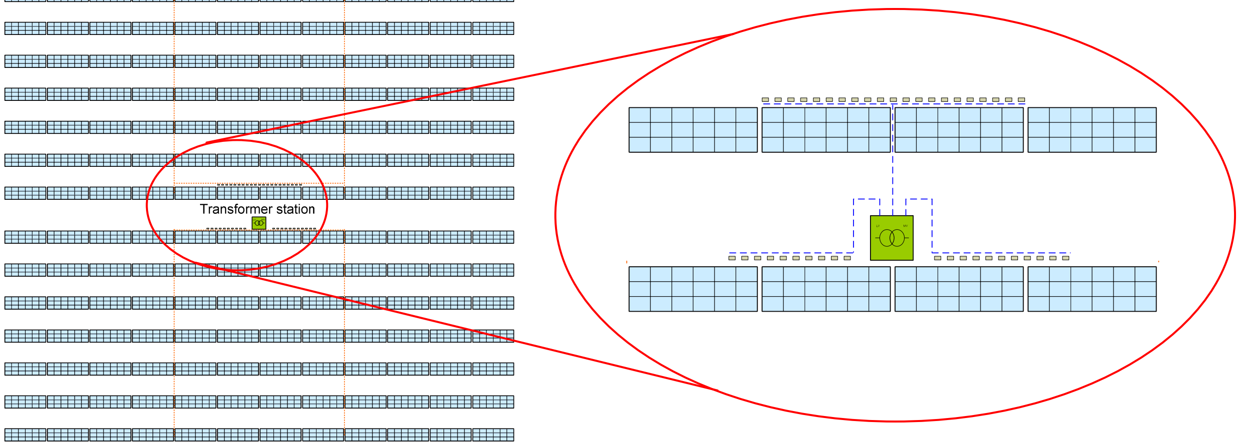


Figure 1 PV field layout based on crystalline modules
This example shows a layout with 14 rows of substructures each with 12 substructures per row (approx. 125 m x 125 m). Each substructure is fitted with 18 modules placed in landscape orientation in 3 rows.

2 Choosing the optimum layout of a power plant

The objective when planning a PV plant is to obtain a high return on investment. On one hand this requires the use of inverters and medium voltage transformers with optimum efficiency, focus on limitation of cable loss and losses due to shading, as well as detailed plant monitoring.
On the other hand planning, material and installation costs should be reduced as much as possible.

2.1 Quadratic PV fields

The use of cost efficient compact transformer stations that can be placed centrally in quadratic PV fields, results in minimisation of cable loss on the DC side and on the AC low voltage side as cable length between modules, inverter and transformer is minimised. See figure 1 PV field layout.

By using inverters that can handle 1000 V input; junction boxes and a number of string combiners can be omitted. The DC cables are laid directly from the string of modules to the inverter.

A 630 kVA transformer station can have 42 inverters connected directly and the necessary switchgear including the low voltage distributor fit into the low voltage area of the transformer station.

Additionally, 665 kWp PV fields of modular design are profitably erected in larger numbers.

See appendix A for an example of suggested wiring.
Subsequently, the advantages are addressed in more detail:

2.1.1 Advantages on the DC side

The high max. and low min. DC voltage of the string inverters permits a string power of 5.28 kWp (when connecting 220 Wp modules that have 60 cells per module). The accordingly reduced number of strings in relation to power reduces cable and installation expenses significantly.

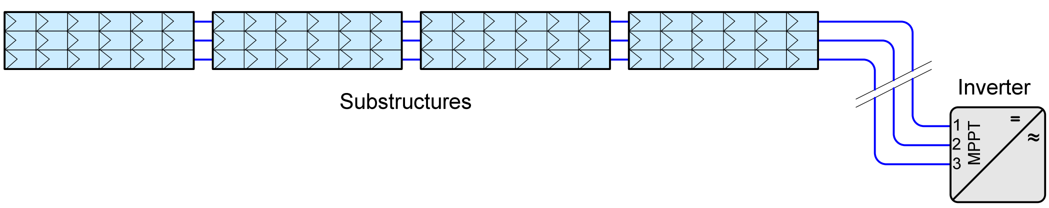


Figure 2 Module wiring based on crystalline modules
Each module row is connected directly to its own MPPT.

The string voltage at NOCT is well above 600 V_{DC} providing optimum efficiency. Additionally, yield reductions due to DC cable losses are greatly reduced.

The individual MPP tracking for every string (or string group when using modules with lower MPP current), which is a major advantage of string inverters, enables maximum energy yield per string.
If additionally the three rows of modules per PV substructure are connected to each their own MPP tracker the risks of losses due to shading are greatly reduced. This is due to the fact that each string group then has its own independent MPP tracker to control and optimise output. If a string

disconnects due to insufficient solar radiation or a failure, the other strings continue generating power, thus maximising the total energy yield.

2.1.2 Advantages on the AC side:

String inverters with IP54 enclosure are suitable for outdoor installations and need no extra shelter when mounted in the shade on the back side of the module substructure.
The low weight and small dimensions of string inverters allows for the placement of the unit on the module construction. If the inverter installation is made close to the transformer, the cost of low voltage AC wiring is greatly reduced, and yield losses due to AC cable losses on the way to the transformer are avoided.

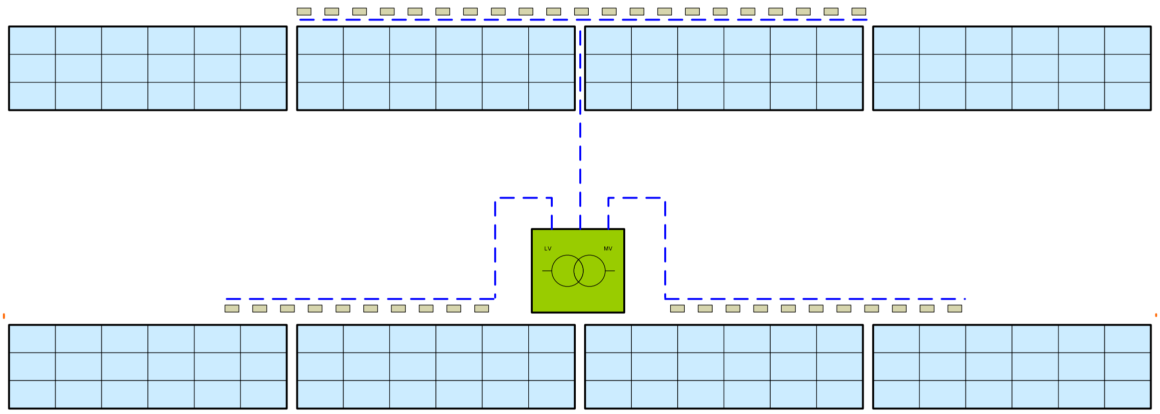


Figure 3 Inverter location
Inverters are mounted on the backside of the module substructures close to the transformer station
The low voltage distribution for all connected inverters fit into the low voltage part of the transformer station and can be pre-assembled in the transformer station prior to delivery. See Appendix A 4.3.

2.2 Alternative field layouts

In the above we have considered a quadratic PV field with centrally placed inverters. The same consideration and subsequent result could also be made with a rectangular layout with 21 rows of substructures of 8 substructures per row.
Similarly it is possible to design layouts where the inverters are placed decentrally. Here the optimum solution depends on the material and installation cost of DC cabling, AC cabling including junction boxes for bundling and protection of AC wiring weighed up against the losses in the DC and AC wiring.

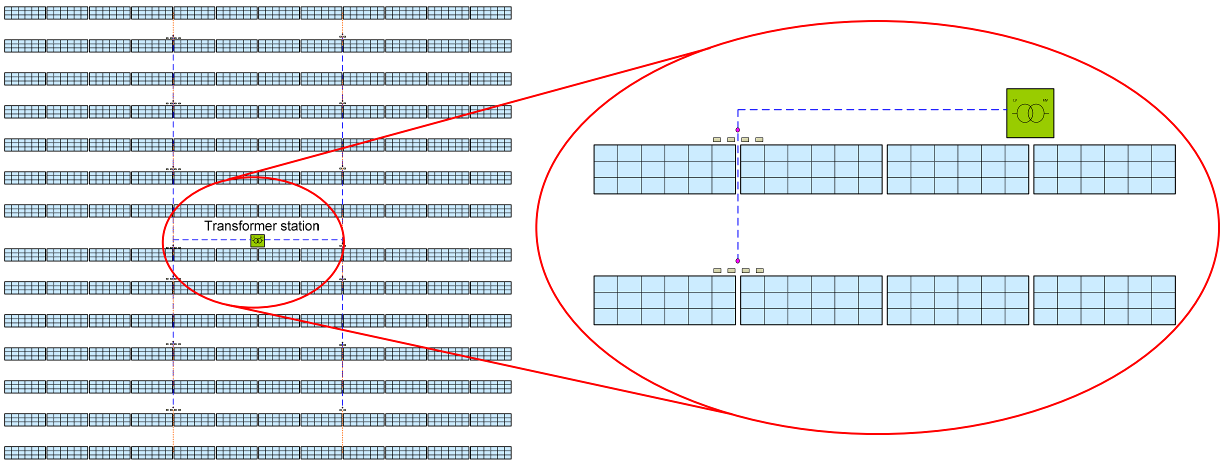


Figure 4 PV field layout with inverters being distributed
This example is identical to figure 1 in terms of module mounting, but inverters are placed close to the modules. Each inverter is on the AC side wired to a junction box which is then wired to the transformer station.

2.3 Compact transformer station

The 630 kVA transformer station is among the most commonly used transformer stations and usually has short lead times. The compact dimensions and the low weight of the transformer station enable the delivery of two units per transport and the use of smaller truck mounted cranes for mounting. As the height of the transformer station is limited (187 cm above ground), it is possible to place it behind the modules. The opposite substructure of modules is only slightly more shaded if distances between substructures remain unchanged.

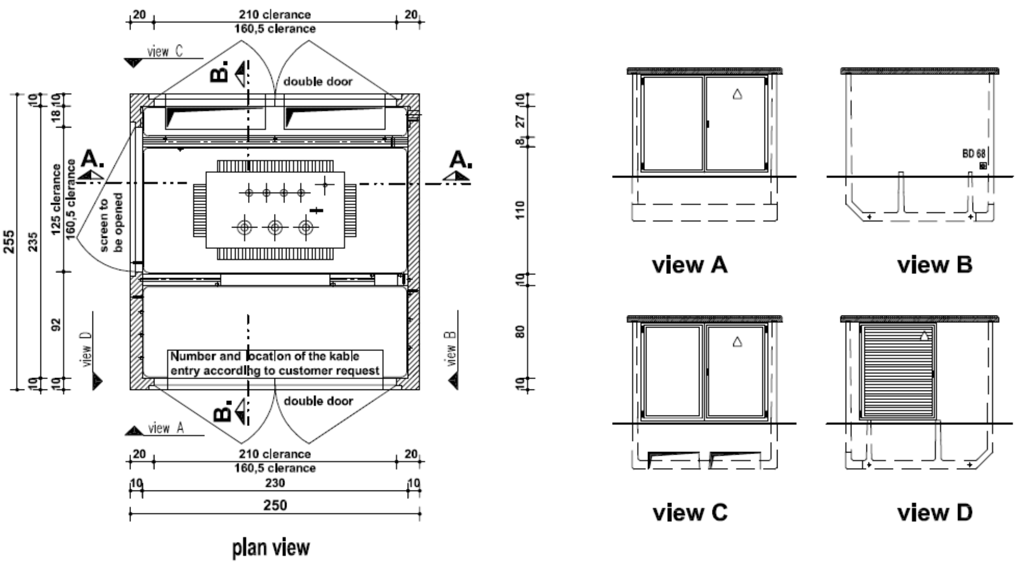


Figure 5 Transformer station

The use of a low loss transformer reduces the nightly power consumption of the transformer to below 0.4% of the yearly production. Consequently, short circuit losses in the transformer have little effect on overall yield. In the medium voltage area of transformers of this size, outgoing feeder panels with HH-fuses can be inserted instead of the more expensive power-switches. All voltage in long cabling is converted to the medium voltage level with consequently smaller losses.

2.4 Module layout

To exemplify the above mentioned advantages an example of a potential module layout is presented.

To minimise losses due to shading (shed shading) it is advised to mount 3 rows of modules in landscape orientation per substructure. Wire the modules so that each row forms its own string. These three strings are then connected individually to the three inputs of the inverter.

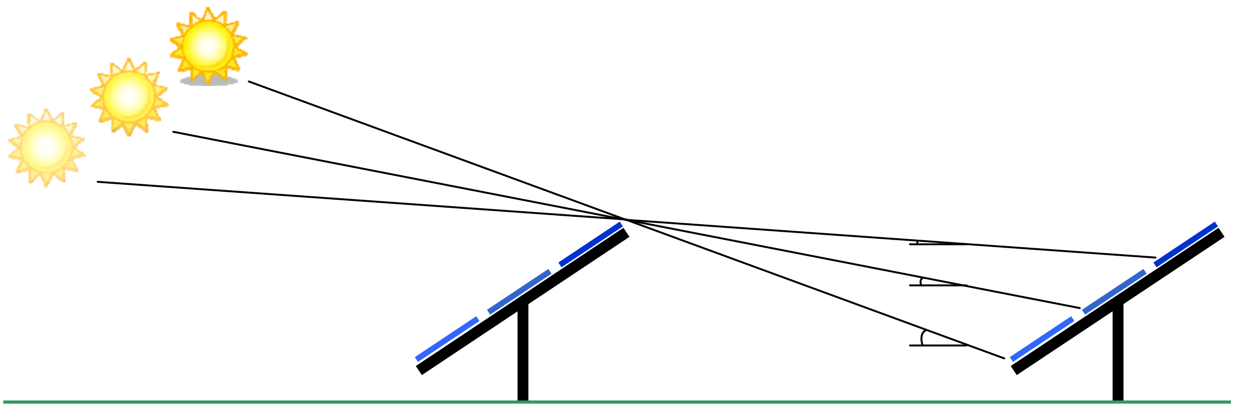


Figure 6 Shading on modules
With the sun in a low position only modules in the same string are affected given each row has separate MPPT's.

Such a configuration will in addition provide a slight advantage on winter days where the lower modules are often in shadow. A similar advantage can be found on summer days with no wind and high irradiation where the top module row will experience a slightly higher temperature level and thereby lower MPP voltage.
The 3 MMP trackers will then optimise the individual rows rather than use a combined average, as would be the case if the strings were connected in parallel.

The layout with 5.28 kWp per string or 15.9 kWp in total will give a layout factor of $P_{solar}/P_{inverter}$ = 1.06 which is within the recommendations given by Dr Bruno Burger[1] for a plant placed in central Europe. The high inverter efficiency and the lower module temperature experienced due to ground based mounting have been taken into consideration.
The layout can be achieved in different ways but the 1000 V open circuit voltage must of course be utilised.

For monocrystalline or polycrystalline modules based on 156 x 156 mm cells there are two options depending on the number of cells per module:

- 1 string of 24 modules (220 W with 60 cells) on each of the 3 input
- 1 string of 30 modules (175 W with 48 cells) on each of the 3 input

[1] Inverter sizing for grid connected PV plants, Dr.-Ing. Bruno Burger, Fraunhofer-Institut für Solare Energiesysteme ISE, Heidenhofstraße 2, D-79110 Freiburg.
http://www.ise.fraunhofer.de/veroeffentlichungen/nach-jahrgaengen/2005/auslegung-und-dimensionierung-von-wechselrichtern-fur-netzgekoppelte-pv-anlagen/at_download/file

For installations in southern Europe where a lower layout factor is recommended the power can easily be lowered by connecting fewer modules on a single string when using polycrystalline modules.

2.5 Data connection

Data for plant supervision can be transmitted to a data warehouse service through webloggers placed at each transformer station. Power to the weblogger and associated modem can be taken from the low voltage side of the transformer, as only a small amount of power (<20 W) is required.
If direct online data access is required it is suggested to connect each weblogger directly to an ethernet connection instead of using a modem.
In case the transformer station is disconnected and the weblogger is powered off, inverter data will be taken from the integrated datalogger in the inverter when power is restored. The integrated datalogger keeps inverter records of the past 3 days in a ring memory.

With the inverters placed centrally in close proximity to the transformer station it is easy to carry out the wiring for data transmission. Inverters can be connected in series using a standard Cat 5 cable. The cable can be connected directly to the inverter by either using screw terminals or pre-fabricated cables with RJ45 connectors.

For all inverter inputs it is possible to monitor current and MPP voltage individually. This means that even with 7 strings of CdTe modules detection of error in an individual string (720 Wp) is possible down to the affected inverter input (5 kWp) without additional equipment. See figure 2.
Data is recorded in 10 minute intervals and is normally transmitted to a data warehouse service daily.

Data wiring is shown in Appendix A 4.1.

3 Service/reliability

String inverters have the benefit of being a standard commercially available component. This means it is possible to let a local installer or plant supervisor with no special training carry out exchange of the inverter if necessary. Therefore, service contracts known from central inverters are not necessary for string inverters. Extra inverters can also be kept in stock locally for fast exchange.

Furthermore, in case of failure only a smaller part of the system will be affected. With the 10 MW plant it means more than 6 inverters must completely fail before the loss reaches 1% of production.

With the proposed compact transformer stations yearly service on the medium voltage grid will require slightly more effort, due to the number of transformer stations. However, no service is required on the DC side as junction boxes are omitted. E.g. no problems due to broken DC fuses.

The 5-year warranty remains unchanged for inverters used in large plant applications and warranty prolongation to 10 years is possible.

To aid the installer or plant supervisor during fault finding each inverter comes with a display.

4 Appendix A – Wiring diagrams

4.1 665 kWp Field wiring

Drawing from Gräper

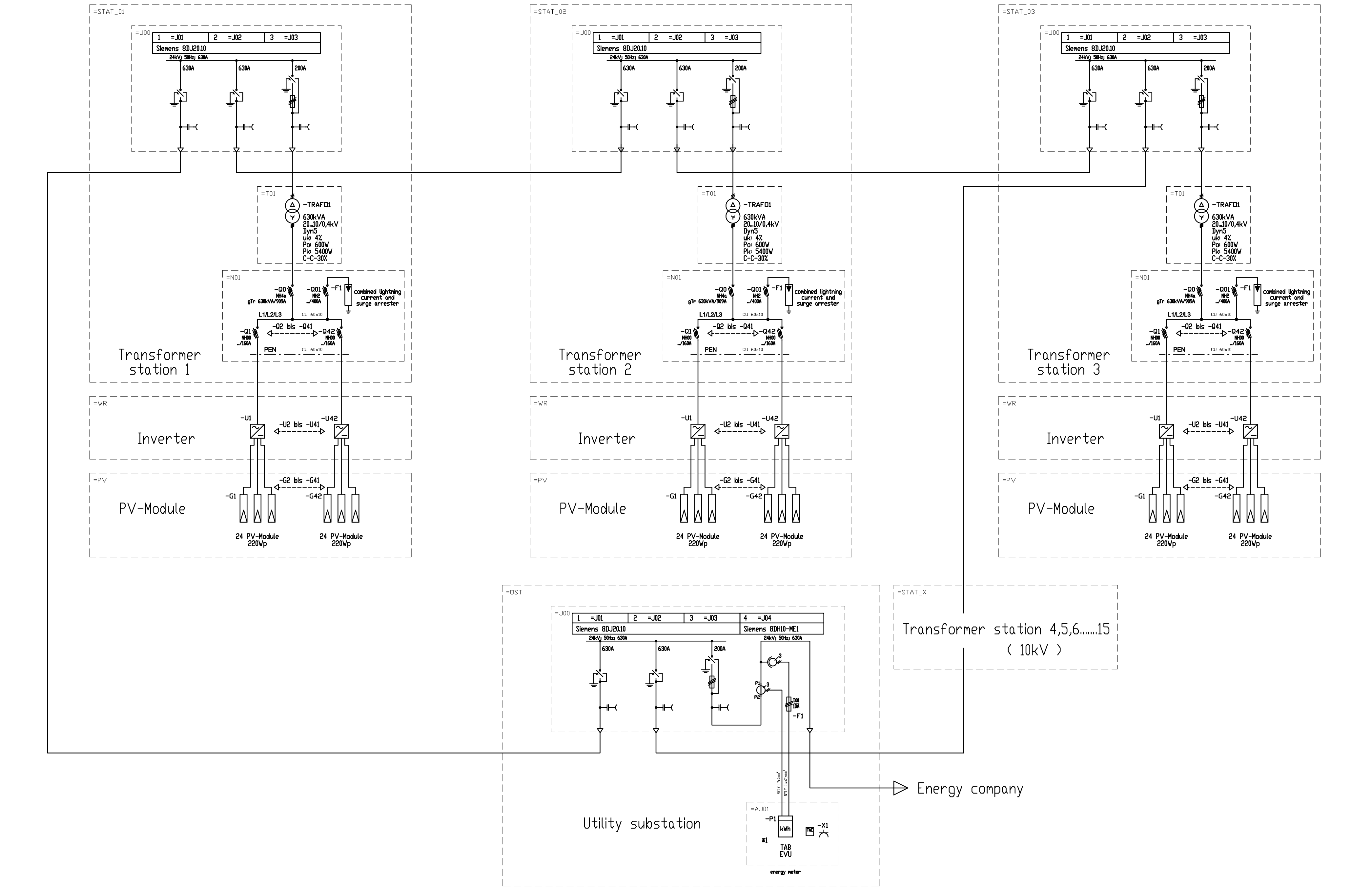
4.2 10 MWp Plant wiring

Drawing from Gräper

4.3 Layout of the low voltage switchgear

Drawing from Gräper

Observe protection mark according ISO 16016!



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				Date	19.01.09	GRÄPER	Beton- und Energietechnik Heinrich Gräper GmbH & Co. KG Ida Gräper Weg 26197 Großenkneten - Ahlhorn	Overview wiring diagram PV powerplant concept	Projectdescription: Danfoss Solar Inverters A / S - "PV-Kraftwerk"		= A00 +
				Design.	K. Freese						
				Check.	M. Coldewey				Order No.: PR-082545	Drawing No.: 08/2.186-EA01	Page 02 - of 2
Status	Revision	Date	Name	Stand.		Source:	Ref.f: Rep.by:				

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Project: DANFOSS-SOLAR_E_082545
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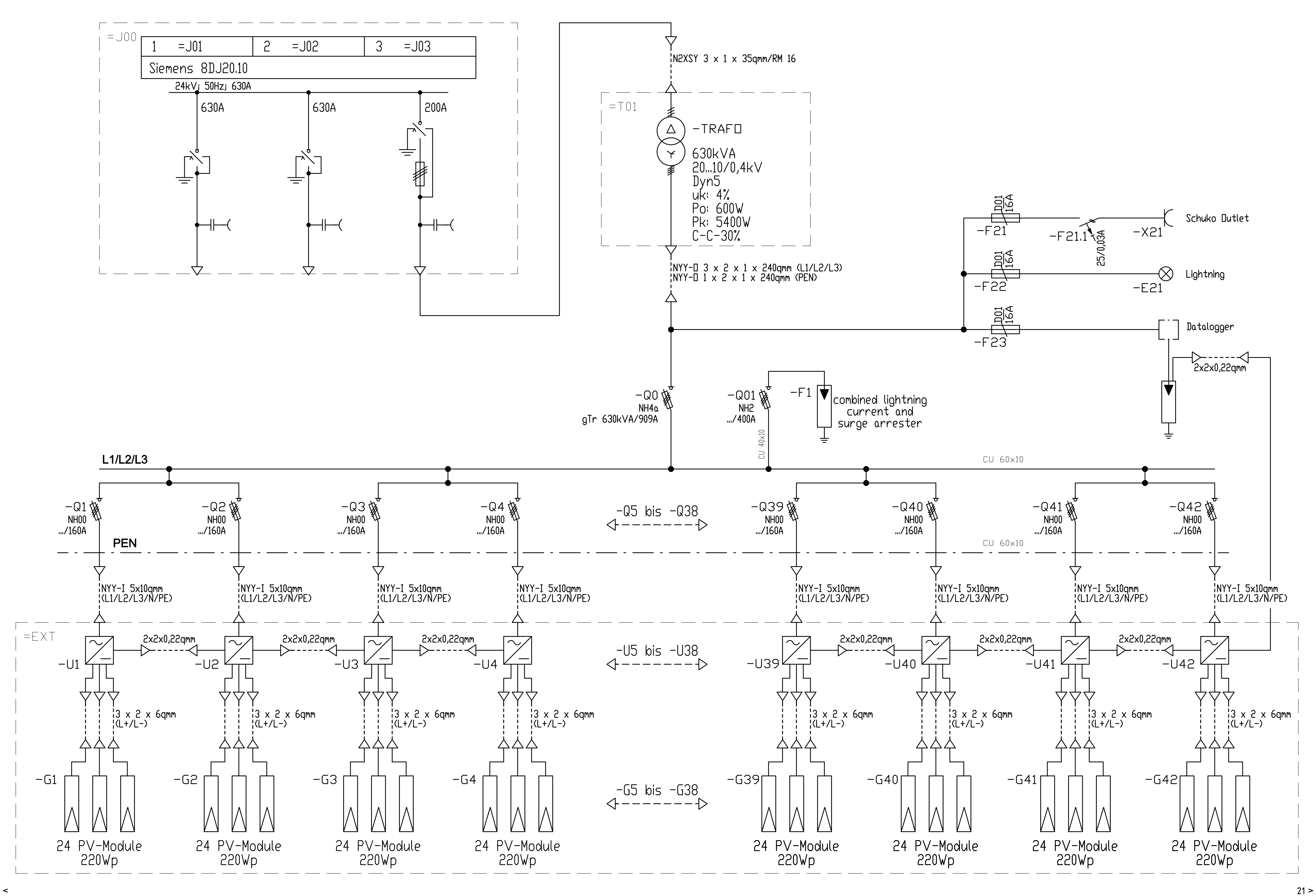

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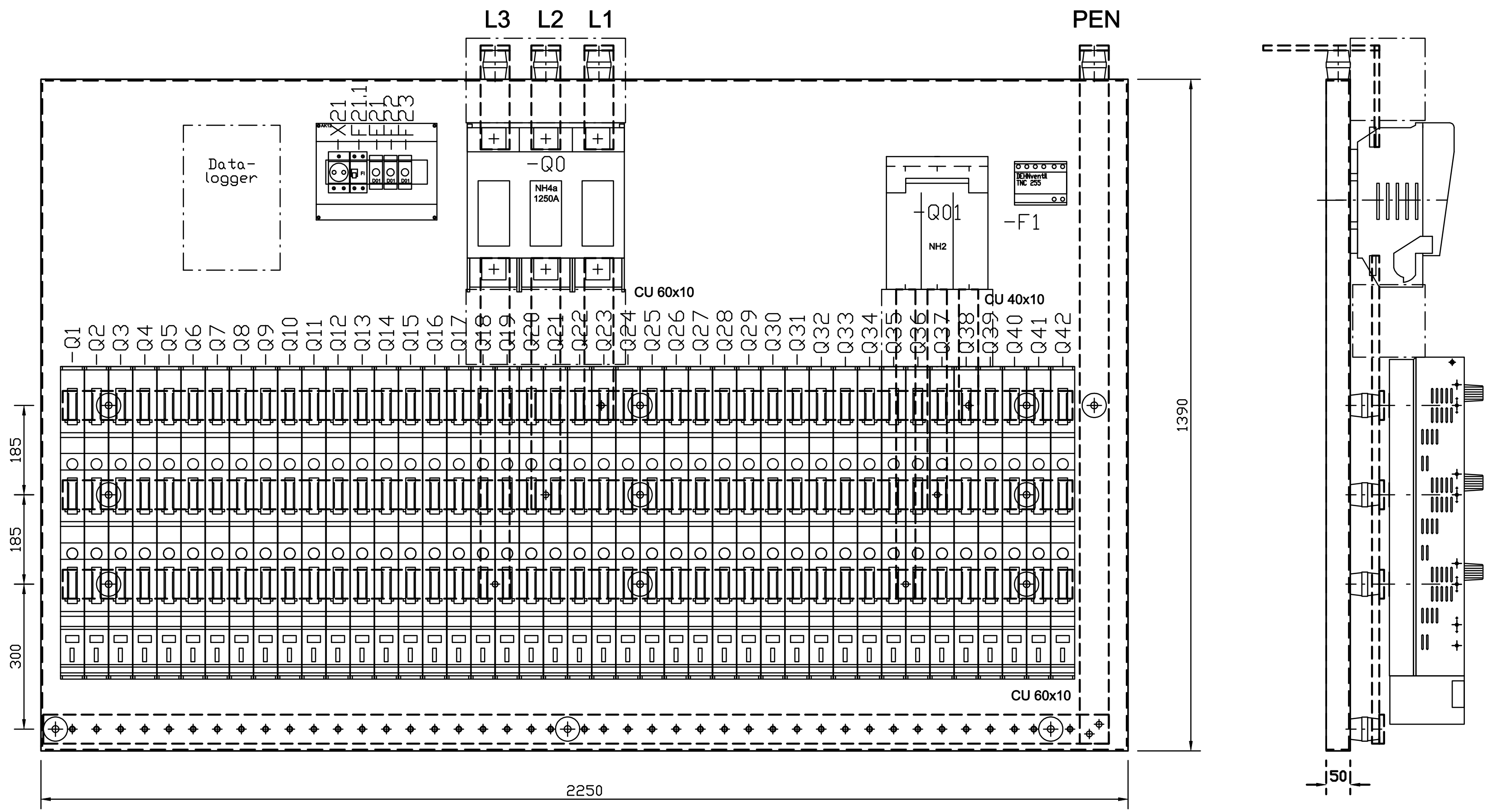
				Date	19.01.09	GRÄPER	Beton- und Energietechnik Heinrich Gräper GmbH & Co. KG Ida Gräper Weg 26197 Großenkneten - Ahlhorn	Overview wiring diagram low voltage switch gear in 20kV-Transformer station
				Design.	K. Freese			
				Check.	M. Coldewey			
Status	Revision	Date	Name	Stand.		Source:	Ref.f: Rep.by:	

Projectdescription: Danfoss Solar Inverters A / S - "PV-Kraftwerk"		= N01	+
Order No.: PR-082545	Drawing No.: 08/2.186-EA01	Page 11 +	of 2

Observe protection mark according ISO 16016!



low voltage switch gear

Typ		busbar system			
G-SLTL1250-AL21		materials	construction	bus bar distance	current rating
400/230V; 3~/PEN/50Hz; 4 polig		Kupfer	Flach	185/185/275mm	910A
form	total dimension (B/H/T)	busbar dimension			
LV-sheet 2250x1390	ca. 2250x1350x300mm	60x10mm (L1/L2/L3/PEN)			
degree of protection	Normen	supply	cable tail	other	
IP20	DIN EN 60439-1 / VDE 0660 Teil 500	up / back	under	-/-	

Technical Informationen

measuring

Energy company	wise	counter cabinet	board	fuse	wire for voltage	wire for current
-/-	-/-	-/-	-/-	-/-	-/-	-/-

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Project: DANFOSS-SOLAR_E_082545
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				Design.	K. Freese
				Check.	M. Coldewey
				Stand.	

GRÄPER
Beton- und Energietechnik
Heinrich Gräper GmbH & Co. KG
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26197 Großenkneten - Ahlhorn

Source: Rep.f: Rep.by:

installation diagram
low voltage switch gear
scale 1:10 (DIN-A3)

Projectdescription:
Danfoss Solar Inverters A / S - "PV-Kraftwerk"

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Order No.: PR-082545
Drawing No.: 08/2.186-EA01
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