Photovoltaic transformerless string inverter

TECHNICAL SPECIFICATION

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1 MAIN FEATURES

The String Soleil inverter is a photovoltaic, three-phase inverter for direct connection to a public AC line (400V, 50Hz) as well as for connection to a step-up, Low-to-Medium Voltage transformer, for power production in PV farms.

It is available in three different power ratings with the same enclosure: 10, 20 and 30kW.

Its form factor, makes it an equipment easy to install wall-mounted and quick to connect electrically, requiring a very few installation skill and a small set of tools for connection and mounting.

Thanks to its fan-less design, it is best suited for outdoor operation and to work in most harsh environmental conditions of temperature (-25°C ... +50°C), dust, humidity (IP65) and pollution (Degree 2).

The inverter is composed by two compartments (sections), separated by a metal panel from each other, within the same enclosure and each with its own cover panel:

- ***Inverter section***, containing all the power electronics and control boards of the machine, accessible only by SIEL's authorized technical staff for maintenance and repairing.
- ***Wiring section,*** containing the terminals for connection to the DC strings from the incoming PV field (each one protected by its own fuse), SPDs for AC and DC sections, the intelligent board for I/O management, a rotating main disconnector (DC and AC), whose handle can be operated from the outside. This section is accessible to the installer during commissioning phase and to SIEL's authorized technical staff for maintenance and repairing.

The front panel of the inverter is equipped with an alphanumeric display, showing the main electrical parameters of operation of the unit (such as AC power, voltage and current and DC power, voltage and currents), as well as status and alarms of the inverter.

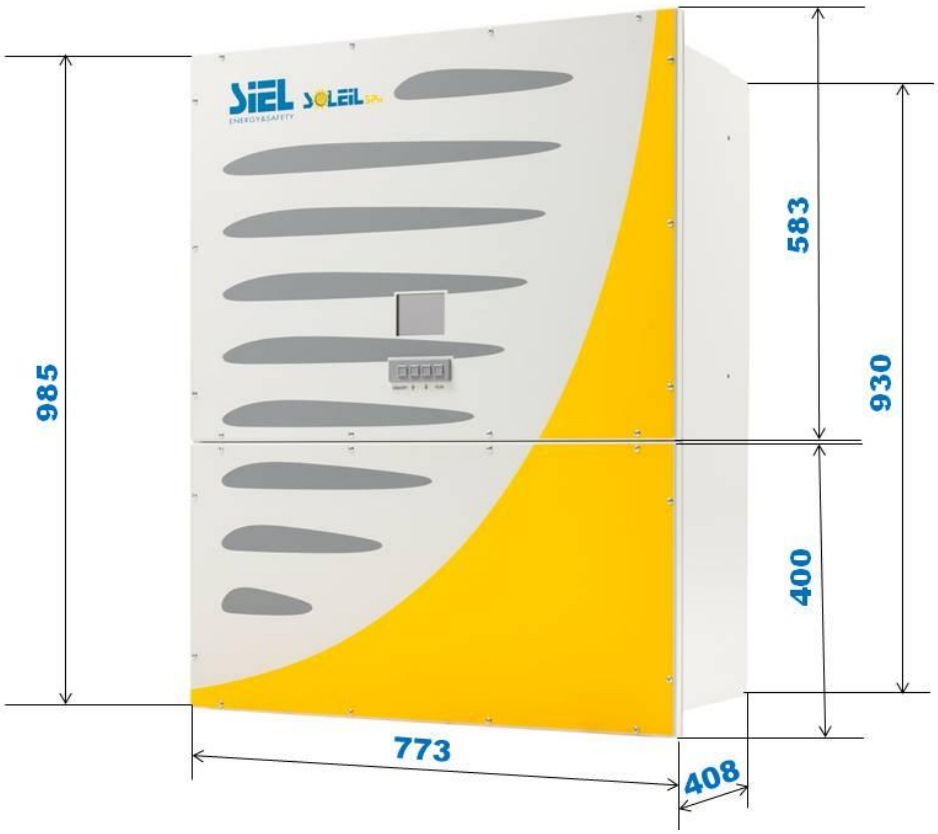
A four-buttons rubber keyboard, located right below the display, allows easy browsing through the pages of the display and can be used to:

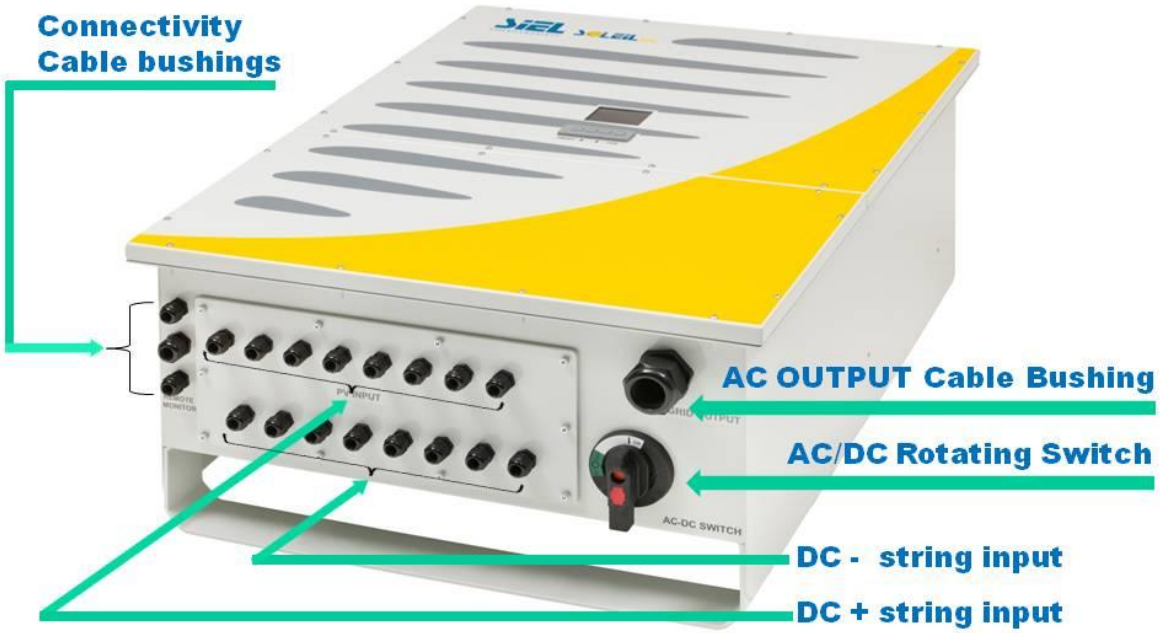
- Select the country-specific grid code, according to which the inverter has to operate,
- Enable and disable the inverter,
- Set-up the values of the parameters for grid support functions (according to selected grid-code).

Furthermore, a powerful I/O interface intelligent board is included (located in the 'wiring section' of the machine), to handle all the connectivity functionalities of the unit:

- Two isolated serial interfaces (with Modbus RTU protocol),
- Four user-configurable optically isolated digital inputs,
- Two digital outputs (relais),
- Four analog inputs (2 inputs 4-20mA, 2 inputs 0-10V),
- Four analog outputs (2 outputs 4-20mA, 2 outputs 0-10V),
- One dedicated PT100 input,
- One dedicated PT1000 input.

2 INVERTER OVERVIEW AND ARCHITECTURE





The inverter chassis is based on a pin fin aluminium heat-sink, located on the back of the unit. This part of the equipment, has a structural function and carries the whole weight load of the unit. Pins are disposed in such a way to achieve an optimal cooling with natural air convection (no external fans needed).

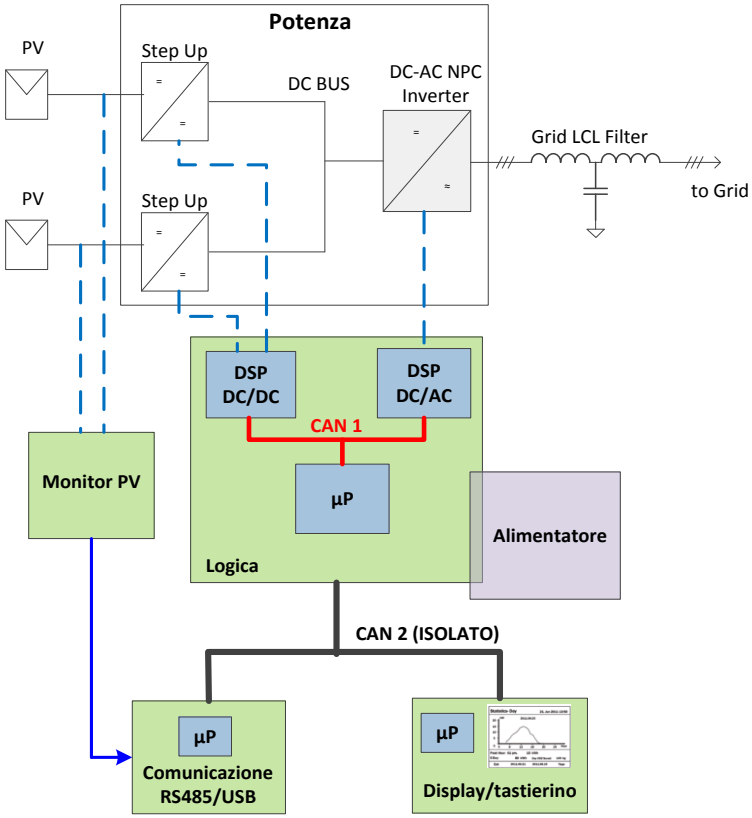
The enclosure, secured to the heat-sink, is made by sheet iron, with anti corrosion coating and painting (RAL 7035 for bright grey parts and RAL 1021 for yellow insertions).

On the back of the unit, three iron bars cross the inverter section. The middle one, carries the holes for wall-mounting by screws and bolts.

The cable entrances/exits are all located on the bottom of the inverter and protected by plastic conformal cable bushings, as well as the rotating switch, for DC and AC disconnector operation (close/open).

In order to properly allow the airflow for cooling, the unit has to be installed vertically, with its back aligned to the wall and secured to it through small-blocks (and nuts), fitting the holes in the middle bar crossing the back of the inverter.

2.1 Inverter functional and physical architecture



From a functional point of view, the inverter can be divided into two sections:

- ***DC section***, embedding two separate DC Step-up converters, each of which features an independent MPPT. These two DC Step-up are directly connected to the incoming PV string from the field. Moreover, this section includes one EMI filter PCB for common-mode emission reduction. This section is controlled by a dedicated DSP.
- ***AC section,*** including the 3 Phase IGBT-based power bridge (3 Level, type 1 architecture), the sinusoidal output filter , an EMI filter PCB for common-mode emission reduction and the relais for connection/disconnection to the mains. These relais, where required by the grid code, act as 'protection interface device', controlled by a redundant logic in a redundant fashion. The inverter is controlled by a dedicated DSP.

Both the DSPs controlling the DC section and the inverter, communicate with a System Microcontroller, in charge of managing the alarms, the communication with the Display (peer-to-peer with another microcontroller of the display), the exchange of messages with the I/O intelligent board and to manage the commands/set-points (P, Q) for network support.

From a physical/layout point of view, the 'inverter section' of the equipment, is ideally divided in two 'level': bottom level of it, hosts all the power electronics and relevant boards (gate-units), with all the power semiconductors mounted on the surface of the heat-sink located inside the equipment.

The control boards, along with the AC output filter board and the system power supply (flyback), are located on the 'upper' level, right above the DC-link PCB, which physically separates the bottom and the upper 'level'. In order to make the temperature of the internal components as much uniform as possible, four small DC fans are present, two located in the 'bottom level', two located in the 'upper level'.

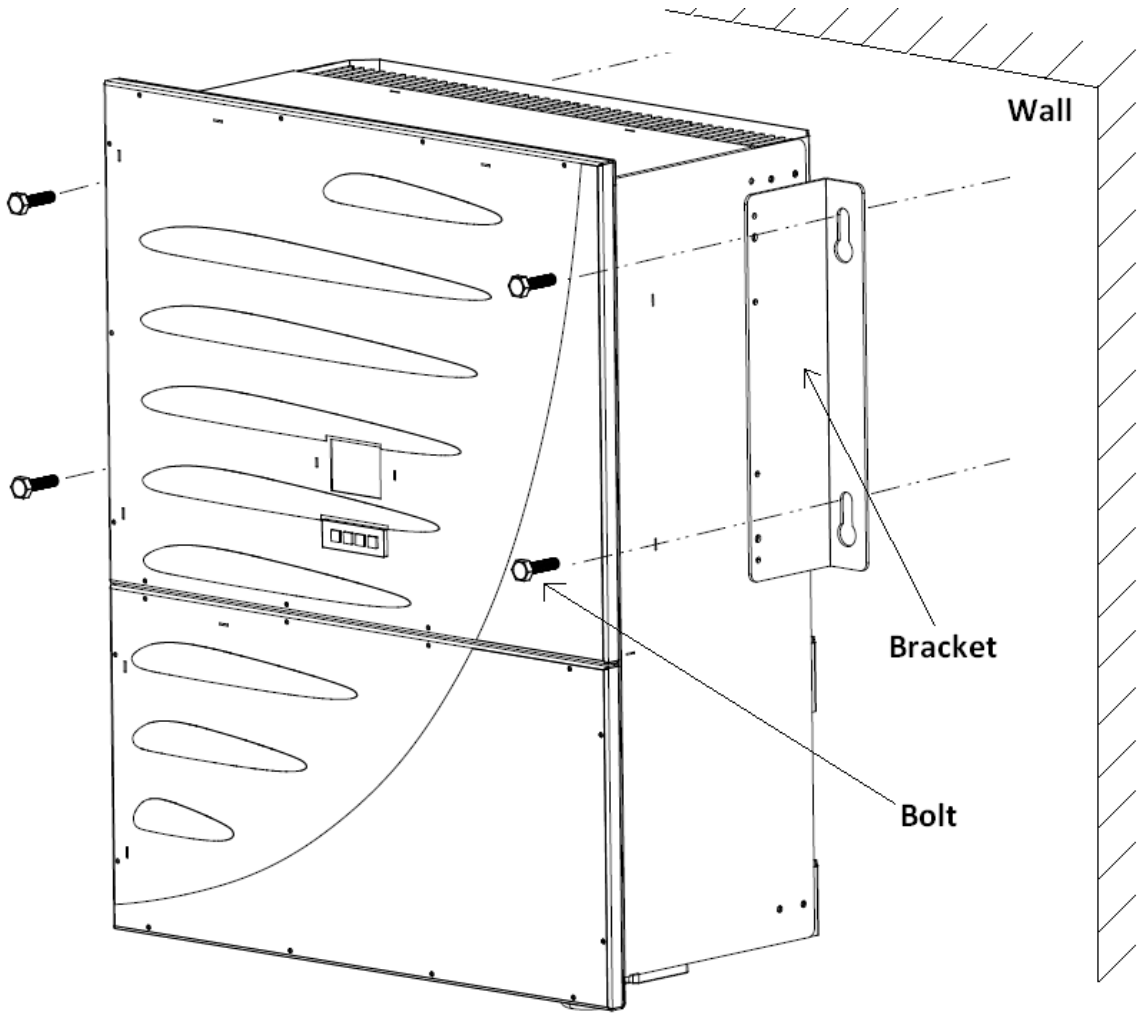
3 INSTALLATION OF THE PRODUCT

This Chapter provides a 'quick start' guide to get the inverter operating. As such, it must be taken as a synthetic summary of the sequence of operations required during the first start of the equipment.

Please conform to all the recommendations about issues on Safety, Environment, Electromagnetic Compatibility as described in the Installation Manual of the Inverter.

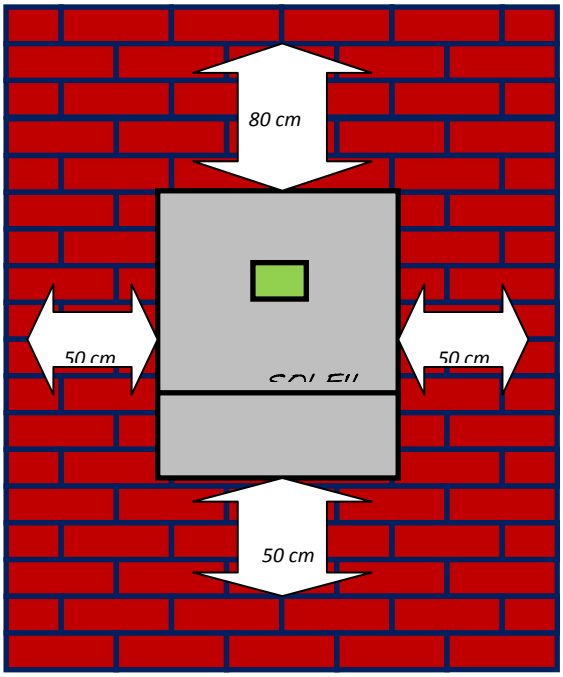
3.1 Wall mounting

Enclosed with the inverter delivery box, a metal bracket, some screws to fix it to the inverter chassis and 4 bolts for wall mounting, are provided, to hang the inverter across a wall. Please make sure that the wall can structurally stand a weight of approx 120kg before start mounting phase.



1. Fix any of the brackets to the inverter, through relevant screws (already positioned in the body of the unit).
2. Lift the inverter up to the desired point of mounting across the wall, which should have previously prepared by drilling in 4 points the wall and inserting the 4 relevant plugs
3. Secure the unit to the wall, by inserting the bolts in the correspondent eyelet of the bracket and tighten each of them.

4. Proper clearance must be ensured above the unit for air circulation, as shown in the following figure:



5. At the same time, appropriate clearance must be also left below the inverter, in order to respect a proper bending of cables entering the inverter for connection.

No roof or repairing is needed for the installation: thanks to its totally sealed, fan-less enclosure, the inverter is suited for completely outdoor, open air installation (IP65).

3.2 Wiring

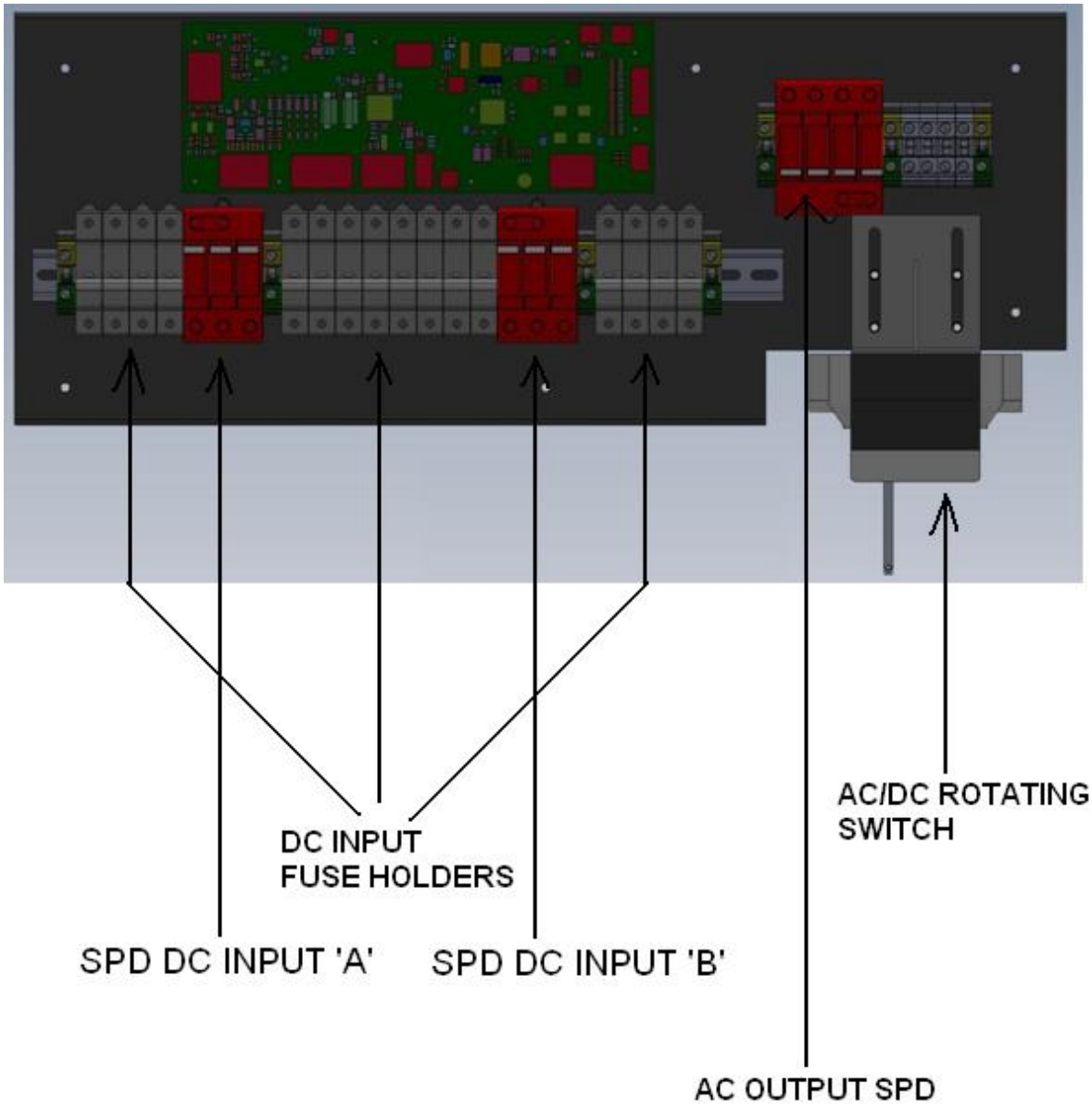
Right after having the inverter secured to its mechanical support, the first check before the inverter can be operated, is to make sure that the rotating AC-DC switch is open, otherwise it is necessary to rotate it in the 'OFF' position.

The sequence of operation to quickly start-up the inverter, after it has been unboxed, is summarized as follows:

a) Open the AC/DC switch of the unit ('OFF' position).

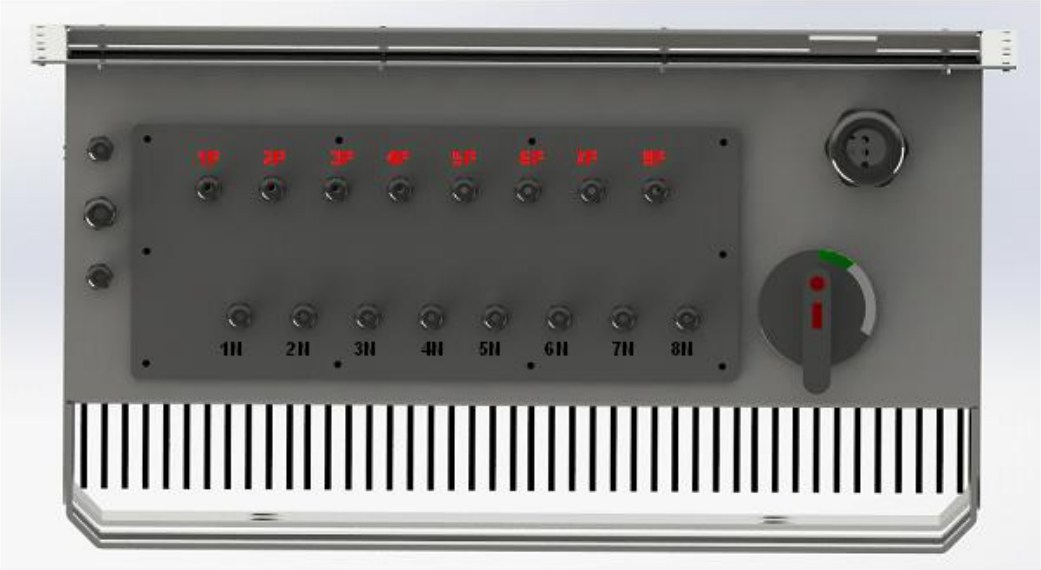
b) Make sure that no DC voltage is present (connectors in every junction box of the PV modules physically disconnected), by measuring it with a multi-meter.

c) Remove the cover panel of 'wiring section'. Here below is depicted what the wiring section looks like, once its panel has been removed:

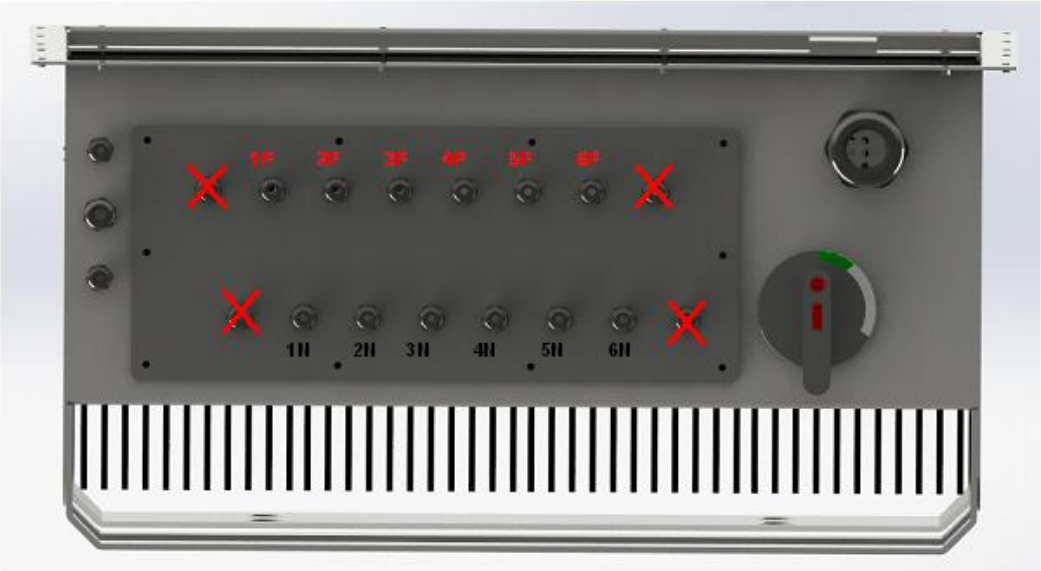


d) Plug every ‘positive’ string cable from PV into its own bushing (please refer to bottom view of the 20 and 30kW units here below):

Soleil 30kW



Soleil 20kW

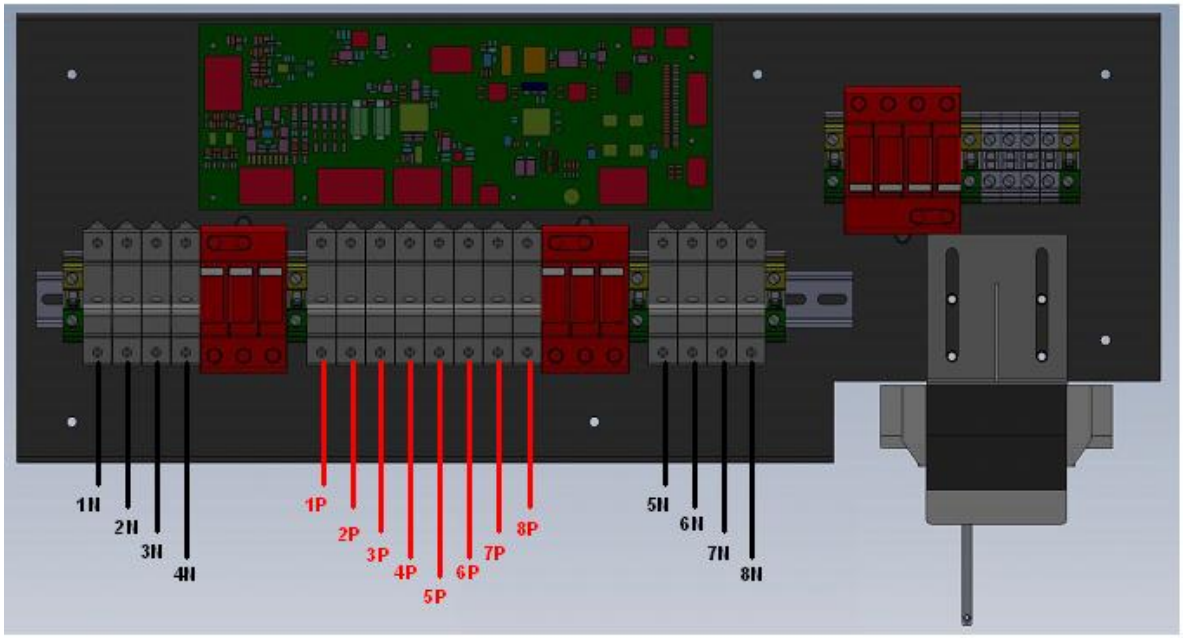


e) Repeat point ‘e’ for every ‘negative’ cables.

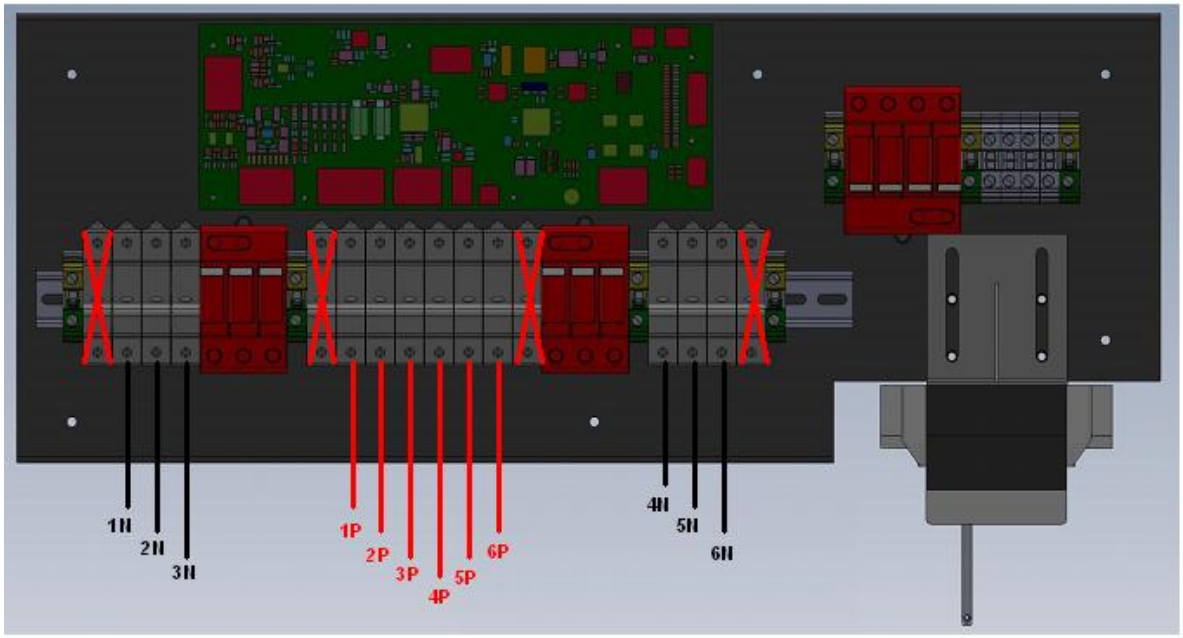
f) Connect ‘positive’ cables to the bottom input of correspondent fuse holder.

g) Repeat point ‘g’ for negative cables. See following drawing.

Soleil 30kW



Soleil 20kW



h) Reclose all the front doors of the fuse-holders.

i) Secure the cable gland on every DC cable bushings.

j) Put the cover panel of 'wiring section' back-on and secure it to the enclosure, by tightening the screws.

k) Connect the modules (junction boxes) in order to provide voltage to 'negative' and 'positive' cables from PV.

l) Close the AC/DC Switch ('ON' position).

3.2.1 Size of AC conductors for connections

The cross section of cables for the AC connection to the grid, has to be properly sized, in order to:

- minimize the Joule effect losses
- keep the series impedance of the cables as low as possible, in order to avoid voltage drops or phase displacement respect to the grid. This is mainly achieved by keeping the length of cables within certain constraints.

Following table provides information about proper size of AC cables, to keep Joule effect losses less than 1%.

Please remark that the cable has to be a 5-pole cable.

AC conductor section [mm2]	***Max length of the 5-pole AC cable [m]***	
	Inverter SOLEIL 3PH TL 30 kW	**Inverter SOLEIL 3PH TL 20 kW**
10	17	26
16	28	42
25	43	65

3.2.2 AC line protection

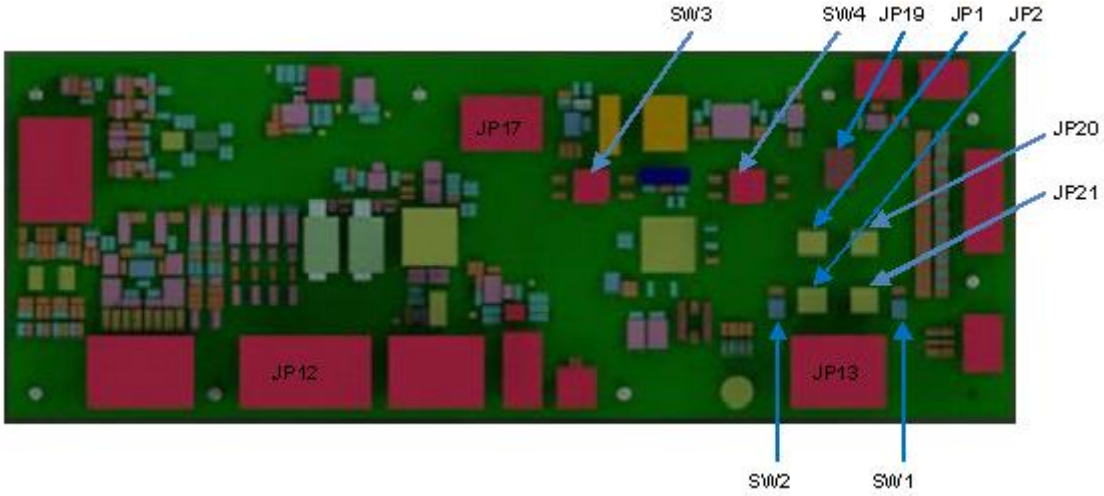
In order to protect the AC line connecting the inverter with the grid, the installer has to provide an automatic circuit-breaker with differential protection (not part of the scope of supply), with following technical characteristics:

	Inverter SOLEIL 3PH TL 30 kW	**Inverter SOLEIL 3PH TL 20 kW**
Type	Automatic circuit breaker, with thermal, magnetic and differential protection	
N. of poles	3P+N	3P+N
Magnetic curve type	B/C	B/C
Differential type	A/AC	A/AC
Differential protection threshold [mA]	300	300

3.3 Intelligent communication board

Il layout della scheda di comunicazione è riportato nella seguente immagine:

In the wiring section, the inverter is equipped with a communication board, whose layout is here below depicted:



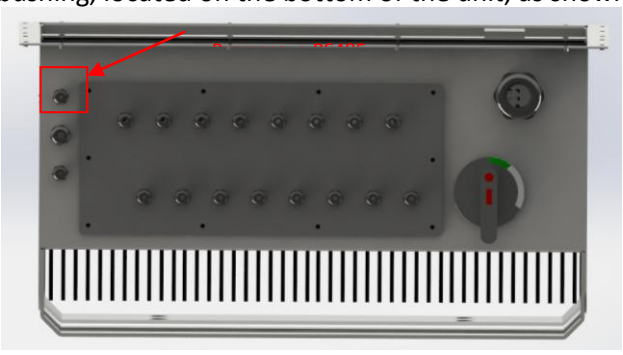
Following table, provides information about the connectors present on the PCB, particularly those requiring cabling or connection with other (optional) plug-in devices:

Identifier	**Descritpion**
JP17	Backup battery housing
JP13	Terminal block for connection with RS485
SW3 - SW4	Rotary switch for ‘grid-code’ setup
JP19	Plug-in Wi-Fi module slot (optional)

3.3.1 RS485 serial interface wiring

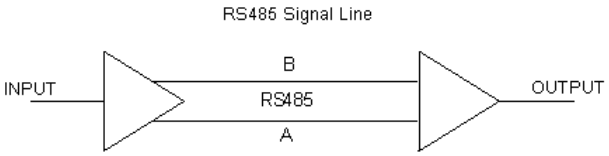
The inverter has two different RS485 isolated serial lines, featuring Modbus RTU protocol.

The connection between the RS485 (JP13 connector) and the Master, requires a Shielded Twisted Pair (STP) cable (for ex. PLTC Belden 22AWG) , with characteristic impedance of 120 Ohm, which has to be routed into its bushing, located on the bottom of the unit, as shown in following picture:



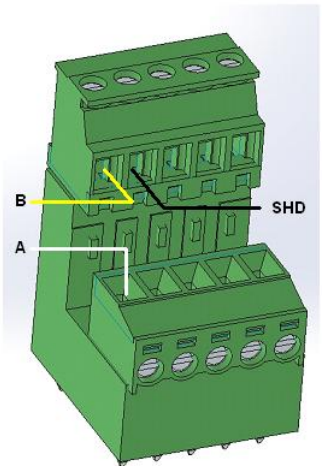
The cable gland ensures a true IP65 protection degree only if the cable is a 5-pole type, with an external diameter between 6 and 12mm.

The mentioned type of cable, carries two conductors Data+ and Data- and it's protected against EMC coupling by an external metal shield tray.



The couple of wires (Data+ or line 'A' and DATA- or line 'B') of the RS485, have to be connected to the JP13 connector as shown in following picture:

Connessione	Simbolo	Connettore - pin
DATA+	A	JP13 pin 1
DATA-	B	JP13 pin 2
Schermo	SHD	JP13 pin 4



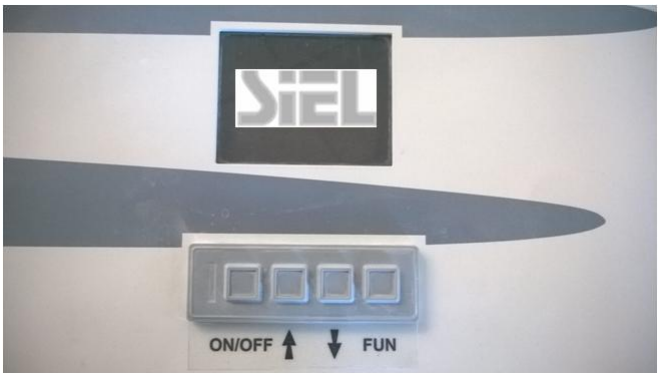
JP13 connector

The length of the RS485 serial cable has to be kept lower than 300m. Minimum recommended section is 0.32mm^2 per single conductor.

For the connection of the single wires, it is highly recommended using terminals (e.g. PA6.6), previously crimped to the wire (see figure above on the right).

4 ‘QUICK START’

At this point, if DC voltage provided by PV modules is more than 200V, the display of the inverter gets ‘ON’ and starts showing firstly the ‘welcome’ message (SIEL logo) and, after a few seconds, the main ‘MENU’



Please notice that the unit is now in ‘Stand-by’ mode, i.e. waiting for the ‘ON’ command to start generation.

Therefore, the sequence of operations to start the unit, is like follows:

a) Set-up the country specific grid code, by moving the cursor down (arrows ‘down’ button) to ‘Settings’ and confirm (ENT button, pressed for less than 1 sec).

   At this point the display shows the possible choices:

   - CEI021
   - CEI016
   - VDE AR-N 4105

   Select the desired grid code by moving the cursor upon it and confirm.

   Please notice that by factory default, the grid code set is ‘CEI021’.

b) If no alarm is present, (no red led is ‘on’), by keeping the ON/OFF button pressed for 2 seconds, the inverter moves to status ‘Ready’, where it performs the synchronization to the grid and starts generating power after some time (depending on the grid code selected). Now the inverter is in the ‘On Grid’ status.

c) If the inverter stops generation, it could happen for following two reasons:

   a. ***Some failures/protections trip occurs***: in this case the red led turns-on and the user has to browse through the pages of the display, from the Main ‘Energy’ page, in order to retrieve information about the alarm/protection occurred. Please refer to Chapter 4 of this document to get insight of the alarm list and relevant root causes. If some alarms requires repairing, please contact SIEL’s Service Department.

      OR

   b. ***The input power from the PV field is not enough to keep the unit in generation***. In this case, no red led in ‘on’, the inverter enters the ‘Ready’ status, waiting for 2 minutes before retry generation. This sequence repeats until either the power is enough to maintain the inverter in the ‘On Grid’ status, or the inverters gives up, because the input voltage gets lower than 200V.

5 DESCRIPTION OF THE EQUIPMENT

5.1 User interface (Keyboard and Display)

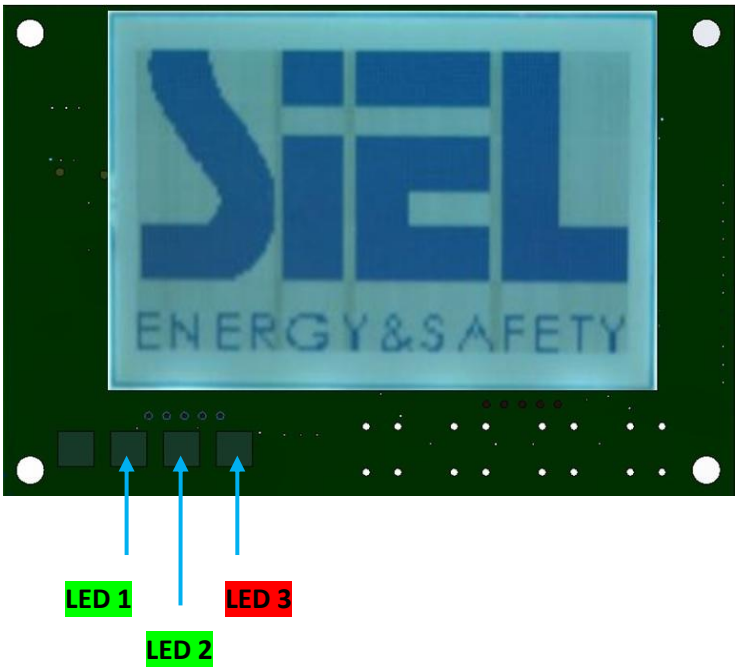
The user interface is constituted by a monochrome display, 3 leds and a 4-buttons rubber keyboard.

KEYBOARD

- **ON/OFF - ENT** button:
  - If pressed for more than 2 secs: it turns ON or OFF the inverter.
  - If pressed for less than 2 secs: it selects a function from the menu (where selection available).
- '**Arrow Up'** and **'Arrow Down'** buttons: used to browse through the pages of the display.
- **FUN (ESC)** button: when pressed, the display moves back to previous page (see hierarchy schema of pages below).

DISPLAY AND LED

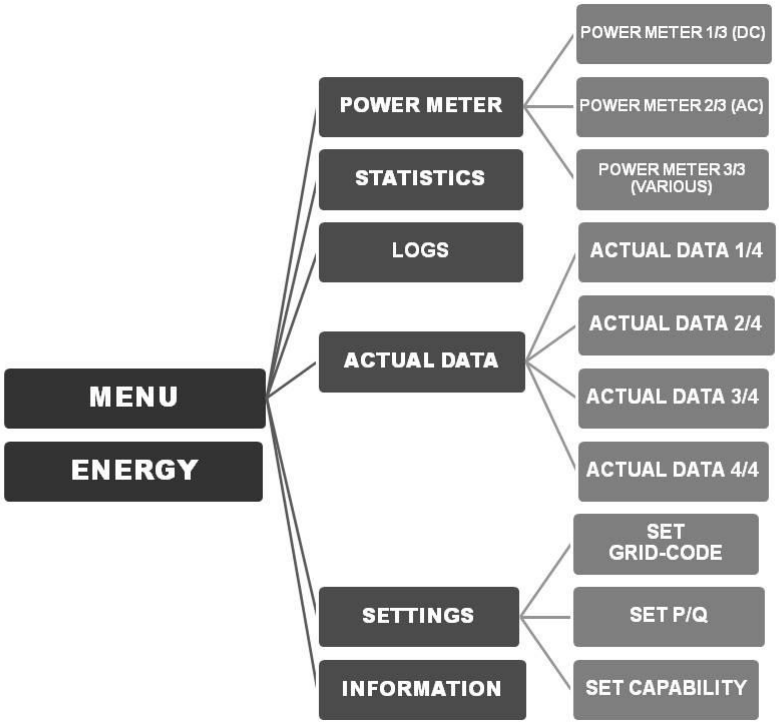
The display is made by a (25columns x 8 rows) array of ASCII characters.



Their pages are browsed through by the ‘arrow’ keys buttons.

Once a page of a certain level has been selected (by pressing ENT), a further pressure on the ENT key will show the following page belonging to the same level.

Here is the Hierarchy of the Display Pages:



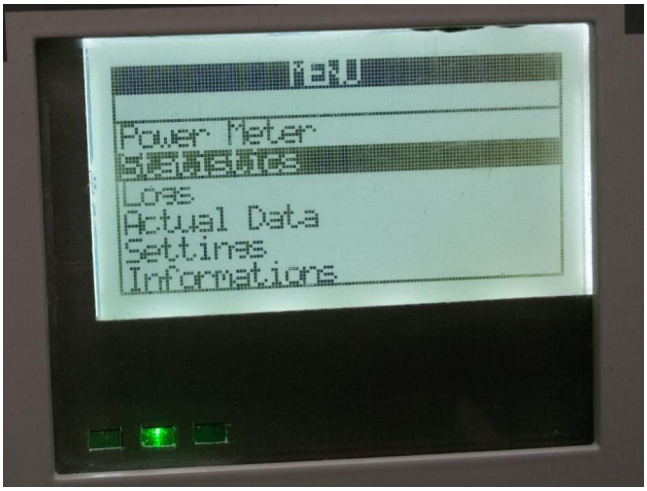
If the status is ‘Ready’ and no alarm is present, the leftmost led is lighted green.

If the status is ‘On grid’ and no alarm is present, the central led is lighted green.

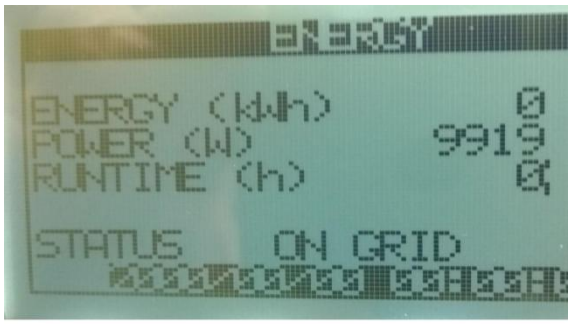
As soon as some alarms is triggered (please see chapter 5.2 Alarm Word), the leftmost and central led are off and the rightmost led is turned red.

FIRST LEVEL PAGES:

- **MENU**: all the functions of the display can be selected from this page, by using the arrow buttons. To confirm the highlighted function (Power Meter, Statistics and so on), keep the 'ENT' button pressed for less than one second. After that, a new page will be displayed (next level).



- **ENERGY**: it is the summary report page about the instantaneous production of the inverter, displaying measures such as the Instantaneous generated AC Power and the present status ('Disconnected', 'Ready' or 'On Grid').



SECOND LEVEL PAGES:

- **POWER METER (1/3)**:

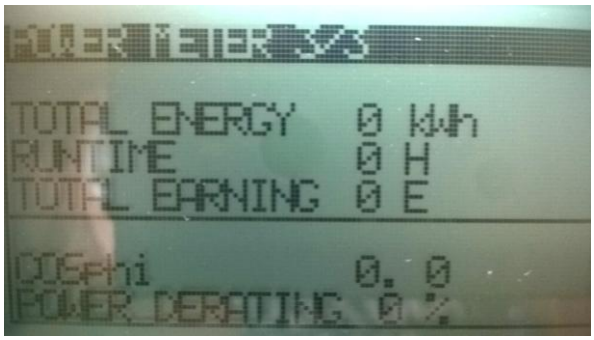
This page shows the DC measures of Power (P1 and P2), Voltage (U1 and U2) and Current (I1 and I2) of the two MPPTs present in the DC section of the inverter.

- **POWER METER (2/3)**:

This page provides information on the AC measures of Active Power, Line-to-line RMS Voltage and Current(RMS) for every single AC phase (1,2,3).

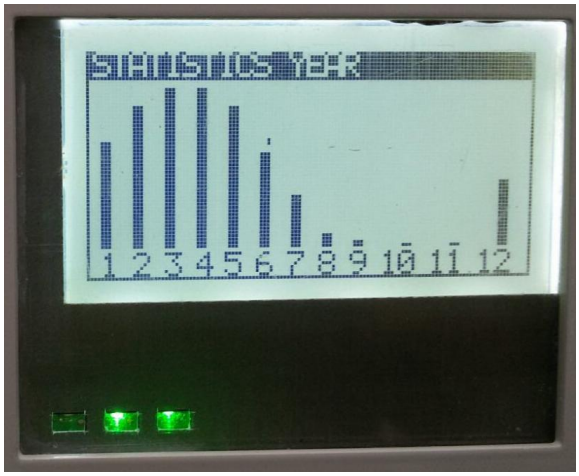
In the last line of this page, total values of P (active power in W), Q (reactive power in VAr) and S (apparent power, in VA) are shown.

- **POWER METER (3/3):**

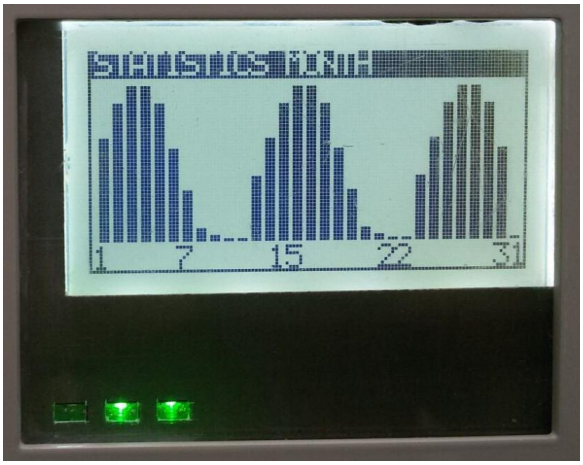


This page gives a summary of the overall performance of the inverter, such as Total Produced Energy (up to date) and number of working hours.

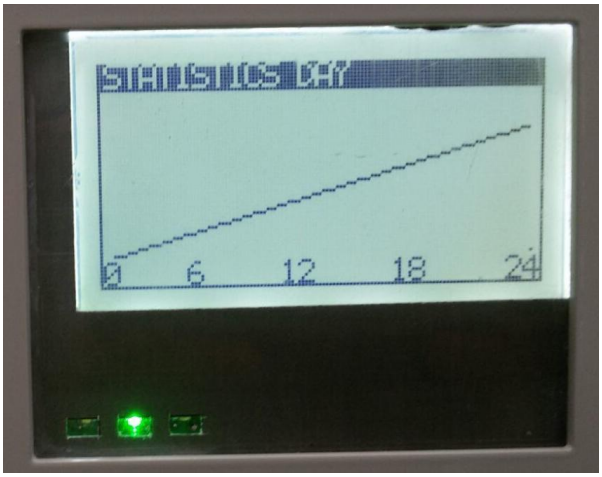
- **STATISTICS:** selecting this function from the Menu of level 1, allows the user to access information about trends of energy production of the inverters, with some different time-basis:
    - **Yearly Statistics of production**



- **Monthly Statistics of production:**



- **Daily Statistic of production:**



- **LOGS:** This page enlists all the recorded events occurred (alarms/status change) and relevant time-stamp. Pressing 'up' and 'down' arrows', the user can scroll the page for a complete view of all the memorized events. The memory of the events is rolling every XYZ recorded events.

  The format of the recorded log is as follows:

Event ID	Hexadecimal code of the status word	Date and time at which the event is set	Date and time at which the event is cleared
Incremental number of the event	0xAAAAA	Yy:mm:dd / hh:mm:ss	Yy:mm:dd / hh:mm:ss

Example:

1	**0x04008**	**2016:02:17 / 16:04:00**	**2016:02:17 / 16:09:00**
2	**0x10000**	**2016:02:17 / 16:09:01**	**-**

Previous exemple shows that :

- EVENT 1: an 'Frequency Out of Range' alarm (bit n.3) has been detected at 16:04:00 on February 17, 2016. The inverter status has immediately been set to 'Ready' (bit n.14). After 5 minutes, the alarm has been cleared (grid frequency has been restored within the acceptance range and lasted in this range for 5 minutes).
- EVENT 2: inverter status has changed from 'ready' to 'on grid' (bit n.14 cleared and bit n. 16 set).

The log of the events, can be downloaded by inserting a USB key into the dedicated slot of the I/O intelligent board and selecting function 'create USB log file' from this page.

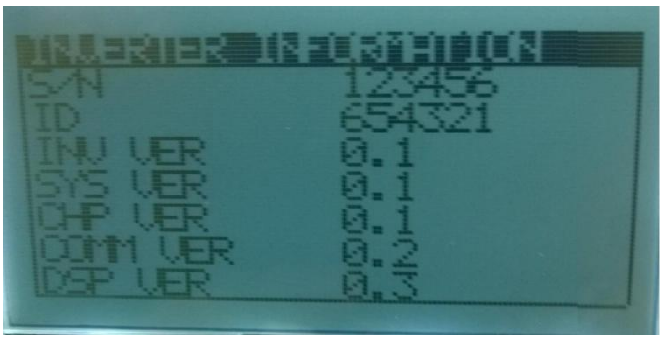
Please remark that this operation requires removal of the 'wiring section' cover, therefore it has to be performed by qualified personnel.

- **ACTUAL DATA (1/4) to (4/4):**

Pages from 1 to 4, keep track of the maximum recorded values of many different measures (Power, Voltage and Current), both in DC or AC (included cosphi and internal temperatures of the power electronics of the unit).

- **SETTINGS:** From this menu, it is possible to set the grid-code (CEI021, CEI016, VDE AR-N 4105), the shape of the P/Q diagram (Active vs Reactive Power capability) of the inverter and set date and time.

- **INFORMATION**



In this page, the revisions of FW installed on all the microprocessors present in the equipment, are summarized.

5.2 Alarm Word

The status and alarm word, already mentioned in par. 5.1 (LOGS), is a 5 hexadecimal ciphers information, where the encoded status of each bit (0 or 1), represents the presence (1) or absence of the alarm.

In order to figure out which are the active bit (set to '1') in a hexadecimal cipher, please follow this procedure:

b19	b18	**b17**	**b16**	**b15**	**b14**	**b13**	**b12**	**b11**	**b10**	**b9**	**b8**	**b7**	**b6**	**b5**	**b4**	**b3**	**b2**	**b1**	**b0**
H4				**H3**				**H2**				**H1**				**H0**			

The hexadecimal encoding of every of the 5 hex ciphers, is like follows (for ex. of cipher H0):

Hex value H0	b3	b2	b1	b0
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1
A	1	0	1	0

B	1	0	1	1
C	1	1	0	0
D	1	1	0	1
E	1	1	1	0
F	1	1	1	1

The same encoding schema goes for ciphers H1,H2,H3 and H4.

Only the two bit b16 and b17 are meaningful for hex cipher H4.

Every bit of the alarm word, carries a binary information ('active'=1, 'not active'=0) about each alarm, according to herein reported table.

The column 'Cause of the event', provides a simplified explanation of the root cause of failure.

Bit	Meaning	Alarm/Status	Cause of the event	Actions for clearing
b0	Power limitation for overtemperature	Alarm	Fault or improper installation condition	Failure fixing
b1	Desaturation of IGBT inverter	Alarm	Fault occurred to inverter module	Failure fixing
b2	Inverter overcurrent	Alarm	Fault occurred to inverter module	Failure fixing
b3	Main Frequency out of range	Alarm	Triggered by an abnormal event of the grid	Grid back to normal condition
b4	Mains Voltage out of range	Alarm	Abnormal grid conditions	Grid back to normal condition
b5	Internal over temperature	Alarm	Abnormal grid conditions	Grid back to normal condition
b6	CANBUS 2 communication fault	Alarm	Fault occurred to isolated CANbus	Failure fixing
b7	Inverter 'Disconnected'	STATUS (val. '1')	'ON/OFF' button pressed by user while in 'On grid' status, or any 'alarm' triggered	-
b8	Insufficient	Alarm	Input power not enough for	-

	irradiation		generation	
b9	EEPROM communication fault	Alarm	Fault	Failure fixing
b10	Manual Mode	Alarm	‘Manual’ mode selected by user	‘Auto’ mode restored back by user
b11	Loss of insulation DC	Alarm	Fault	Failure fixing
b12	CANBUS 1 communication fault	Alarm	Fault occurred to internal system CANbus	Failure fixing
b13	Emergency power-off	Alarm	EPO contact open	EPO contact closed and inverter reset
b14	Inverter ‘Ready’	STATUS (val. ‘1’)	‘ON/OFF’ pressed by user, inverter checking for proper grid condition before starting generation	-
b15	Presence of operator	Alarm	Any action done on user keyboard	-
b16	Inverter ‘On grid’	STATUS (val. ‘1’)	Some time elapsed after inverter entered ‘Ready’ status with grid OK	-
b17	External Protection Trip (dig. Input 0): val	Alarm	Dig. Input 0 shortened to 0V.	Feed Dig. Input 0 with 10V
b18	Don’t care	-	-	-
b19	Don’t care	-	-	-

6 TECHNICAL CHARACTERISTICS

Model	10	20	30
1. DC side input			
Max Total Input Power [W]	13000	21000	31500
Max Input Power per MPPT [W]	13000	13000	18500
Max Input DC Voltage for operation [V]	950		
Absolute Max Input DC Voltage (no operation)[V]	1000		
Min Voltage for start [V]	360V		
Min Voltage for stop [V]	200		
Operating voltage range [V]	200-950		
Number of MPPTs	2		
Number of input PV strings per MPPT	3	3	4
MPPT Voltage range (2 MPPTs independent from each other) [V]	360-850		
MPPT Voltage range (2 MPPTs in parallel)[V]	300-800		
Max Input DC Current per string [A]	12	12	13.5
Type of connectors per string input	Fuse holder with screw terminal, (Max cable section: 25mm^2)		
2. DC input Protections and Switch			
Polarity inversion protection	Present (diode)		
Overvoltage protection per MPPT	Single MOV per pole		
Overvoltage protection input DC string	SPD Class II (DIN rail) with spark-gap		
Fuse per single DC input [A]	15	15	20
DC switch [A]	2x55A @ 1000V		
Ground Fault Detection	According to local standard		
3. AC side Output			
Connection	3Ph + N + PE		
Rated AC Power [kW] (p.f. = 0.9)	10	20	30
Max AC Apparent Power [kVA]	11,1	22,2	33,3
Rated Voltage Vn (line-to-line) [V]	400		
Voltage operation range (line-to-line) [V]	+10% / -15% (According to specific country code)		
Rated Frequency [Hz]	50 - 60		
Frequency range for operation [Hz]	47,5 – 52,5 / 58 - 62 (According to specific country code)		
Rated Current (p.f. = 0,9) [A]	16	32	48
Rated P.F.	1		
P.F. variation range	0.9 leading / 0.9 lagging		
Max Current THD (Max Power Output) [%]	3		
Short Circuit Current (contribution to Isc as generator) [A]	24	48	72
Max Efficiency [%]	98	98,1	98,2(*)
Euro Efficiency [%]	97	97,2	97,2(*)
Max MPPT Static Efficiency [%]	98,95		

Model	10	20	30
Max MPPT Dynamic Efficiency [%]	99,8		
Type of connectors AC	Screw Terminal block (DIN rail) (Max cable section : 25mm^2)		
4. AC Output Protections and Switch			
Overvoltage protection for inverter PCB	Four MOV star-connected (3Ph + N with spark-gap (between N and PE)		
Overvoltage protection AC	SPD Class II (DIN rail) with spark-gap (between Neutral and PE)		
Output switch	55A @ 690V (4P)		
5. Other data			
Ventilation system	Natural Air		
Control	Digital		
Output wave form	PWM Sinusoidal		
Operating temperature [°C]	-25°C / +50°C		
Storage temperature [°C]	-30°C / +60°C		
Dimensions of the inverter enclosure (LxWxH) mm	985 x 773 x 400		
Dimensions of the inverter with bracket for hanging (LxWxH) mm	985 x 830 x 400		
Inverter weight [kg]	95	100	110
Overvoltage category DC	II		
Overvoltage category AC	II		
IP class	IP65		
Humidity range	95% with no condensation		
Max Noise (1m) [dBA]	<50dbA		
6. Regulation and Standards			
Marking	CE		
Safety	IEC 62109-1, IEC62109-2		
Emissions / Immunity	IEC 61000-6-3, IEC61000-6-1		
Harmonics	IEC 61000-3-12, IEC 61000-3-2		
Country-Specific Grid Codes	• CEI021:2012+V1:2013, CEI016:2014 + V1:2014 • VDE AR-N 4105:2011 • RD1699, RD1663, RD661, P.O.12.3 • G83-1/1:2003, G59-1/2:2011		
Anti-islanding	IEC 62216		
Efficiency	BS EN 50530:2010+A1:2013		

Remarks

(*) Measured with DC input 500V

7 EFFICIENCY DIAGRAMS

Soleil 30kW