The document is a patent application published under the Patent Cooperation Treaty (PCT). It describes a high-concentration photovoltaic module that includes a plurality of first concentrating optical systems, each comprising a Fresnel lens (10) of the SoG type, which is realised on a single frontal glass pane (12) and which concentrates the solar radiation (11) onto a photovoltaic receiver (21), provided with a multi-junction photovoltaic cell (14) and to which a second concentrating optical system (22) is coupled, which conveys and further concentrates the solar radiation (11) onto the photovoltaic cell (14).
HIGH CONCENTRATION PHOTOVOLTAIC MODULE

The present invention relates to a new modular system for high-concentration photovoltaic generation.

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In more detail, the invention relates to a solar light concentrating device, a photovoltaic receiver and a high-concentration photovoltaic module, obtained using the concentrator and receiver devices, as well as the relative generator.

A concentrating photovoltaic generating system is known which usually comprises a series of cells (termed photovoltaic cells), which convert solar light in input into electrical energy, and at least a concentrator device, which enables concentrating the solar light on the above-mentioned cells. The concentrator device can be made of reflecting type (mirrors) or a lens type devices.

The factor of concentration can be calibrated to best effect with both lenses and mirrors.

However lenses pose greater limitations because of the inevitable chromatic aberrations due to refraction.

Photovoltaic concentration systems have a greater complexity than the traditional photovoltaic systems; therefore, in order to minimise costs and make them competitive it is necessary to minimise the most expensive components they are made of, i.e. the cells.

This means increasing the concentration factors to the highest possible levels so that the cells can be as small as possible and their effect on overall costs is insignificant.

Photovoltaic concentrators are organized in regular matrices to constitute the modules.

Again in relation to the competitiveness of the solutions obtained the matrices must be realisable in a simple way with only a few assembly operations.

While on the one hand an advantageous solution has not yet been found for manufacturing a complete reflector matrix, over recent years a technology has been refined which enables construction, with low manufacturing costs, of matrices of Fresnel lenses on glass, known as SoG (Silicone on Glass) lenses, which are lenses made of silicone and
printed on flat panes of glass. This technology has enabled obviating a significant limitation of Fresnel lenses for photovoltaic applications, which is represented by the poor durability of items moulded in plastic materials.

Owing to the materials used (glass on the external surface, silicone on the internal surfaces), SoG lenses have a long working life (tens of years), even when continually exposed to sunlight. The main limitation of SoG lenses is constituted by the limitation in the realisable factors of concentration, which rarely reach beyond 400X.

The other limitations of SoG lenses are as follows:

- chromatic aberration, which displaces the focalisation into focal planes having different heights on the cells because of the light wavelengths; thus the cells are not uniformly illuminated;
- dependence of the focal length on the working temperature (which modifies the refractive characteristics of silicone).

Another problem encountered in realising concentrator modules is the management of the heat concentrated on the photovoltaic cells. The need for specific devices (heat sinks) for dissipating the heat increases in a usually unacceptable way the cost and complexity of the concentrator photovoltaic modules.

The aim of the present invention is therefore to obviate the above-described drawbacks and, in particular, to realise a module for high-concentration photovoltaic generation that uses Fresnel lenses, for example of the SoG type, and which enables obtaining a high factor of concentration, greater than 1100X, with high optical system efficiency, given equal dimensions and number of photovoltaic cells used, with respect to the prior art.

A further aim of the present invention is to realise a module for high-concentration photovoltaic generation that enables dissipation of the heat concentrated on the cells without any need for additional heat sinks.

A further aim of the present invention is to realise a concentrator device and a photovoltaic receiver device that can be used in modules for high-concentration photovoltaic generation according to the present invention.

A further aim of the invention is to realise a high-concentration photovoltaic generation system having a significant competitive advantage in terms of simplicity and rapidity of installation, as well as a considerable reduction in working costs, by virtue of the characteristics of the module and the
mounting and installation system, with respect to traditional constructional solutions.

These and other aims are attained by a module for high-concentration photovoltaic generation according to appended claim 1; other detailed technical characteristics are disclosed in the following claims.

Further characteristics and advantages of a module for high-concentration photovoltaic generation according to the invention will more fully emerge from the description that follows, relative to a preferred embodiment thereof given by way of non-limiting example, and from the appended drawings, in which:

- figure 1 illustrates an optical system on which the module for high-concentration photovoltaic generation according to the invention is based;
- figure 2 is a partial view of the module for high-concentration photovoltaic generation according to the invention;
- figure 3 is a transversal section of a module for high-concentration photovoltaic generation according to the invention;
- figure 4 is an overall view of a receiver used in the module for high-concentration photovoltaic generation according to the present invention;
- figure 5 is a section view of the HCPV receiver of figure 4, according to the invention;
- figure 6 is a partial view of the electrical connections used in the module for high-concentration photovoltaic generation according to the present invention;
- figure 7 is a lateral view of the case for the module for high-concentration photovoltaic generation, according to the present invention;
- figure 8 is an overall view of one of the heads of the case of figure 7, according to the present invention;
- figures 9 and 10 show some constructional details of the module for high-concentration photovoltaic generation, according to the present invention;
- figure 11 is a section view of a component of the module for high-concentration photovoltaic generation, according to the present invention;
- figure 12 is an overall perspective view of a generator using a
series of modules for high-concentration photovoltaic generation, according to the present invention;
- figures 13A and 13B illustrate, respectively, a lateral view and a front view of the generator of figure 12, according to the present invention;
- figures 14A and 14B show two perspective views of combination of modules for high-concentration photovoltaic generation, according to the present invention;
- figure 15 is an exploded view of the generator of figure 12, according to the present invention;
- figure 16 is a diagram of the electrical connections of a combination of modules for high-concentration photovoltaic generation, according to the present invention;
- figure 17 is a block diagram of the inverter used in the module for high-concentration photovoltaic generation, according to the present invention.

With reference to the mentioned figures, the new high-concentration photovoltaic (HCPV) module 20, according to the present invention, is based on a concentrator optical system comprising a Fresnel lens 10 of the SoG (Silicone on Glass) type, which incorporates a glass pane 12 and which concentrates the solar radiation 11 onto an HCPV photovoltaic receiver 21 constituted by a substrate 24 and by a multi-junction photovoltaic cell 14 to which a secondary optical element system (SoE) 22 is coupled, which conveys and further concentrates the solar radiation 11 on the photovoltaic cell 14.

The photovoltaic module 20, which is the object of the present invention, comprises, in particular, an assembly of 72 concentrator optical elements of the type schematically drawn in figure 1, organised into a matrix of 6 elements x 12, as illustrated in figure 2, in which the front glass 12 incorporating the Fresnel lenses 10 is not indicated.

More specifically, the concentrators are assembled in an aluminium case 17 made using an assembly of appropriately-bent aluminium sheets, as illustrated in figures 2 and 3.

In particular, figure 3 illustrates a transversal section of the HCPV module 20, which shows a series of receivers 21 assembled on the bottom 23 of the case 17 of the module 20 (in particular, in figure 3, 9 x 6 = 54 of the 72 receivers 21 constituting the module 20 are visible).
The Fresnel lenses 10 are made on a single frontal glass pane 12, by means of a printing process of the silicone obtained starting from a metal matrix which reproduces, in negative, the profile of the lenses; the 72 lenses are printed together in a single step on the glass pane 12.

The dimensions of the module 20 can be, for example, about 1142 x 590 x 200 mm and each lens 10 has, in this example of dimensioning, an area of about 92 x 92 mm.

Also in this example, the multi-junction photovoltaic cell 14 is 3 x 3mm and the geometric concentration factor is about 1100X.

The overall performance of the optical system is greater than 80% and together with the use of the cells 14 having a performance of greater than 40%, the conversion performance of the whole module 20 is greater than 32%.

Figures 4 and 5 illustrate the HCPV receiver 21, comprising the second optical system 22, formed by an optical prism, preferably trunco-pyramidal, made of quartz or glass, which functions as a concentrating optical guide due to a total reflection of light rays on the inclined faces of the trunco-pyramidal prism, and which is assembled on the photovoltaic cell 14.

The optical prism acts as a conveyor and/or a concentrator of the light concentrated by the lens 10, enabling obtaining a high overall concentration of greater than 1000X.

A further aim of the SOE optical system 22 is the homogenization of the light, in both the spatial and spectral senses; in fact, the SOE optical system 22 is designed so as to obtain a homogeneous distribution of the light on the surface of the photovoltaic cell 14 and cancel the chromatic aberrations, so that the cell 14 operates in the ideal conditions.

In fact, the multi-junction cells, constituted by many stacked cells (having a plurality of cells superposed one on another), suffer in particular from chromatic aberrations and, if the light distributions on the various cells (dependent in general on the radial position and the spectral distribution) are not homogeneous, the fill factor (parameter that describes the I-V curve performance) assumes low values and compromises the efficiency of the whole system.

The described system enables obtaining factors of concentration of up to 2000X, thanks to the use of the quartz or glass SOE system 22, suitably combined with the Fresnel lens 10, at the same time maintaining an excellent spatial and spectral homogeneity on the photovoltaic cell 14.
The concentration factor is in fact one of the fundamental parameters for obtaining a reduction in the overall cost of the system and it is important to maintain this factor as high as possible in order to make the system competitive.

The concentration systems based on the Fresnel lenses according to the prior art are usually made with reflective SOEs and the concentrator systems they are used in do not obtain such high concentration factors, with high light uniformity on the cell; alternatively concentrator systems are used with Fresnel lenses that make no use of secondary optics, but in this case the factor of concentration does not exceed a few hundreds of units.

The other critical points that have not yet found compelling responses in relation to concentrating module of a traditional type relate to:

- cost reduction of the parts required for the cooling of the heat produced by each single photovoltaic cell;
- minimisation of the cost of the electrical connections among the various receivers constituting the module;
- simplification of the assembly of the receivers internally of the module;
- realisation of a simple and low-cost casing.

All of these elements are in part in reciprocal contradiction; in fact, if on the one hand by reducing the dimensions of each single receiver thermal dissipation is simplified, at the same time the connection costs and assembly costs of the receivers rise as a result of the increase in their number.

The realising of the case itself poses important mechanical challenges in term of precision, inasmuch as the smaller the receivers, the greater the problems of alignment, and, consequently, the more problematic the mechanical construction thereof.

The new solution proposed, according to the present invention, is optimal as the dimensioning of the module is such that each photovoltaic cell is subjected to a maximum thermal potential of about 6÷8 W.

In these conditions, thanks to the proposed solution, it is possible to efficiently disperse the heat without the addition of heat sinks, simply by using the aluminium bottom 23 of the module 20.

In these conditions, each photovoltaic cell 14 provides an electrical potential of about 3W and it is possible to set up an HCPV module 20 having about 0.7 m² of surface and constituted by 72 cells, with an outlet
potential of higher than 200W.
With respect to other solutions realised, using many lower power cells, the disclosed invention minimises the number of cells and thus also minimises the cost of the electrical connections and the assembly cost of the HCPV receivers 21 internally of the module 20.

This simplification is made possible by the original fixing methods and "thermal connection" of the receivers 21 on the aluminium bottom 23 of the module 20, as described in the following part of the description.

Figure 5 schematically illustrates the HCPV receiver 21 assembled on the aluminium bottom 23 of the HCPV module 20.

In particular, the optical system 22 of the receiver 21 is constructed on a substrate 24 made of DBC (Direct Bonded Copper), which is made up of a ceramic nucleus (alumina) 25 of about 400 μm thickness, clad by two copper sheets 26 of about 300 μm thickness each.

The photovoltaic cell 14 is appropriately mounted on the substrate 24, the lower side of which is solidly connected to the upper copper sheet 26 of the DBC substrate 24.

Both the electrical and the thermal bondings are made by means of an epoxy resin layer 27 having high thermal conductivity (C > 20 W/(m²k)).

The depositing of the layer of resin 27 is achieved industrially with an easily-automatable high-production low-cost screening process, followed by a depositing of the cell 14 using a die-attach process, followed by kiln-firing at a temperature of a few hundred degrees.

The mechanical connection of the SOE system 22 to the cell 14 is advantageously realised using a layer 28 of silicone glue having high optical transparency and deposited on the photovoltaic cell 14 before assembly of the prism of the optical system 22.

Once the cell 14 has been mounted, each receiver 21 is prepared with the prism prior to final assembly of the module 20.

The use of the layer 28 of silicone glue simplifies the assembly process of the prism, since no type of additional mechanical support is necessary on the receiver 21.

This is made possible, in particular, by the dimensioning of the receiver 21, since, as the cell 14 is of small dimensions (about 3X3mm), the SoE prism has a mass of only a few grams which thus enables fixing using only the layer 28 of silicone glue, without additional supports.

Each receiver 21 is lastly assembled on the aluminium bottom panel 23 of
the HCPV module 20 and glued there with a layer 29 of glue or conductive resin (for example of the silicone type or epoxy type) characterised by good thermal conductivity (C > 0.7 W/m*k).

The assembly can easily be automated by use of an anthropomorphic robot or an automatic x-y-z positioner with a special pick-up tool; further, the layer 29 of conductive glue can be preliminarily dispensed automatically on the rear side of each receiver 21 before assembly.

According to the assembly diagram illustrated in figure 5, it is thus possible to obtain an excellent heat spreading performance of the assembly.

In fact, for example, with a potential of about 7W on each photovoltaic cell 14 and with an ambient temperature of 25°C, the temperature of the photovoltaic cell 14 is brought to about 80°C and the temperature of the bottom 23 of the module 20 to between 60°C and 70°C, without necessarily having to add other dissipating elements of the heat from the receivers 21, as the aluminium bottom 23 alone, though slim, is sufficient to manage the heat dispersion.

The simplicity of the assembly is clearly an advantage of the present solution with respect to the prior art, given same performance levels.

All the receivers 21 of the module 20 are electrically connected in series one to one another.

The electrical connections are made by using wires or bridges 30 in unclad copper, profiled and suspended at a sufficient height for guaranteeing electrical isolation from the metal parts, as shown in detail in figure 6.

The connecting bridges 30 can be welded to the receivers 21, once the receivers 21 are assembled on the aluminium bottom 23 of the module 20.

The welding of the two sides of each copper bridge 30 can be advantageously carried out by a robot welder, which not only can weld the two terminal points but can also appropriately position each bridge 30 in the module 20.

The connecting bridges 30 are made of unclad copper so as to prevent the concentrated light rays internally of the module 20, in a case of defocalisation, from burning any isolating claddings made of a plastic material, striking the electrical connections.

The disclosed solution thus solves a problem that is characteristic of concentrating modules without the addition of protective gaps between the receivers and the lenses, as usually happens in traditional photovoltaic modules of known type.
The two end heads of the electrical connection, which constitute the output of the module 20, are connected to an output connector 31, which is screwed on the rear panel of the module 20.

To protect the connector 31 from the concentrated solar rays, a board 32 bearing a printed circuit (PCB) 32 is advantageously placed with the coppered side facing upwards, which also functions as an interconnecting board between the series of receivers 21 and the output connector 31, as shown in detail in figure 6.

The casing 17 of the module 20 is constructed starting from a single sheet 33 of aluminium, realised with a double-bend 34 for stiffening the structure of the module 20 in a longitudinal direction (according to the profile shown in detail in figure 7), which constitutes a sort of main "cover".

This solution enables obtaining a structure of the module 20 that is sufficiently rigid, enables maintaining the receivers 21 correctly spaced with respect to the upper glass pane 35 (provided with silicone lenses on the internal side) and gives the whole module 20 the necessary longitudinal rigidity (to which the lateral double-bends 34 significantly contribute, as mentioned in the foregoing).

The casing 17 of the module 20 is completed by the heads 35 (shown in detail in figure 8), also made of aluminium, which are fixed to the sheet 33 with silicone sealant along the whole edge (portions denoted by reference numeral 36 in figure 8).

The heads 35 are also fashioned by pleating from flat sheets or can be pressed, also from slim flat sheets; the thickness of all the walls of the module 20 can be chosen to be from 1 to 2 mm.

A valve 37 is positioned on the lower bottom 23 of the module 20, which valve 37 enables a sort of "breathing" of the module 20 (as shown in detail in figures 9, 10 and 11).

In fact, the valve 37 sets the internal atmosphere of the module 20, which is sealed in all parts thereof, in communication with the external atmosphere, via an air-exchange conduit 40 towards an inside of the module 20 and an air intake duct 41 of air from outside; the valve 37 is constituted by a labyrinth constructed for preventing introduction of water and dust internally of the module 20, but at the same time enabling air exchange between the inside and outside the module 20 via the above-mentioned conduit 40 and duct 41.

The particular construction of the valve and the positioning thereof in the
module guarantee protection from entry of rainwater in all the possible spatial orientations of the module itself.
In practice, the valve 37 comprises two shells 38, 39 made of moulded plastic and glued to one another and the fixing to the bottom 23 of the module 20 is realised using silicone glue which also acts as a sealant.
A fine-metal net (denoted by reference numeral 42 in figure 11) can be inserted for improving the dust-blocking action, in a case in which the module 20 is used in desert environments and/or environments characterised by a high level of environmental dust.

The module 20 is used as a base element for realising a high-concentration photovoltaic generator 50 (HCPV), shown in its entirety in figures 12, 13A and 13B, which is constituted by 144 modules (of the type denoted by reference numeral 20 and described up to this point), mounted on a solar tracker 43 having a high degree of angular precision.
The tracker 43 is realised with appropriate kinematic mechanisms in order to enable it to rotate by 360° about a horizontal axis, thus enabling a positioning of modules 20 "face down" so as to facilitate the periodical cleaning operations.
Further, the modules 20 are grouped on the generator 50 in maxi-modules (shown in detail in figures 14A and 14B), i.e. groups of eight modules 20, all housed on a light metal frame 44.
The modules 20 of each group are pre-aligned in the factory, in such a way that the optical axes thereof are parallel, by means of a mechanical calibration effected before the modules 20 are sent for assembly in the field; this aligning operation, carried out in a controlled environment, considerably simplifies operations in the field, thus reducing installation costs.
The other parts of the solar tracker 43 are also constructed in such a way that during the manufacturing stage a pre-calibration is carried out; this prevents a subsequent calibration in the field, as long as the assembly of the various parts is done following the coded combinations (by way of example, figure 15 shows in detail the assemblable parts of the tracker 43, as well as three of the eighteen maxi-modules (groups of eight modules 20) which constitute the whole photovoltaic generator 50).
The electrical output of each module 20 is connected to a dedicated energy converter; this converter can be of two types, i.e. a DC/DC converter or a DC/AC inverter.
In the case of use of a DC/DC converter, each DC/DC converter integrates an MPP (Maximum Power Point) tracker and a DC/DC power converter with an isolated output suitable for injecting direct current onto a common bus at 400-600V (as shown in figure 16), which illustrates with a single-wire diagram the electrical connections of the modules belonging to a maxi-module constituted by eight modules.

The outputs of all eighteen maxi-modules of the generator are in turn connected in parallel and cabled to the input of a DC/AC inverter having a power corresponding to a sum of all the single DC/DC converters (45) connected, for injection of the generated energy into the electric grid.

The presence of a maximum power point tracker (MPPT) circuit associated to each module enables maximising the performance of the system since all the modules are independent of one another from the electrical point of view.

In this way, any decay in performance of a single module does not penalise the performance of the others; this architecture prevents, for example, one or more of the modules from compromising the overall performances of the generator due to an unexpected soiling or ageing thereof.

In a case of use of a DC/AC converter, the architecture is once more the one shown in figure 16, in which the converters are complete inverters, each equipped with MPPT and inverter with sinusoid single-phase output (230Vac) suitable for injection of power into the public electricity grid; in this case too, the outputs of the converters are all connected in parallel to one another and the eighteen maxi-modules are grouped into a three-phase circuit (six maxi-modules for each phase) and connected to the electrical grid at 400VAC with neutral.

The DC/AC inverter is the most complete component, internally including also the DC/DC converter described in the foregoing, which constitutes the relative sub-assembly at the input phase.

The DC/AC module inverter, as shown in the block diagram of figure 17, comprises the following blocks on the DC/DC side (module 20 side):

- the DC/DC power conversion circuit 55, of the isolated flyback type, which has the task of raising the voltage VM generated by the module 20 from about 200Vdc to about 400Vdc; this first stage also provides electrical insulation from the AC side;
- a service power supply 46, which has the task of generating the
service voltages necessary for the functioning of the control circuits on the AC side;
- a microcontroller 47, combined to a control logic, which has the task of managing the energy conversion, the diagnostics and the opto-isolated communication with the radio communication system 53.
- a radio communication system 53, provided with an antenna 54 for centralising the data and software updates (in a case where the DC/AC part is not present, the radio communication system 53 is only connected to the microcontroller 47 of the DC/DC input phase).

The following blocks are present on the DC/AC side:
- a DC/AC converter 48 of the BUCK type which has the task of dispensing energy into the grid (VR);
- a service power supply 49, which has the task of generating the service voltages necessary for the functioning of the control circuits on the AC side;
- an auxiliary power supply system 51 of the DC side, starting from the AC side, usable when the module 20 does not supply energy to the DC side;
- a microcontroller 52, combined to a control logic, which has the task of managing the energy conversion, the diagnostics and the opto-isolated communication with the radio communication system 53;

The microcontroller 47 (DC side) has as its main task that of maximising the power extracted from the module 20, and, in particular, the software run by the microcontroller 47 enables:
- verifying the status of the input voltage and the service voltages;
- measuring the internal temperature of the device;
- evaluating whether to switch the converter 55 on or not;
- determining the working point of the converter 55;
- implementing an MPPT algorithm for maximising the power extracted from each photovoltaic module 20.

The microcontroller 52 (AC side) has as its main task that of dispensing to the grid all the available power and, in particular, the software run by the microcontroller 52 enables:
- verifying the status of the rail voltage (VRR) and the service voltages;
- measuring the internal temperature of the device;
- measuring the voltage of the VR grid;
- evaluating whether to switch the converter 48 on or not;
- determining the working point of the converter 48;
- implementing an algorithm for maximising the current to be sent into the
  grid.

In both types of converters (DC/DC converter and inverter DC/AC) the first
conversion phase is the DC/DC 45 phase, realised, with a high-frequency
switching architecture of the flyback type, optimised in performance (up to
98%) and controlled by the microcontroller 47, which regulates the power
extracted from the module 20 by means of the regulating of the switching-
on duty-cycle of the switching transistor.

During normal functioning, the regulating of the \( t_{on} \) of the switching
transistor, by the microcontroller 47, is not done in order to maintain the
output voltage VRR of the DC/DC phase constant, but to maintain the
voltage on the module 20 constant at a value prefixed by the MPPT
algorithm.

On the DC/AC side, the microcontroller 52 manages the converter 48 by
injecting an alternating current into the grid so that the continuous voltage
VRR is maintained, regulated at the desired value.

In this way, on the one side, the DC/DC converter 45 extracts the
maximum potential available from the module 20, while, on the other side,
the DC/AC converter 48 injects it into the grid, controlling that the
intermediate voltage is maintained at the correct value.

A special function carried out by the DC/DC converter 45 is the V-I
scanning of the module 20; this function, entirely original, enables rapidly
varying the duty-cycle of the switching transistor of the input flyback 55
from the minimum value to the maximum value, by passing the converter
through all the possible statuses in a short time interval (of the order of
milliseconds).

Each different status of the DC/DC power converter 55 is recorded and
memorised by the microcontroller 47 which records the values \((V_{in}, I_{in})\)
associated thereto.

In this way, the DC/DC microcontroller 47 provides a table of values which
constitutes the V-I curve of the connected module 20 in that particular
irradiance condition.

The recorded values are transmitted to the rest of the system by means of
the radio interface incorporated in the inverter.

In this way, the photovoltaic system can, at any moment, acquire the V-I
curve of any one of the modules 20 which constitute the generator 50 for diagnostic purposes, without any need for using additional monitoring devices.

The system is therefore provided, in a very integrated way, with powerful real-time diagnostics that enable a detailed verification of the functioning of the performance of each single module 20. Further, the scanning function of the input can be started up periodically without significantly affecting the overall performance of the system as it is completed within a fraction of a second.

From the description, the characteristics of the structural module for high concentration photovoltaic generation, object of the present invention, clearly emerge, as do the advantages thereof.

In particular, these advantages are represented by:

- use of SoG Fresnel lenses with a very high concentration factor, up to 2000X, as well as a high degree of spatial and chromatic uniformity of the light on the photovoltaic cell;
- use of "dielectric" SOEs made of quartz or glass of small dimensions and simple fixing on the photovoltaic cell;
- use of a photovoltaic receiver based on a DBC substrate, of small dimensions, able to effectively disperse the thermal potential concentrated on the cell;
- fixing the SOE to the cell based on simple gluing using transparent silicone resin;
- fixing the cell to the substrate by means of epoxy resin having a very high thermal conductivity;
- fixing the receiver to the bottom of the module using a glue having a high thermal conductivity;
- use of only the bottom of the module as a heat sink, without additional elements;
- electrical connections between the receivers of the module effected via unclad copper wires, automatically welded between one receiver and another;
- an original output connection system with a small printed circuit, which enables protecting the plastic connector from the out-of-axis concentrated solar rays;
- elimination of the need to use gaps for protection from the out-of-axis concentrated solar rays internally of the module;
the casing for the module constructed from flat aluminium sheets in three pieces and realised using a lateral cover with multiple longitudinal pleating for obtaining the necessary rigidity and two aluminium heads of the same thickness of the cover obtained by bending or pressing;

- use of a moisture regulating valve of simple construction and effective isolation from water and dust;

- realising an HCPV generator of 144 modules, which can rotate by 360°C about a horizontal axis;

- pre-assembly of the modules in maxi-modules of eight elements pre-calibrated in the factory;

- pre-calibration of the alignment of the various parts of the tracker in the factory, so that field assembly does not require the use of specialised personnel;

- electrical conversion architecture based on a power converter for each HCPV module, which can be of the DC/DC or DC/AC type, with a consequent independence of the performance of the various modules and non-sensitivity of the system to a non-homogeneous fall in performances;

- use of the DC/AC converter, one for each HCPV module, with two microcontrollers which manage, in cooperation with one another, the two conversion sides, and a radio interface of the spread-spectrum type for communication with the rest of the system;

- DC/AC or DC/DC which has a scanning function of the V-I curve of the module to which it is connected; this function can be commanded by the HCPV system for the purpose of periodical diagnostics.

Lastly, it is clear that numerous other variants might be made to the photovoltaic module in question, without forsaking the principles of novelty of the inventive idea, while it is clear that in the practical actuation of the invention, the materials, the shapes and the dimensions of the illustrated details can be of any type according to requirements, and can be replaced by other technically equivalent elements.
CLAIMS

1. A high-concentration photovoltaic module (20), characterised in that it comprises a plurality of first concentrating optical systems, each comprising a Fresnel lens (10) of the SoG type, which is realised on a single frontal glass pane (12) and which concentrates the solar radiation (11) onto a photovoltaic receiver (21), provided with a multi-junction photovoltaic cell (14) and to which a second concentrating optical system (22) is coupled, which conveys and further concentrates the solar radiation (11) on the multi-junction photovoltaic cell (14).

2. The photovoltaic module (20) of claim 1, characterised in that said concentrating optical systems are assembled internally of a casing (17) realised by an assembly of bent metal sheets.

3. The photovoltaic module (20) of claim 2, characterised in that said photovoltaic receivers (21) are assembled on a metal bottom (23) of said casing (17) of the module (20).

4. The photovoltaic module (20) of at least one of the preceding claims, characterised in that said second concentrating optical system (22) comprises an optical prism, made of quartz or glass, which functions as a concentrating optical guide due to a total reflection of light rays onto the inclined faces of said prism, said optical prism being assembled on the photovoltaic cell (14).

5. The photovoltaic module (20) of claim 4, characterised in that said optical prism (22) is constructed on a metal substrate (24), which is made up of a ceramic nucleus (25), clad by two copper sheets (26), a photovoltaic cell (14) being mounted on said metal substrate (24), a lower side of which is electrically and thermally connected to one of the copper sheets (26).

6. The photovoltaic module (20) of at least one of the preceding claims, characterised in that said photovoltaic receivers (21) are reciprocally electrically connected in series, by wires or bridges (30) made of unclad copper, profiled and suspended at a determined height from the bottom (23) of said case (17) of the module (20), and terminal ends of said connecting wires (30) in output from said module (20) are connected to an output connector (31), screwed on a rear panel of the module (20).

7. The photovoltaic module (20) of at least one of the preceding claims, characterised in that said casing (17) is made starting from a single metal sheet (33), made with a double-bend (34) for longitudinal stiffening, to
which lateral metal heads (35) are connected, fixed to said metal sheet (33).

8. The photovoltaic module (20) of at least one of the preceding claims, characterised in that a valve (37) is positioned on said bottom (23) of the case (17), which sets the internal atmosphere of the module (20) in communication with the external atmosphere, via an air-exchange conduit (40) towards an inside of the module (20) and an air intake duct (41) of air from outside.

9. The photovoltaic module (20) of claim 8, characterised in that said valve (37) comprises two shells (38, 39) joined to one another and has a labyrinthine internal geometry.

10. The photovoltaic module (20) of at least one of claims 8 and 9, characterised in that a fine-mesh metal net (42) is inserted internally of said valve (37).

11. A photovoltaic generator (50) comprising a plurality of the photovoltaic modules (20) of claim 1, said modules (20) being mounted on a solar tracker (43) able to rotate said modules (20) by 360° and made up of pre-assembled parts.

12. The photovoltaic generator (50) of claim 11, characterised in that said modules (20) are grouped in groups of eight modules (20) each, with each of said groups being housed on a metal frame (44).

13. The photovoltaic generator (50) of claim 12, characterised in that the modules (20) of each group are pre-aligned, in such a way that the optical axes thereof are parallel, by means of a mechanical calibration carried out before assembly of the modules (20) on the generator (50).

14. The photovoltaic generator (50) of at least one of claims form 11 to 13, characterised in that each module (20) is electrically connected in output to a DC/DC energy converter (45) or to a DC/AC inverter.

15. The photovoltaic generator (50) of claim 14, characterised in that said DC/DC converter (45) integrates an MPP tracker and a DC/DC power converter (55) with an isolated output which injects direct current onto a common bus (46).

16. The photovoltaic generator (50) of claim 14, characterised in that the outputs of said groups of photovoltaic modules (20) are connected in parallel and cabled to the input of a DC/AC inverter having a power corresponding to a sum of the powers of the connected DC/DC converters (45).
17. The photovoltaic generator (50) of claim 14, characterised in that a maximum power point tracker (MPPT) circuit is associated to each module (20).

18. The photovoltaic generator (50) of claim 14, characterised in that said DC/AC inverter comprises a DC/DC power converter (55) of an isolated flyback type, which raises and isolates the voltage (VM) generated by said module (20), a first service power supply (46) which generates the service power supplies required for the functioning of the control circuits on the DC side, a first microcontroller (47) on the DC side, which manages the energy conversion, the diagnostics and the communication with a radio communication system (53) of the spread-spectrum type, a DC/AC converter (48) of the BUCK type, which supplies energy into the grid (VE), a second service power supply (49), which generates the service supplies required for functioning of the control circuits on the AC side, an auxiliary power supply system (51) of the DC side usable when said module (20) is not supplying energy to the DC side, a second microcontroller (52) of the AC side, which manages the energy conversion, the diagnostics and the communication with said radio communication system (53), enabled for centralising the data and the software updates.

19. The photovoltaic generator (50) of claim 18, characterised in that said first microcontroller (47) verifies the input voltage status and the service voltage statuses, measures the temperature internally of the generator (50), evaluates whether to switch on, or not, said DC/DC converter (45), determines the working point of said DC/DC converter (45) and implements an MPPT algorithm for maximising the power extracted from each photovoltaic module (20).

20. The photovoltaic generator (50) of claim 18, characterised in that said second microcontroller (52) dispenses all the available power into the grid, verifies the output voltage status (VRR) of the DC/DC phase and the service voltage statuses, measures the temperature internally of the generator (50), measures the grid voltage (VR), evaluates whether to switch on, or not, said DC/AC converter (48), determines the working point of said DC/AC converter (48) and implements a current maximisation algorithm for maximising the voltage to be sent in input to the grid.

21. The photovoltaic generator (50) of claim 18, characterised in that said DC/DC converter (45) performs a V-I scan of each single photovoltaic module (20) that is periodically programmable in such a way that each
different status of said DC/DC converter (45) is recorded and memorised by said first microcontroller (47) by means of a table of values which constitutes the V-I curve of each single photovoltaic module (20) in a determined irradiance condition that is possibly transmitted on request by radio to the rest of the system via the radio communication system (53).
A. CLASSIFICATION OF SUBJECT MATTER

INV. H01L31/054

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Date of the actual completion of the international search

9 May 2016

Date of mailing of the international search report

18/05/2016

Name and mailing address of the ISA

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Fax: (+31-70) 340-3016

Authorized officer

Boero, Mauro
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