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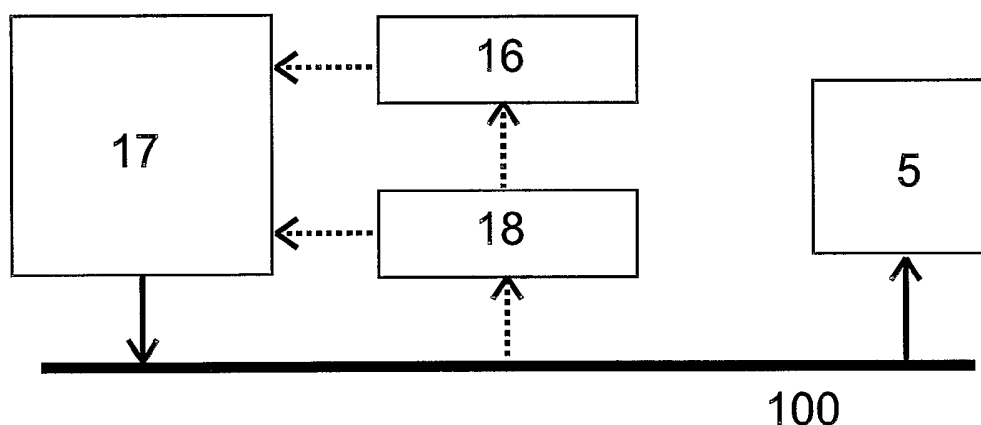
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(54) Title: DISTRIBUTED SYSTEM FOR ELECTRICALLY SUPPLYING A POWER BUS AND METHOD OF CONTROLLING POWER SUPPLY USING SUCH SYSTEM



(57) Abstract: The invention concerns a distributed system for electrically supplying a power bus, comprising a power bus (100) connected to at least one electrical load (5); a supply subsystem comprising a plurality (17) of supply sections (17'), at least two supply sections (17') of said plurality (17) being primary supply sections, that is apt to produce electrical energy starting from other forms of energy, characterised in that each one of the primary supply sections is apt to assume an operating mode selected from a set of operating modes comprising at least two of the following modes: a first mode of maximum power point tracking, a second mode of high power generation, a third mode of regulation; and controlling means (16, CS, CSC, CM, 27) apt to select and control for each primary supply section an operating mode from said set of operating modes. The invention further concerns a method of controlling power, using a power system according to the invention.

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DISTRIBUTED SYSTEM FOR ELECTRICALLY SUPPLYING A  
POWER BUS AND METHOD OF CONTROLLING POWER SUPPLY  
USING SUCH SYSTEM

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5           The present invention concerns a distributed system for electrically supplying a power bus and method of controlling power supply using such system.

          More in particular, the invention concerns a distributed system for electrically supplying a power bus providing a plurality of power supply  
10       sections differently activable according to predefined modes in order to ensure power supply of the power bus according to the demand of the load, safeguarding the same system and hence favouring its duration.

          A particularly advantageous application field of the present invention is that of controlling power supply in spacecrafts. For illustrative  
15       simplicity, we will often refer to this case, but it has to be clear that the present invention is advantageously applicable to any terrestrial case of power supply and power control.

          In the space field, progress of performances and of complexity of functions performed by spacecrafts is associated with a continuous  
20       increase of onboard available power.

          In the past, power increase has been achieved by increasing the size of generating systems and inserting new technology components into apparatuses the architectures of which have remained substantially unchanged since over 30 years.

25       Since this process is becoming more and more expensive (limits on voltages due to electrostatic discharges, limits on currents due to dissipation/ground, and Electromagnetic Interference or EMI), availability of new architectures for power supply systems is becoming an imperative need.

30       Making reference to Figure 1, a generic power system of a spacecraft according to the prior art is supplied by photovoltaic generators FV. Power controlling unit 4 adjusts the voltage distributed to different loads or sub-systems 5 (voltage of the power bus 100) in the several operating modes by means of a switching converter 2. To this end, the  
35       power controlling unit 4 monitors the state of the power bus 100 both before and after such switching converter 2. The power controlling unit 4 still controls energy storage in batteries 1 through a charge/discharge regulator 3.

A very important aspect is represented by the need of controlling in an efficient way the different conditions of electric load: very intense peaks lasting few minutes may occur, but even long period during which the onboard sub-systems absorb power in a very reduced measure, with respect to the productive potentialities of the photovoltaic system.

A graph of the power density of a photovoltaic system as a function of the operating voltage is shown in Figure 2. Characteristics at the beginning of mission ("Begin Of Life", BOL) at low temperature and those at the end of life ("End Of Life", EOL) at high temperature are shown, and respective maximum power point (MPP1 and MPP2) positions are marked.

In fact, power available from a photovoltaic system is subject to great variations depending on lighting intensity, temperature (with a negative value of thermal coefficient related to photovoltaic conversion efficiency), and time spent in orbit (degradation due to exposure to space environment).

Power effectively supplied to the load also greatly depends on the instant value of the electric load 5, because the great nonlinearity of the current-voltage characteristic of solar cells (see Figure 2).

In the past several configurations have been used for the power system of spacecrafts, some of which are particularly efficient in facilitating control of excess of onboard available power (that is important in the initial stages of the mission), while others are optimised for controlling load peaks (that is important for particular missions, such as those of remote sensing with onboard radar and, in general, in the final stages of the mission).

With respect to this group of problems, nowadays there exist specific solutions which however only improve single aspects.

An example comprises solutions aiming at efficiently controlling conditions of reduced electric load.

On purpose to keep bus voltage within predetermined limits, current flow into the load is controlled by appropriate voltage regulators, which dissipates electric power generated in excess by the photovoltaic system.

In order to reduce stresses imposed to regulators, some systems are provided with an additional functionality, allowing them to directly reduce the amount of electric power produced by the generator.

A typical example, much used on European telecommunications satellites, is the "Sequential Shunt Switching Regulator" (S3R) system.

As shown in Figure 3, the photovoltaic system is subdivided into  $N$  equivalent sections FV, each one of which may be either singly connected to the power bus 100 or short-circuited through a corresponding switch 6 for disabling power generation.

A blocking diode 9 is after generators FV.

A capacitive element 8 is in parallel with the electrical load 5.

The number of active sections is automatically adjusted, depending on the power demanded by the load. Fine voltage regulation is carried out by controlling one of the sections according to a "Pulse Width Modulation" (PWM) 11 through a suitable PWM controller 7.

The controller measures voltage  $V_{bus}$  on the power bus 100, after generators FV, and compares it with a reference voltage through a comparator 10. PWM control of one of the sections then occurs by fastly switching ON/OFF the photovoltaic system, with a ratio between times  $T_{on}$  and  $T_{off}$  ("duty-cycle") such that it produces a mean current having the demanded value.

The S3R system is described by D. O'Sullivan, A. Weinberg, in "The sequential switching shunt regulator (S3R)", Proc. of the 3rd Spacecraft Power Conditioning Seminar, Noordwijk, The Netherlands, 21-23 Sept. 1977, pp. 123-131, and it is described in Patents BE853124, US4186336.

The capacity to partially disable electric power production by the primary power supply generation system is very important in the first years of mission, when productive potentialities of the system, that has not yet been subject to degradation imposed by exposure to space environment, are in excess with respect to the absorption by the load 5. When this functionality is lacking, excess power must be consumed onboard, or, alternatively, it must be controlled by the voltage regulators, imposing very heavy operating conditions to these. This situation lasts for the most duration of the mission.

The concept of subdividing the generation system into modules or sections, which may be disconnected from the load in presence of a reduced absorption is kept in Patent US6181115. It discloses a device based on a photovoltaic primary generation system, subdivided into a

plurality of modules, further comprising a storage battery unit. Each module is provided with a three-state control device, as a slave of a central control unit, that determines its state on the basis of the bus voltage and of the charge state the batteries. The given states are: 1) power supply of the bus, 2) power supply of the storage unit, 3) shortcircuit of the module.

Some aspects of such device have been discussed by P. Perol in "An efficient Low Cost modular power system for fully regulated bus in low earth applications", proc. 6th European Space Power Conference, Porto, Portugal, 6-10 may 2002, pp. 375-381.

The above Patent does not mention any mode of regulating the current generated by a single module, nor it provides any other form of generating or storing electrical energy.

Another type of solutions for controlling power is that aiming at efficiently controlling peaks of electrical load.

In order to bridge the gap between the power demanded by the load and that supplied by the photovoltaic system, possibly occurring in different orbit stages because of eclipses or of power absorption peaks, intervention of electrical energy storage systems is required.

Power supplied by storage batteries may be minimised through power conditioning techniques, making the photovoltaic system operate in proximity of the maximum power point ("Maximum Power Point Tracking", or MPPT).

Research of the maximum power point may be conducted by traditional approaches of different types, which are based on iterative algorithms and which reach the point "hooking" condition after a not negligible time, during which batteries are asked for supplying a power higher than that demanded under steady state conditions.

Moreover, during steady state operation, holding the maximum power point is usually carried out by periodically disturbing the operating point of generators FV, so as to check and possibly track the maximum power point position: this operation introduces fluctuations of electrical variables (EMI), which in particular applications may be troublesome.

Use of MPPTs in space systems has been rather limited so far, although it has been subject of studies since years. One of the first paper on this subject has been presented at the Spacecraft electric power

seminar, Frascati, Italy, may 1974: A. Poncin, "Advanced power conditioning using a maximum power point tracking system", pp. 75-86 of the proceedings.

Among the most complete papers appeared in scientific literature, the following ones must be surely cited: C. Hua and C. Shen, "Comparative Study of Peak Power Tracking techniques for Solar Storage System", 13th Applied Power Electronics Conference and Exposition, 15-19 Feb. 1998, pp. 679-685; P.T. Huynh and B.H. Cho, "Design and Analysis of a Regulated Peak-Power Tracking System", IEEE Trans. on aerospace and electronic systems, 35 (1999) pp. 84-91. Patents on the subject have been also filed, among which there is US4794272.

A typical example of power system with MPPT used in spacecrafts is that effectively used for missions Rosetta and Mars Express, and schematised in Figure 4.

The photovoltaic system interfaces with the power bus 100 by means of a series PWM regulator 11, that in normal operating mode controls the switching converter 2 so as to obtain a current flow so to hold the voltage on the load at the desired value.

Together with the intervention of the storage batteries 1, control rule of PWM 11 is changed. In this operating mode, duty-cycle is adjusted so as to hold the operating voltage of the photovoltaic system in proximity of the maximum power point. Such control is carried out by a MPPT controller 12, and it occurs on the basis of the power  $P_{sa}$  detected before the same, that is compared with the maximum power  $Max P_{sa}$ , suitably estimated, through a comparator 13. MPPT controller 12 controls the current flow so as to hold the voltage on the load at the desired value.

Power control, aimed to tracking conditions of maximum power transfer from the photovoltaic system to the load (MPPT), is very important during power absorption peaks, since it allows exploiting at best productive potentialities of the primary generator.

Surely valuable at the end of life of the satellite, when the efficiency of the generation system is degraded because of the exposure to space environment, the MPPT may be useful at the beginning of life as well, for those missions characterised by a load profile greatly variable in time, with demand for intervention of the batteries together with load peaks, as for example in satellites the load of which comprises a radar, or in general in remote sensing satellites in low earth orbit (LEO) which have

to concentrate communications with the land station in a short time period: in these cases use of MPPT allows reducing stresses imposed to batteries, so increasing their duration under the same size conditions or allowing their size to be reduced under the same duration conditions.

5                   Alternatively, some proposed systems provide operating modes allowing obtaining high power generation without resorting to heavy tracking procedures.

                  This is obtained by making the generation system operate in proximity of the maximum power point. They are substantially open loop  
10                   controls, which estimate the position of the maximum power point on the basis of off-line measured values and/or of stored algorithms.

                  For example, a microprocessor system is disclosed in US5530335, in which the program stored on the microprocessor sets the converter duty-cycle to a value that is estimated as corresponding to a  
15                   high output power. Estimation occurs under open circuit conditions, on the basis of a measured voltage value.

                  These systems allow obtaining a fast response to transient with respect to MPPT and an output voltage free of those low frequency residual ripples, which are associated with many tracking algorithms.  
20                   However, the maximum power point is not exactly tracked, and the voltage is not adjusted according to the load necessities.

                  A still different type of solutions of controlling power is that aiming at optimising the restoration of the storage batteries.

                  When exiting an eclipse, it is necessary to restore the charge  
25                   state of the storage batteries. This operation is usually carried out by drawing current from the bus, after the voltage regulator (for example S3R, Rosetta/MEX), as shown in Figure 1.

                  Alternatively, configurations have been proposed that make use of dedicated converters, which are connected to the photovoltaic system  
30                   before the switching converter 2, as shown in Figure 5 (for example the sequential shunt switching series regulator, or S4R).

                  Some aspects of system S4R are protected by Patent US6181115 and they have been discussed by A. Capel, in "Comparative performance evaluation between the S4R and the S3R regulated bus topologies", Proc. of the 6th European Space Power Conference, Porto,  
35                   Portugal, 6-10 May 2002, pp.193-199.

S4R configuration, with battery supply before the regulator, thanks to the charge regulator 3', offers undoubted advantages from the point of view of system efficiency and of control simplicity.

5 From a point of view of implementation, the advantages obtained by directly connecting the regulator 3' of charging the storage batteries 1 to the generation system FV and a discharge regulator 3'' after the switching converter 2 have to be compared with the loss of the MPPT functionality during charging stage, with its consequent slowing down.

10 Moreover, for a particular type of storage batteries, i.e. lithium ion batteries, a very precise voltage control is required in the final stage of charging, that is surely simplified when starting from an already regulated supply voltage.

Also Patent US6246219 insists on the subject. It proposes a variation of string switching shunt regulator, that, in addition to the output  
15 bus, also comprises an auxiliary bus, which may be used for recharging the batteries.

The introduction of the MPPT functionality into S3R system and S4R system has been described by A.H. Weinberg, S.H. Weinberg in "A new maximum power point tracker topology", proc. 6th European Space  
20 Power Conference, Porto, Portugal, 6-10 may 2002, pp. 257-262. The solution is protected by Patent EP1034465. It is a solution providing the insertion of MPPT into both S3R and S4R, with limited configuration modifications, by simply acting on the reference value for the bus voltage, that is set so as to obtain the desired function of tracking the maximum  
25 power point for the whole generation system.

Great attention is devoted to recharging the battery, that occurs by means of dedicated sections, the whole current of which is determined on the basis of the maximum power point: in presence of reduced absorption by the battery, the dedicated sections may also supply  
30 the main bus.

A peculiarity of the method is the fact that it is not provided a single regulation of the operating point of the single sections of the generation system, which may be either connected in direct current or disconnected from the bus.

35 The fact that the monitored operating point refers to the sum of the generated currents constitutes a limit of the described solution, since the located operating point does not ensure that all the sections are

operating under MPPT conditions, because of differences which may occur due to accident causes (for example damages for impacts with micrometeorites) or due to systematic causes (for example differences between panels, shadows or thermal gradients in particular lighting conditions).

Another limit of the proposed solution is the conflict between bus voltage regulation and MPPT system: in the case when supplying the load by means of a not adjusted voltage is not allowed, it is necessary to introduce suitable circuit artifices, with significant system complication, as described by the same authors outside the patent scope.

It is an object of the present invention a distributed system for electrical supply of a power bus that solves the problems described above.

It is a further object of the present invention a method of controlling power using the system object of the invention.

It is specific subject matter of the present invention a distributed system for electrically supplying a power bus, the system comprising:

- a power bus for distributing electrical energy, connected to at least one electrical load;
- a supply subsystem comprising a plurality of supply sections, at least two supply sections of said plurality of supply sections being primary supply sections, said primary supply sections being apt to produce electrical energy starting from other forms of energy, said primary supply sections having an output power varying as the output current varies so as to reach a peak value for a corresponding value of the output current, characterised in that each one of the primary supply sections is apt to assume an operating mode selected from a set of operating modes comprising at least two of the following modes:
  - a first mode of maximum power point tracking, in which a primary supply section supplies the maximum suppliable power to the power bus,
  - a second mode of high power generation, in which a primary supply section supplies a power within a range centred on a predetermined power value to the power bus,
  - a third mode of regulation, in which a primary supply section delivers an amount of power so as to keep one or more electrical variables associated with the system within a predetermined range to the power bus; and

- controlling means apt to select for each primary supply section an operating mode from said set of operating modes, and to control the operating mode of each primary supply section.

Each primary supply section may comprise a plurality of elementary devices for generating primary energy supply.

Preferably according to the invention, at least one primary supply section comprises photovoltaic converters.

Preferably according to the invention, at least one supply section of said plurality of supply sections is a secondary supply section, apt to store electrical energy.

Preferably according to the invention, the set of operating modes further comprises:

- a disabled mode, in which the power delivered to the power bus is lower than a predetermined threshold.

Preferably according to the invention, the absolute value of the output voltage of a primary supply section being in disabled mode is lower than a predetermined threshold value. This is practically equivalent to having a short circuit in disabled mode. Preferably according to the invention, the absolute value of the output current of a primary supply section being in disabled mode is lower than a predetermined threshold value. That is, the circuit is open, the output of the primary supply section is insulated from the power bus.

Preferably according to the invention, the output current of a primary supply section, being in high power generation mode, is kept within a range centred on a determined reference value by the controlling means.

Preferably according to the invention, said reference current value is determined on the basis of the value of the primary supply section output current, measured in disabled mode.

Such value of the primary supply section output current, measured in disabled mode, is equivalent to the value measured when the voltage is lower than a predetermined threshold.

Preferably according to the invention, the output voltage of each primary supply section, being in high power generation mode, is kept at a value close to a predetermined reference voltage value.

Preferably according to the invention, the reference voltage value is determined on the basis of the value of the primary supply section output voltage, measured in disabled mode.

Such value of the primary supply section output voltage, measured in disabled mode, is equivalent to the value measured when the current is lower than a predetermined threshold.

Preferably according to the invention, in regulation mode, one of said one or more system variables is the voltage of the power bus.

Preferably according to the invention, in regulation mode, one of said one or more system variables is the current of the power bus.

Preferably according to the invention, one or more system variables are associated with the system, the operating mode of each one of the primary supply sections being established so that the overall power supplied to the power bus is such that it keeps said one or more system variables within predetermined limits.

Preferably according to the invention, each primary supply section, which is forced to pass to maximum power point tracking mode, leaving a different operating mode, assumes high power generation mode as initial state.

Preferably according to the invention, the system further comprises bus monitoring means which generates signals apt to represent values of one or more electrical variables associated with the system, and sends them to said controlling means.

Preferably according to the invention, said controlling means comprises at least one section controller that determines the operating mode of at least one supply section on the basis of the signals received from said bus monitoring means.

Preferably according to the invention, said at least one section controller determines the operating mode of at least one supply section on the basis of the operating mode of the other supply sections.

Preferably according to the invention, said at least one section controller being apt to be driven by one or more devices external to the system during the operation of the same system.

Preferably according to the invention, said controlling means comprises at least two section controllers.

Preferably according to the invention, each one of said at least two section controllers sending signals to at least another section controller and receiving signals from at least another section controller.

5 Preferably according to the invention, each primary supply section comprises at least one multi-state controller, said multi-state controller controlling power transfer from the primary supply section to which it belongs to the power bus, in accordance with a controlling rule depending on the selected operating mode.

10 Preferably according to the invention, each one of the primary supply sections comprises switchable connection means, said switchable connection means being apt to enable and disable power transfer from the primary supply section to the power bus.

15 Preferably according to the invention, each multi-state controller comprises at least one converter and at least one generation device, the converter being apt to convert the electrical energy produced by said generation device.

Preferably according to the invention, said converter is a switching converter.

20 Preferably according to the invention, each multi-state controller further comprises:

- section monitoring means, apt to generate signals representative of physical quantities describing primary supply section operation conditions,

- state controlling means, at least receiving the signals output by at least one of the following means:

- controlling means,

- bus monitoring means

- section monitoring means,

- and supplying to the converter and to the switchable connection means one or more driving signals apt to keep one or more variables associated with the system within limits foreseen for the operating mode selected for the primary supply section comprising the multi-state controller.

35 Preferably according to the invention, said converter comprises at least one variable conductance device having twofold function of switchable connection means and of switching the current of said converter.

Variable conductance devices may be, for instance, switches, on-off switches, transistors.

Preferably according to the invention, the converter is a boost or step-up converter.

5            Preferably according to the invention, the converter, in high power generation mode, is forced to operate with a predetermined duty-cycle value.

The duty-cycle reference value may be advantageously stored in the corresponding supply section.

10           Preferably according to the invention, at least one secondary supply section comprises at least one kinematic device for storing energy.

Preferably according to the invention, said at least one energy storage kinematic device is at least one flywheel.

15           Preferably according to the invention, at least one primary supply section operates in one of the modes selected from the group:

- voltage regulation, the amount of power supplied to the power bus being controlled so as to keep the voltage of the power bus close to a nominal value;

- regulation, the amount of power supplied to the power bus being controlled so as to keep one or more electrical variables associated with the system within predetermined limits;

- maximum power point tracking, the amount of power supplied to the power bus (100) being kept close to the maximum power point;

- disabling, power transfer towards the power bus not occurring.

25           Preferably according to the invention, in regulation mode the controlled variable is the voltage of the power bus.

Preferably according to the invention, in regulation mode the controlled variable is the current of the power bus.

30           Preferably according to the invention, each one of the secondary supply sections also comprises:

- section monitoring means, apt to monitor the charge state of the secondary supply sections and to consequently generate signals representative of the same state and of the electrical system variables describing the operating conditions of the same secondary supply section, said signals being sent to the state controlling means.

35           Preferably according to the invention, each one of the secondary supply sections also comprises either a charge/discharge

regulator or a discharge regulator and a charge regulator connected to the power bus.

Preferably according to the invention, each one of the secondary supply sections comprises:

- 5                   - section controlling means, which at least receives the signals output by the bus monitoring means and by section monitoring means, and which outputs, either towards the charge/discharge regulators or towards the discharge regulators and the charge regulators, driving signals apt to keep electrical variables associated with the system within  
10 limits foreseen for the operating mode selected for the secondary supply section considered from time to time.

Generic driving signals are considered, which may reach devices internal to the secondary supply section or even possible external devices.

- 15                   Preferably according to the invention, the system further comprises an auxiliary bus.

Preferably according to the invention, each supply section of said plurality of sections is apt to be singly set for supplying energy to the power bus or to the auxiliary bus.

- 20                   Preferably according to the invention, each primary supply section, when supplying energy to the auxiliary bus, is apt to assume at least one of the operating modes provided for supplying energy to the power bus.

- 25                   Preferably according to the invention, at least one secondary supply section is apt to receive power from the auxiliary bus.

In the system according to the invention either all or part of the primary supply sections connected from time to time to the auxiliary bus may be used for regulating charging of the secondary supply sections.

- 30                   In this case, making reference to the use of batteries as energy storage devices, the control system will preferably contain a "Battery Error Amplifier" (BEA), apt to produce a signal representative of the charge state of the battery. If there are at least two batteries, each one will have its own "Battery Charge Regulator" (BCR); in this case, the auxiliary bus may be still used, but it has to be regulated in maximum power tracking or high  
35 power generation mode.

It is further specific subject matter of the present invention a method of controlling power, using a power system subject of the

invention, the method being apt to use said controlling means so that each primary supply section assumes an operating mode selected from said set of operating modes.

5 Preferably according to the invention, the method comprises the steps of:

- establishing the number of supply sections supplying energy to the power bus so that the overall power supplied by said supply sections is sufficient to supply the load in the foreseen conditions;
- in presence of a power absorption by the load lower than the maximum power available from one of the primary supply sections, keeping:
  - at least one primary supply section in voltage regulation mode,
  - at least one primary supply section in disabled mode,
  - 15 - one or more secondary supply sections in a mode in which they do not supply energy to the power bus.

Preferably according to the invention, the method further comprises the step of:

- in presence of a power absorption by the load higher than the maximum power available, in the specific operating modes, from the set of all the primary supply sections, keeping:
  - at least one of the secondary supply sections in a mode in which it supplies energy to the power bus, having determined the number of the secondary supply sections operating in said mode in such a manner to obtain an overall power sufficient to supply the load,
  - 25 - all the primary supply sections in maximum power point tracking mode.

Preferably according to the invention, the method further comprises the step of:

- in presence of a power absorption by the load higher than the maximum power available from the set of all the primary supply sections, keeping:
  - at least one of the secondary supply sections in a mode in which it supplies energy to the power bus, having determined the number of the sections operating in said mode in such a manner to obtain an overall power sufficient to supply the load,
  - 35

- at least one of the primary supply sections in voltage regulation mode,
- all the primary supply sections, not being in voltage regulation mode, in maximum power point tracking mode.

5 Voltage regulation by the primary supply sections together with secondary supply sections simplifies the control rule for setting the mode of the primary supply sections.

Preferably according to the invention, the method further comprises the step of:

10 - in presence of a power absorption by the load higher than the maximum power available from one of the primary supply sections, and lower than the maximum power available from the set of all the primary supply sections, keeping:

15 - at least one primary supply section in voltage regulation mode,

- at least one primary supply section in high power generation mode, having determined the number of sections operating in this mode in such a manner to supply the load,

20 - all the secondary supply sections in a mode in which they do not supply energy to the power bus.

Preferably according to the invention, the method further comprises the step of:

25 - in presence of a power absorption by the load higher than the maximum power available from one of the primary supply sections, and lower than the maximum power available from the set of all the primary supply sections, keeping:

30 - at least one primary supply section in voltage regulation mode, - at least one primary supply section in maximum power point tracking mode, having established the number of sections operating in said mode in such a manner to supply the load,

- all the secondary supply sections in a mode in which they do not supply energy to the power bus.

Preferably according to the invention, the method further comprises the step of:

35 - keeping in disabled mode the sections which do not supply energy to the power bus.

Preferably according to the invention, the method further comprises the step of:

- establishing the number of sections supplying energy to the auxiliary bus so as to obtain an overall power sufficient to supply the same auxiliary bus.

Preferably according to the invention, the method further comprises the step of:

- selecting the supply sections supplying energy to the auxiliary bus among those not used for supplying energy to the power bus.

Preferably according to the invention, the method further comprises the step of:

- keeping in disabled mode the sections which are not used for supplying energy to the power bus nor to the auxiliary bus.

Preferably according to the invention, the method further comprises the step of:

- keeping at least one of the primary supply sections connected from time to time to the auxiliary bus in voltage regulation mode, and all the other ones in maximum power point tracking mode.

Preferably according to the invention, the method further comprises the step of:

- keeping at least one of the primary supply sections connected from time to time to the auxiliary bus in voltage regulation mode, and all the other ones in high power generation mode.

Preferably according to the invention, the method further comprises the step of:

- when the charge state of the secondary supply section is lower than a predetermined charge state, delivering towards the auxiliary bus the output power of at least one primary supply section.

Preferably according to the invention, the method further comprises the step of:

- keeping at least one primary supply section among those connected to the auxiliary bus in current regulation mode, and all the remaining primary supply sections connected to the auxiliary bus in maximum power point tracking mode.

Preferably according to the invention, the method further comprises the step of:

- setting at least one primary supply section, among all those connected to the auxiliary bus, in regulation mode, the regulated variable being the current, and all the remaining primary supply sections connected to the auxiliary bus in high power generation mode.

5           The present invention will now be described, by way of illustration and not by way of limitation, by referring to the Figures of the enclosed drawings, in which:

- Figure 1 shows a general diagram of the power system of a typical spacecraft;

10           - Figure 2 shows power density of a space photovoltaic system as a function of the operating voltage;

- Figure 3 shows the architecture of the S3R power system according to the prior art;

15           - Figure 4 shows a power system operating as MPPT according to the prior art;

- Figure 5 shows a traditional system for recharging the storage batteries by drawing power directly from the photovoltaic system;

- Figure 6 shows a block diagram of a power system according to the invention;

20           - Figure 7 shows a block diagram of a first portion of the system according to the invention according to a preferred embodiment of it;

- Figure 8 shows a block diagram of a second portion of the system according to the invention according to a preferred embodiment of it;

25           - Figure 9 shows a block diagram of a particular of Figure 8.

Making reference to Figure 6, the power control and management system according to the invention may be schematised as follows.

30           An electric power supply system 17 directly supplies power to a power bus 100, that supplies power to a load 5 (possibly constituted by a plurality of different loads).

35           Monitoring means 18 monitors the state of the power bus 100 and it may consequently act, through signal transmission (dashed lines), directly on both the supply system 17 and on controlling means 16, that may directly act on the supply system 17.

It should be noted that such controlling means 16 may act both automatically according to preset rules, and under stimulus from an

external device directly connected thereto. In this way, for example in a satellite, if the onboard computer calculates that at a certain moment a device will need a higher power, it will ask said controlling means 16 for preventively organising the supply system in order to satisfy the demand, so saving time needed for a reorganisation at the moment of the effective need.

Making reference to Figure 7, supply system 17 is constituted by a plurality of supply sections 17', apt to supply electrical energy to the power bus 100 under driving by controlling means 16. This subdivision into sections is essential for dealing with possible variations of the electrical load 5.

Each section 17' may operate in different operating modes depending on needs, i.e., in general, depending on the power demanded by the load 5 and on the environmental conditions to which the system according to the invention is subject.

Hence, controlling means 16 establishes the operating mode of each section so as to obtain a whole power adequate for supplying the load 5 under conditions considered from time to time. Such controlling means 16 comprises one or more section controllers CS, each one of which manages the operating modes of at least one corresponding supply section.

According to a preferred embodiment of the system according to the invention, among the section controllers CS, there is one section controller CSC having functions of coordination of all the section controllers CS.

According to another embodiment of the system according to the invention, a section controller CS is associated with each supply section. Such controllers CS may communicate with each other and/or directly with the corresponding supply sections.

To this end, each section controller CS may be connected to input and output lines which allow it to send signals to all the other section controllers CS and to the same sections, and to receive signals from all the other section controllers CS as well as from the same sections.

The section controller may comprise electrically programmable means.

Making reference also to Figure 8, each supply section internally comprises a controller CM, preferably a multi-state controller.

The multi-state controller CM of each supply section separately regulates the transfer of power from the generation device DG included within the supply section towards the power bus 100.

5 Each multi-state controller CM may assume different states, corresponding to different operating modes.

Making reference also to Figure 9, the multi-state controller CM comprises state controlling means 27, a converter 25 and section monitoring means 26.

10 Each multi-state controller CM comprises at least one converter 25, apt to convert the electrical energy produced by the generation device DG of the primary supply section to which it belongs, in a form adequate for supplying the power bus 100 in the selected operating mode.

15 In the operating modes in which the power generated by the primary supply section is forwarded towards the power bus, converter output current may usually assume only values either higher (Buck or step-down converters) or lower (boost or step-up converters) than the input current. Converters may also be implemented in which there are both higher and lower values (Cuk or Sepic converters).

20 According to the invention, the multi-state controller CM and/or the converter 25 preferably comprise switchable connection means 28.

25 Said converter 25 preferably comprises at least one variable conductance device having the twofold function of switchable connection means and of switching the current of said converter. Variable conductance devices may be for example switches, on-off switches, transistors.

30 Said variable conductance device, in the operating mode in which the primary supply section considered from time to time, supplies energy to the power bus 100, contributing to control the current of the converter 25 and assuming, in a mode in which power transfer from the supply section is disabled (disabled mode), a state in which it contributes to keep the power generated by the primary supply section considered from time to time at a value lower than a predetermined threshold.

35 Two basic modes of the system according to the invention are maximum power point tracking mode, in which mode each primary supply section supplies the maximum power as possible under the specific system environmental conditions to the power bus 100, and a high power

generation mode, in which mode each primary supply section supplies a power close to a predetermined power value to the power bus 100.

High power generation mode presents an inferior noise at low frequency.

5           A third basic operating mode is regulation mode, in particular voltage regulation mode, in which transferred power is regulated so as to keep the voltage of the power bus 100 within predetermined limits. In general, regulation mode allows keeping one or more system electrical variables within predetermined limits.

10           Moreover, in order to deal with situations in which there is a reduced power transfer, the system according to the invention provides the possibility to set an adequate number of supply sections 17' in disabled mode, in which power transfer from the single supply section to the power bus 100 is suspended.

15           This solution first of all entails advantages from the point of view of the simplicity of the section controllers CM, used for converting electrical energy from the source DG, included within the supply section, in a form adequate for being put on the power bus 100 meeting the predetermined conditions: in fact, it allows reducing power dynamics (relative variation) of  
20           the power managed by each section controller CM, with advantages from the point of view of both performances and complexity of employed devices.

          Moreover, redundancy introduced by using a plurality of equivalent controllers CM for controlling the supply sections, distributed  
25           over different supply sections 17' of the electrical supply system 17, allows obtaining benefits also with respect to the system overall reliability: failure probability under conditions of reduced load is diminished, most of all when means 16 activates sections 17' in turn. At the same time, the maximum power supplied by the supply system 17 is subject to a gradual  
30           degradation, since failure of each supply section 17' only entails the loss of a quota of the whole maximum power.

          Supply sections forming the electrical supply system 17 may be classified into two groups, depending on the type of source DG contained therein: sections comprising primary supply sources DG,  
35           wherein electrical energy is generated at the expense of other energy forms, such as for example photovoltaic or thermoelectric generators, and

sections comprising secondary supply sources DG, comprising energy storage means, such as for example batteries.

5 In this regard, the system according to the invention allows using, as secondary supply sources DG, also energy storage kinematic devices, or flywheels.

Secondary supply sections only intervenes in situations when generated primary supply power is not sufficient for supplying the load under the foreseen conditions (conditions consisting, for example, in keeping the output voltage within a predetermined range), or in the case  
10 when a power excessive for the power bus 100 may be used for recharging such secondary supply sections.

In order to limit the intervention of secondary supply sections, in correspondence with load peaks, the system according to the invention also provides another operating mode of the primary supply sections, i.e.  
15 maximum power point tracking mode. In this mode, voltage value on the supply section is controlled so as to keep it close to the point in which the power supplied to the load is maximum.

In other words, the operating point of each primary supply section, that is in maximum power point tracking mode, is continuously  
20 adjusted during system operation, so that each primary supply section either produces the maximum power as possible or supplies the maximum power to the power bus under the specific system environmental conditions. The difference between this two cases depends on the nonlinearity of efficiency of the converter interposed between generation  
25 device and bus; in effect, the difference consists of measuring power before or after the converter.

In the system according to the invention, the response to the transient is greatly improved since the initial operating point for maximum power point tracking operating mode is fixed so as to be close to the  
30 steady state operating point, or in any case in a condition of high power generation.

For estimating this initial value two different approaches are possible: for example, if a relationship linking source DG short circuit current to the maximum power point current, it is possible to measure the  
35 source short circuit current and to use the known relationship for establishing the initial value of the algorithm of searching and tracking. Similarly, it is possible to act if the known relationship concerns voltages.

In the cases when supply sections are interfaced with the power bus 100 through switching converters 25, it is possible to directly establish the initial value of the duty-cycle related to the converter 25.

5 In presence of electronic computing and storing means, it is further possible to use a stored value for the initial value of the controlled variable (for example maximum power point current or voltage) or of the duty-cycle.

10 The duty-cycle reference value may be updated some or all the times when the primary supply section considered from time to time exits maximum power point tracking mode.

The duty-cycle reference value may be calculated as a function of the current or voltage measured in disabled mode.

15 For speeding up and stabilising the power-on transient of the sections, each primary supply section, which is forced to pass to maximum power point tracking mode, leaving a different operating mode, preferably assumes high power generation mode as initial state.

High power generation mode may be also used under steady condition.

20 In particular, for intermediate values of power absorbed by the load 5, when the power generated by at least two primary supply sections is sufficient to supply the load 5 without demanding intervention of secondary supply sections, it is possible to keep at least one of the primary supply sections in high power generation mode, while the other one or ones adjust the power supplied to the load 5 so as to supply it  
25 under the requested conditions.

The operating mode of these latter primary supply sections is called regulation mode, in particular voltage regulation mode, in which the voltage on the load is kept within a predetermined range.

30 With respect to the case when the supply section not used for the regulation is kept in maximum power point tracking mode, this mode entails reduced fluctuations of the current supplied by the supply sections, with a consequent reduction of induced electromagnetic interferences (EMI).

35 Each section controller CS controls one or more supply sections, carrying out a preset series of operations, which may be updated after the start of operation of the system, for example through a remote control.

This possibility of reprogramming the controllers CS is very important, most of all for spacecrafts, since it allows intervening for recovering system functionality that could be lost after failures or design errors.

5                   In the scope of each operating mode, fine control of electrical variables is entrusted to the multi-state controller CM, that assumes a state depending on the selected mode, implementing a corresponding automatic control rule.

10                   For example, in voltage regulation mode, the multi-state controller CM behaves as an output voltage regulator, in high power generation mode the controller CM behaves as an input voltage regulator, in maximum power point tracking mode it carries out a sequence of operations which allow selecting the operating point of the section supplying the power bus 100.

15                   In disabled mode, the power supplied by the supply section to the power bus 100 is set below a predetermined threshold by means of proper switchable connection means 28 (for example by shortcircuiting or opening output electrical lines of a photovoltaic generator).

20                   With reference to the cases when the multi-state controller CM is based on a switching converter 25, the system according to the invention may use a main switch of the converter 25 for carrying out the function of switchable connection means 28. In case of "boost converter" or "step-up converter", the input loop is usually formed by a switch and an inductive element: it is thus possible to carry out the function disabling the  
25                   supply section, by stably keeping the switch in the closed position. Similarly, in "buck converters" or "step-down converters", the supply section may be disabled by stably keeping the switch open in series to the supply lines.

30                   One of the preferred embodiments of the system according to the invention provides the presence of an auxiliary bus, in addition to the main bus.

35                   The sections containing primary supply sources have further operating modes, in which produced electrical energy is supplied to the auxiliary bus, according to modes comprising at least one of the modes provided for supplying the main power bus 100.

                  In particular, it is provided the possibility to control the power thoroughly supplied to the auxiliary bus (not shown) so as to adjust

charging of the energy storage devices. This functionality is obtained by sending on the auxiliary bus the electric power produced by a suitable number of primary supply sections, chosen among those which are not demanded to supply the power bus 100.

5           The system according to the invention allows enriching power systems of new functionalities, aimed at reducing stresses on the storage batteries of the secondary sections and at improving the system overall reliability, without significantly increasing its complexity.

10           The distributed system for supplying the power bus 100 according to the invention may be applied in all those systems in which a variable electrical load is supplied by electric power sources characterised by a nonlinear relationship between the power supplied to the load and the output voltage, presenting a sole power maximum in correspondence with a voltage value defining the maximum power point, related to the specific  
15           source operation conditions.

          A typical example, that does not exhaust the range of possible applications, is constituted by spacecrafts supplied by photovoltaic generators, in which periods of reduced electrical load, in which the electric power available from the generation system exceeds the  
20           absorption by the load, follow periods in which the load reaches peak values in which, since it is not possible to generate power sufficient for meeting load demands, intervention of energy storage systems is necessary.

          The invention has been described, by way of illustration and  
25           not by way of limitation, according its preferred embodiments and variations, but it should be understood that those skilled in the art can make changes and/or integrations, without so departing from the related scope of protection, as defined by the enclosed claims.

30

## CLAIMS

1. Distributed system for electrically supplying a power bus, the system comprising:

- 5       - a power bus (100) for distributing electrical energy, connected to at least one electrical load (5);
- a supply subsystem comprising a plurality (17) of supply sections (17'), at least two supply sections (17') of said plurality (17) of supply sections being primary supply sections, said primary supply sections being apt to produce electrical energy starting from other forms of energy, said primary supply sections having an output power varying as the output current varies so as to reach a peak value for a corresponding value of the output current, characterised in that each one of the primary supply sections is apt to assume an operating mode selected from a set of operating modes comprising at least two of the following modes:
  - 15       - a first mode of maximum power point tracking, in which a primary supply section supplies the maximum suppliable power to the power bus (100),
  - a second mode of high power generation, in which a primary supply section supplies a power within a range centred on a predetermined power value to the power bus (100),
  - 20       - a third mode of regulation, in which a primary supply section delivers an amount of power so as to keep one or more electrical variables associated with the system within a predetermined range to the power bus (100); and
  - 25       - controlling means (16, CS, CSC, CM, 27) apt to select for each primary supply section an operating mode from said set of operating modes, and to control the operating mode of each primary supply section.

2. System according to claim 1, characterised in that at least one primary supply section comprises photovoltaic converters.

30       3. System according to claim 1 or 2, characterised in that at least one supply section (17') of said plurality (17) of supply sections is a secondary supply section, apt to store electrical energy.

4. System according to anyone of claims 1 to 3, characterised in that the set of operating modes further comprises:

- 35       - a disabled mode, in which the power delivered to the power bus (100) is lower than a predetermined threshold.

5. System according to anyone of claims 1 to 4, characterised in that the output current of a primary supply section, being in high power generation mode, is kept within a range centred on a determined reference value by the controlling means (16, CS, CSC, CM, 27).

5           6. System according to claim 5, when depending on claim 4, characterised in that said reference current value is determined on the basis of the value of the primary supply section output current, measured in disabled mode.

10           7. System according to anyone of claims 1 to 4, characterised in that the output voltage of each primary supply section, being in high power generation mode, is kept at a value close to a predetermined reference voltage value.

15           8. System according to claim 7, when depending on claim 4, characterised in that the reference voltage value is determined on the basis of the value of the primary supply section output voltage, measured in disabled mode.

9. System according to anyone of claims 1 to 8, characterised in that, in regulation mode, said system variable is the voltage of the power bus (100).

20           10. System according to anyone of claims 1 to 8, characterised in that, in regulation mode, said system variable is the current of the power bus (100).

25           11. System according to anyone of claims 1 to 10, characterised in that one or more system variables are associated with the system, the operating mode of each one of the primary supply sections being established so that the overall power supplied to the power bus (100) is such that it keeps said one or more system variables within predetermined limits.

30           12. System according to anyone of claims 1 to 11, characterised in that each primary supply section, which is forced to pass to maximum power point tracking mode, leaving a different operating mode, assumes high power generation mode as initial state.

35           13. System according to anyone of claims 1 to 12, characterised in that it further comprises bus monitoring means (18) which generates signals apt to represent values of one or more electrical variables associated with the system, and sends them to said controlling means (16).

14. System according to claim 13, characterised in that said controlling means (16, CS, CSC, CM, 27) comprises at least one section controller (CS) that determines the operating mode of at least one supply section on the basis of the signals received from said bus monitoring means (18).

15. System according to claim 14, characterised in that said at least one section controller (CS) determines the operating mode of at least one supply section on the basis of the operating mode of the other supply sections (17').

16. System according to claim 15, said at least one section controller (CS) being apt to be driven by one or more devices external to the system during the operation of the same system.

17. System according to claim 16, characterised in that said controlling means (16, CS, CSC, CM, 27) comprises at least two section controllers (CS).

18. System according to claim 17, each one of said at least two section controllers (CS) sending signals to at least another section controller (CS) and receiving signals from at least another section controller (CS).

19. System according to anyone of claims 1 to 18, characterised in that each primary supply section comprises at least one multi-state controller (CM), said multi-state controller controlling power transfer from the primary supply section to which it belongs to the power bus (100), in accordance with a controlling rule depending on the selected operating mode.

20. System according to claim 19, characterised in that each one of the primary supply sections comprises switchable connection means (28), said switchable connection means (28) being apt to enable and disable power transfer from the primary supply section to the power bus (100).

21. System according to claim 19 or 20, characterised in that each multi-state controller (CM) comprises at least one converter (25) and at least one generation device (DG), the converter (25) being apt to convert the electrical energy produced by said generation device (DG).

22. System according to claim 21, characterised in that said converter (25) is a switching converter.

23. System according to claim 21 or 22, characterised in that each multi-state controller (CM) further comprises:

- section monitoring means (26), apt to generate signals representative of physical quantities describing primary supply section operation conditions, state controlling means (27), at least receiving the signals output by at least one of the following means:

controlling means (16, CS, CSC, CM),

bus monitoring means (18)

section monitoring means (26),

and supplying to the converter (25) and to the switchable connection means (28) one or more driving signals apt to keep one or more variables associated with the system within limits foreseen for the operating mode selected for the primary supply section comprising the multi-state controller (CM).

24. System according to anyone of claims 21 to 23, characterised in that said converter (25) comprises at least one variable conductance device having twofold function of switchable connection means and of switching the current of said converter.

25. System according to anyone of claims 21 to 24, characterised in that the converter is a boost or step-up converter.

26. System according to claim 24 or 25, characterised in that the converter (25), in high power generation mode, is forced to operate with a predetermined duty-cycle value.

27. System according to anyone of claims 1 to 26, characterised in that at least one secondary supply section comprises at least one kinematic device for storing energy.

28. System according to claim 27, characterised in that said at least one energy storage kinematic device is at least one flywheel.

29. System according to claim 27 or 28, characterised in that at least one primary supply section operates in one of the modes selected from the group:

- voltage regulation, the amount of power supplied to the power bus (100) being controlled so as to keep the voltage of the power bus (100) close to a nominal value;

- regulation, the amount of power supplied to the power bus (100) being controlled so as to keep one or more electrical variables associated with the system within predetermined limits;

- maximum power point tracking, the amount of power supplied to the power bus (100) being kept within a range centred on the maximum power point;

5       - disabling, power transfer towards the power bus (100) not occurring.

30. System according to claim 29, characterised in that in regulation mode the controlled variable is the voltage of the power bus (100).

10       31. System according to claim 29, characterised in that in regulation mode the controlled variable is the current of the power bus (100).

32. System according to anyone of claims 23 to 31, when depending on claim 3, characterised in that each one of the secondary supply sections also comprises:

15       - section monitoring means, apt to monitor the charge state of the secondary supply sections and to consequently generate signals representative of the same state and of the electrical system variables describing the operating conditions of the same secondary supply section, said signals being sent to the state controlling means (27).

20       33. System according to claim 3 or anyone of claims 4 to 32, when depending on claim 3, characterised in that each one of the secondary supply sections also comprises either a charge/discharge regulator (3) or a discharge regulator (3'') and a charge regulator (3') connected to the power bus (100).

25       34. System according to claim 3 or anyone of claims 4 to 33, when depending on claim 3, characterised in that each one of the secondary supply sections comprises:

30       - section controlling means, which at least receives the signals output by the bus monitoring means (18) and by section monitoring means, and which outputs, either towards the charge/discharge regulators (3) or towards the discharge regulators (3'') and the charge regulators (3'), driving signals apt to keep electrical variables associated with the system within limits foreseen for the operating mode selected for the secondary supply section considered from time to time.

35       35. System according to anyone of claims 1 to 34, characterised in that the system further comprises an auxiliary bus.

36. System according to claim 35, characterised in that each supply section of said plurality of sections (17) is apt to be singly set for supplying energy to the power bus (100) or to the auxiliary bus.

5 37. System according to claim 35 or 36, characterised in that each primary supply section, when supplying energy to the auxiliary bus, is apt to assume at least one of the operating modes provided for supplying energy to the power bus (100).

10 38. System according to anyone of claims 35 to 37, characterised in that at least one secondary supply section is apt to receive power from the auxiliary bus.

15 39. Method of controlling power, using a power system according to anyone of claims 1 to 36, characterised in that it is apt to use said controlling means (16, CS, CSC, CM, 27) so that each primary supply section assumes an operating mode selected from said set of operating modes.

40. Method according to claim 39, characterised in that it comprises the steps of:

20 - establishing the number of supply sections supplying energy to the power bus (100) so that the overall power supplied by said supply sections is sufficient to supply the load (5) in the foreseen conditions;

- in presence of a power absorption by the load (5) lower than the maximum power available from one of the primary supply sections, keeping:

25 - at least one primary supply section in voltage regulation mode,

- at least one primary supply section in disabled mode,

- all the secondary supply sections in a mode in which they do not supply energy to the power bus (100).

30 41. Method according to claim 40, characterised in that it further comprises the step of:

- in presence of a power absorption by the load (5) higher than the maximum power available, in the specific operating modes, from the set of all the primary supply sections, keeping:

35 - at least one of the secondary supply sections in a mode in which it supplies energy to the power bus (100), having determined the number of the secondary supply sections operating in said mode in such a manner to obtain an overall power sufficient to supply the load (5),

- one or more primary supply sections in maximum power point tracking mode.

42. Method according to claim 41, characterised in that it further comprises the step of:

5                   - in presence of a power absorption by the load (5) higher than the maximum power available from the set of all the primary supply sections, keeping:

10                   - at least one of the secondary supply sections in a mode in which it supplies energy to the power bus (100), having determined the number of the sections operating in said mode in such a manner to obtain an overall power sufficient to supply the load (5),

                  - at least one of the primary supply sections in voltage regulation mode,

15                   - all the primary supply sections, not being in voltage regulation mode, in maximum power point tracking mode.

43. Method according to anyone of claims 39 to 42, characterised in that it further comprises the step of:

20                   - in presence of a power absorption by the load (5) higher than the maximum power available from one of the primary supply sections, and lower than the maximum power available from the set of all the primary supply sections, keeping:

                  - at least one primary supply section in voltage regulation mode,

25                   - at least one primary supply section in high power generation mode, having determined the number of sections operating in this mode in such a manner to supply the load (5),

                  - all the secondary supply sections in a mode in which they do not supply energy to the power bus (100).

30                   44. Method according to claims 42 and 43, characterised in that it further comprises the step of:

                  - in presence of a power absorption by the load (5) higher than the maximum power available from one of the primary supply sections, and lower than the maximum power available from the set of all the primary supply sections, keeping:

35                   - at least one primary supply section in voltage regulation mode,

- at least one primary supply section in maximum power point tracking mode, having established the number of sections operating in said mode in such a manner to supply the load,

- all the secondary supply sections in a mode in which they do not supply energy to the power bus (100).

45. Method according to anyone of claims 39 to 44, the method comprising the step of:

- keeping in disabled mode the sections which do not supply energy to the power bus (100).

46. Method according to anyone of claims 39 to 45, using the system according to anyone of claims 35 to 38, characterised in that it further comprises the step of:

- establishing the number of sections supplying energy to the auxiliary bus so as to obtain an overall power sufficient to supply the same auxiliary bus.

47. Method according to claim 46, characterised in that it further comprises the step of:

- selecting the supply sections supplying energy to the auxiliary bus among those not used for supplying energy to the power bus (100).

48. Method according to claim 46 or 47, when not depending on claim 45, characterised in that it further comprises the step of:

- keeping in disabled mode the sections which are not used for supplying energy to the power bus (100) nor to the auxiliary bus.

49. Method according to anyone of claims 39 to 48, characterised in that it further comprises the step of:

- keeping at least one of the primary supply sections connected from time to time to the auxiliary bus in voltage regulation mode, and all the other ones in maximum power point tracking mode.

50. Method according to anyone of claims 39 to 49, characterised in that it further comprises the step of:

- keeping at least one of the primary supply sections connected from time to time to the auxiliary bus in voltage regulation mode, and all the other ones in high power generation mode.

51. Method according to anyone of claims 39 to 50, using the system according to claim 34, characterised in that it further comprises the step of:

- when the charge state of the secondary supply section is lower than a predetermined charge state, delivering towards the auxiliary bus the output power of at least one primary supply section.

5 52. Method according to anyone of claims 39 to 40, the method comprising the step of:

- keeping at least one primary supply section among those connected to the auxiliary bus in current regulation mode, and all the remaining primary supply sections connected to the auxiliary bus in maximum power point tracking mode.

10 53. Method according to anyone of claims 39 to 52, using the system according to claims 3 and 8, the method comprising the step of:

- setting at least one primary supply section, among all those connected to the auxiliary bus, in regulation mode, the regulated variable being the current, and all the remaining primary supply sections connected to the auxiliary bus in high power generation mode.

15

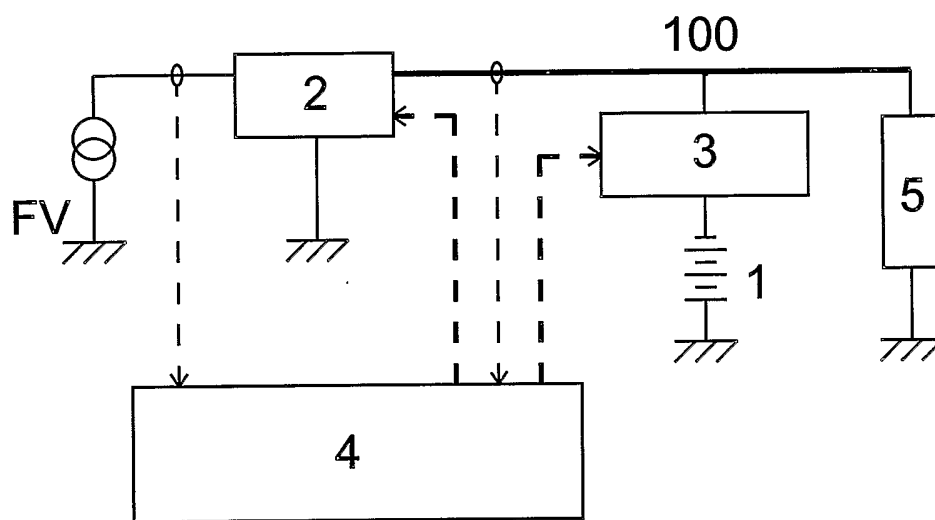


Fig. 1

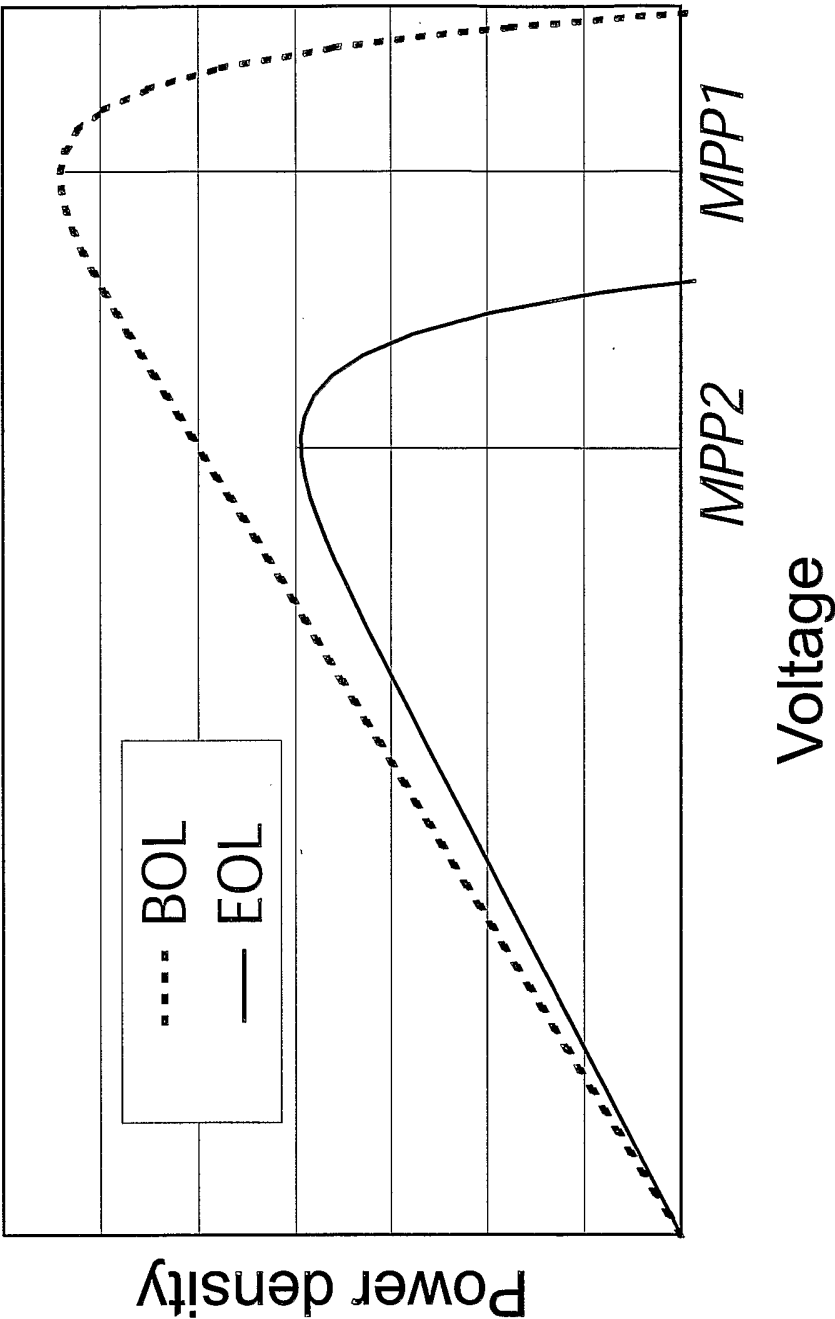


Fig. 2

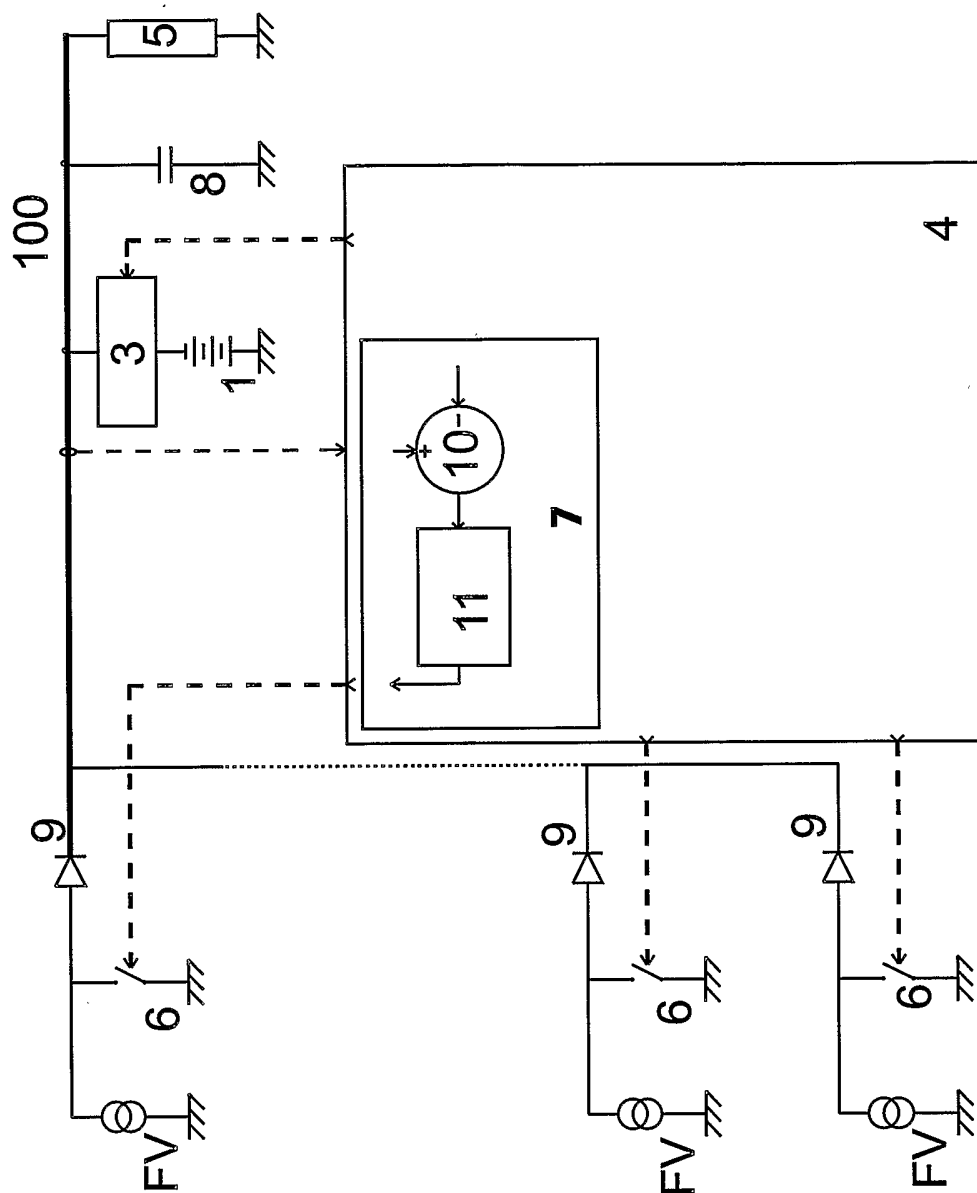


Fig. 3

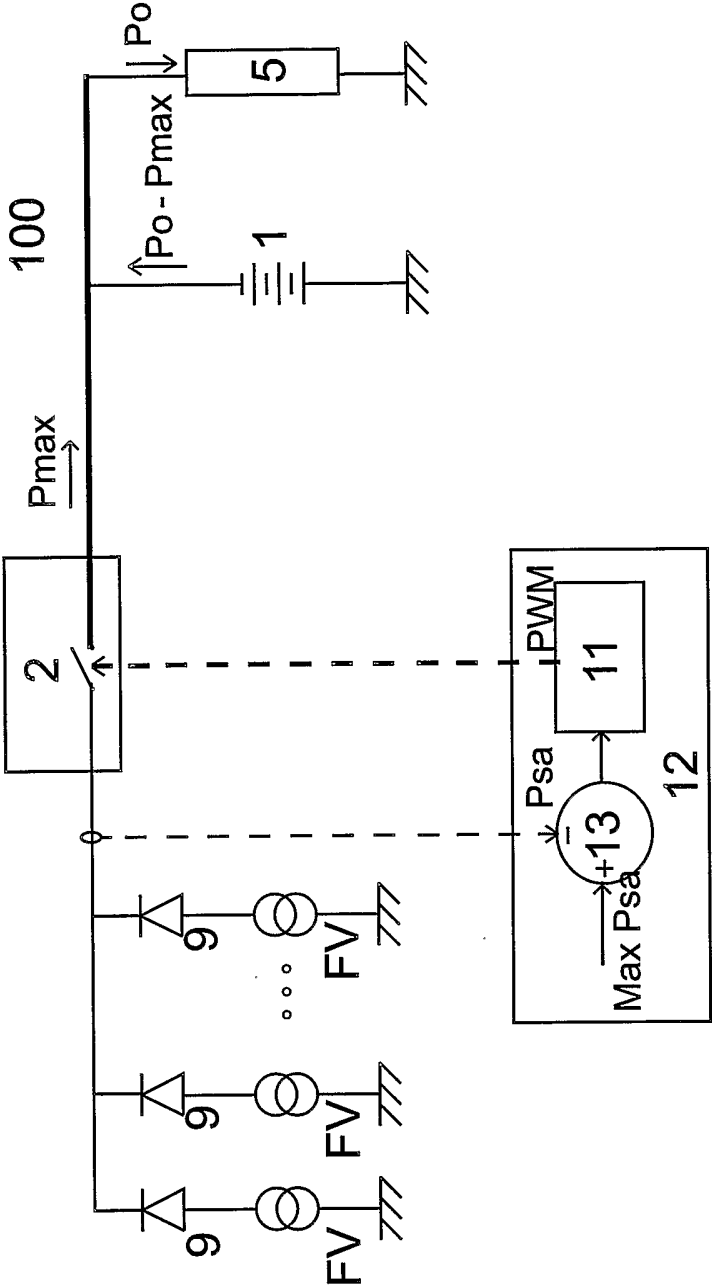


Fig. 4

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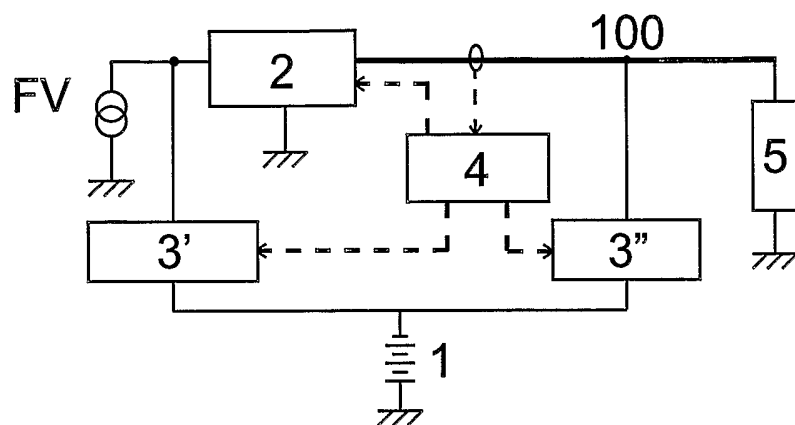


Fig. 5

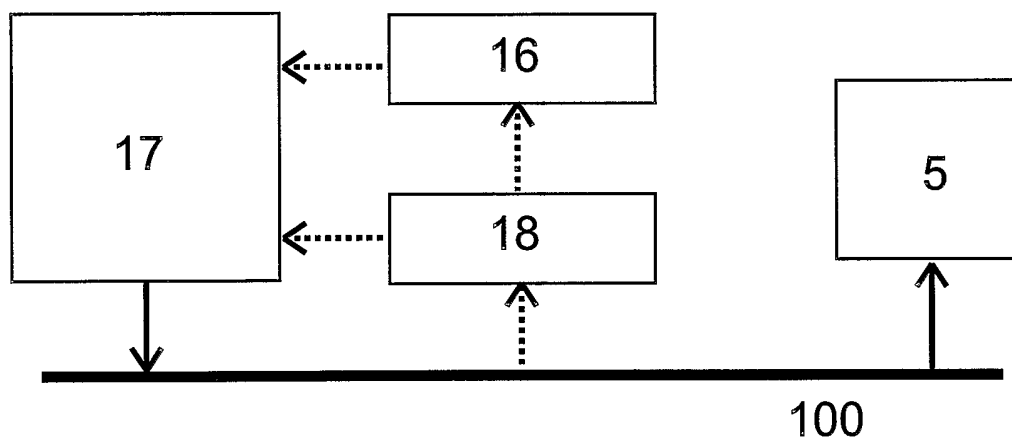


Fig. 6

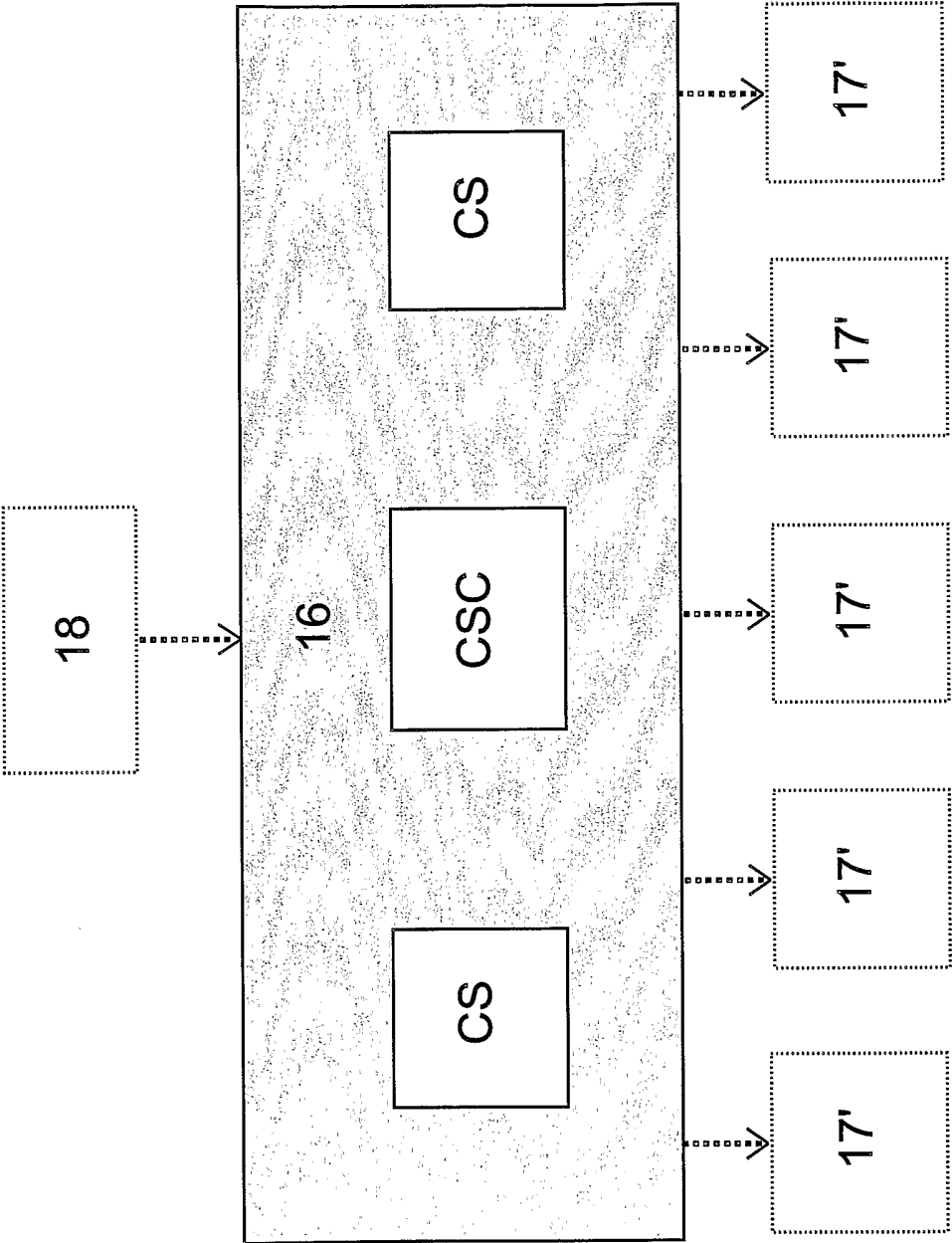


Fig. 7

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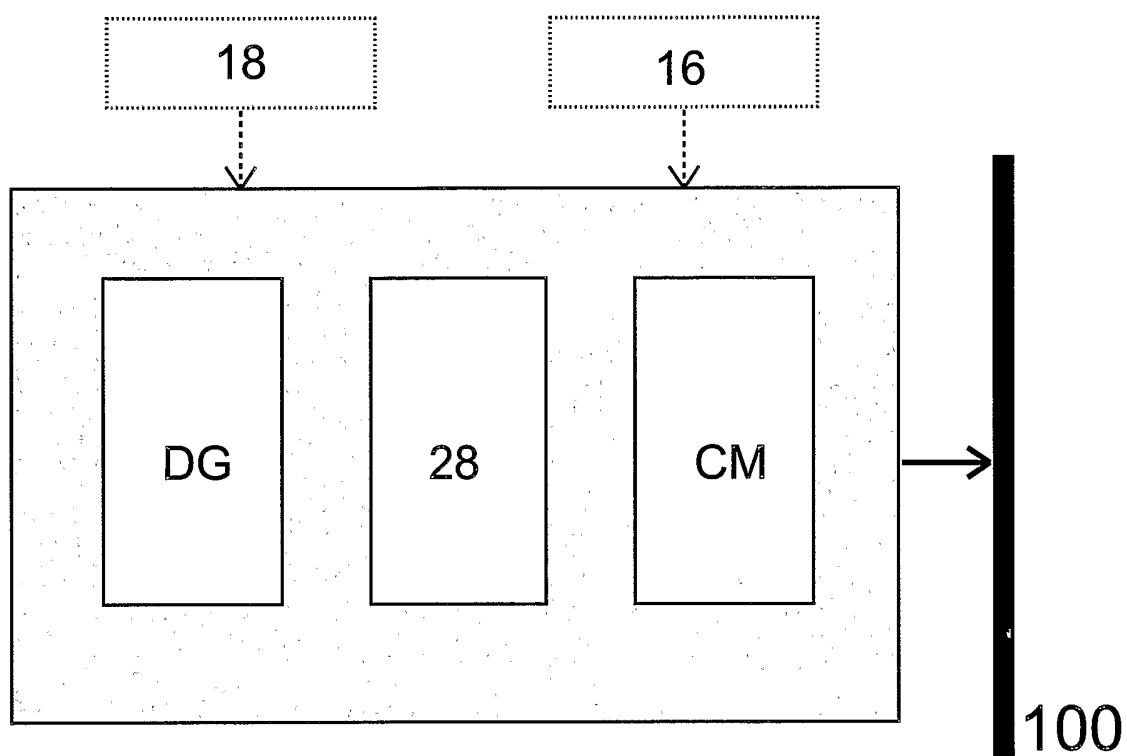


Fig. 8

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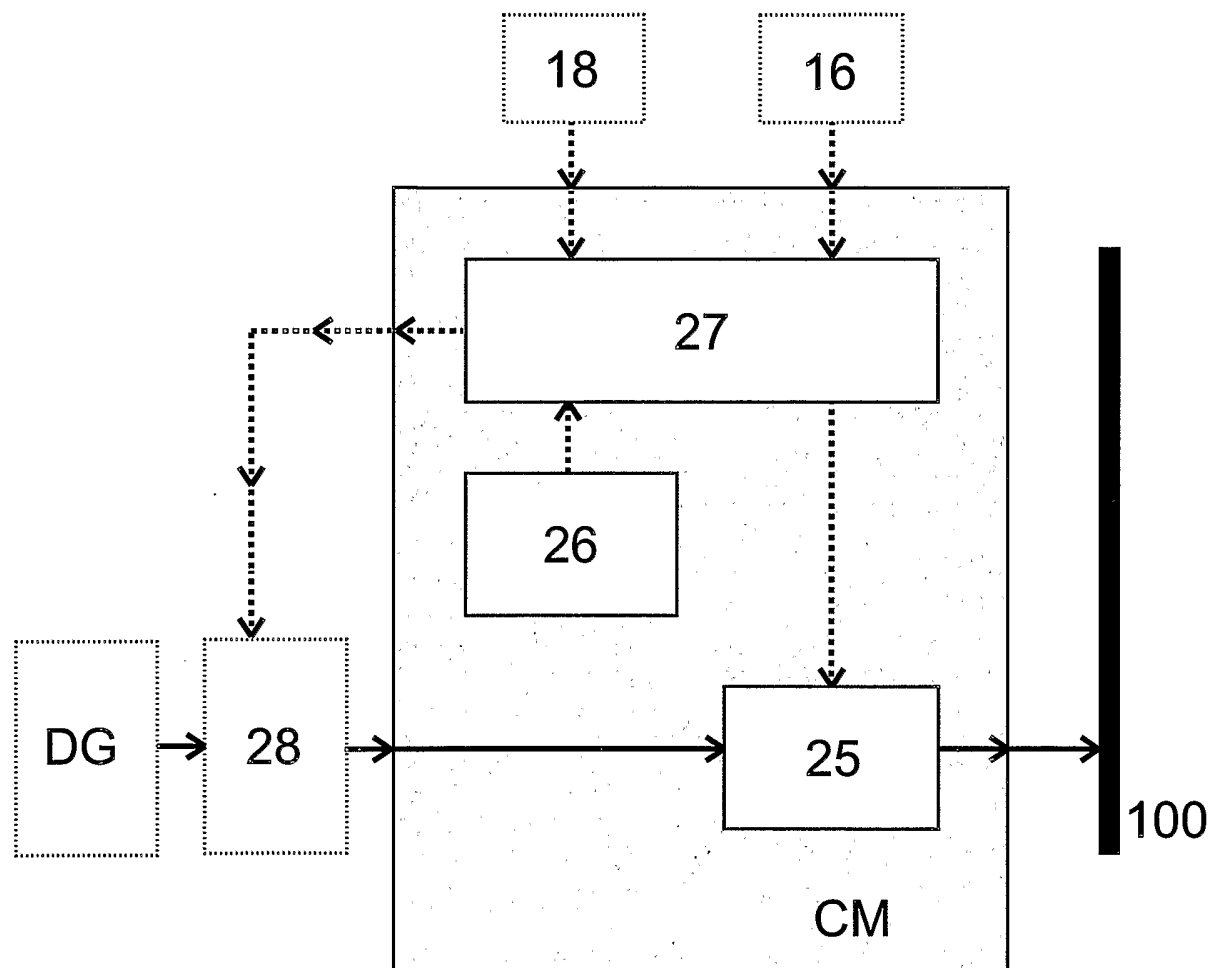


Fig. 9