

(43) International Publication Date  
24 November 2016 (24.11.2016)

- (51) International Patent Classification:  
*H02J 1/10* (2006.01) *B60L 8/00* (2006.01)
- (21) International Application Number:  
PCT/BG2015/000022
- (22) International Filing Date:  
15 July 2015 (15.07.2015)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
112017 21 May 2015 (21.05.2015) BG  
112048 3 July 2015 (03.07.2015) BG
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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Declarations under Rule 4.17:**

— of inventorship (Rule 4.17(iv))

**Published:**

— with international search report (Art. 21(3))

(54) Title: PHOTOVOLTAIC SYSTEM FOR GENERATING AND SUPPLYING ENERGY TO DC GRID AND ITS CONSUMERS

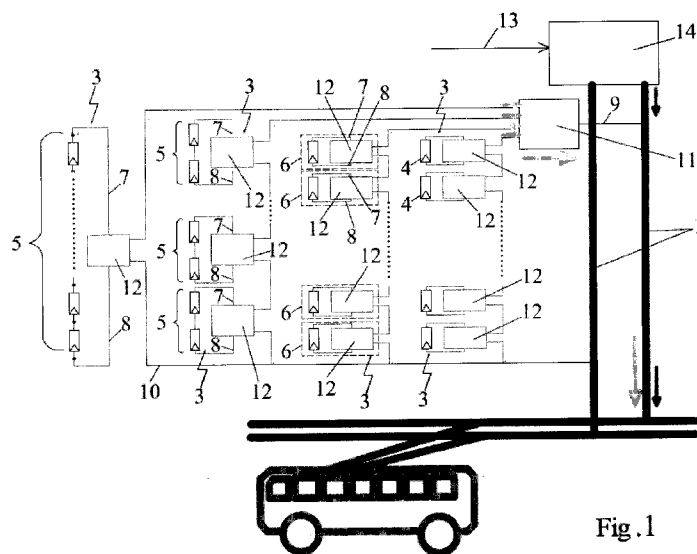


Fig. 1

(57) Abstract: The system is designed for direct coupling to DC-grids, as these of public transport. It works synchronously with conventional power supplies and remains permanently connected to the DC-grid even if the consumption is low or zero. The PV-system includes PV-field, composed from photovoltaic structure representing a single PV-panel or group of PV-panels. Each PV-structure has the (+)output and (-)output, to which an optimizer (12) is connected. Each of optimizers has outputs connected to each other and/or in the configuration of the PV-field to the common (+) and (-)output lines (9,10). The optimizer's type fulfill both of conditions - PV-field to have nominal voltage, relevant to the voltage of the DC-Grid (1) and limited voltage lower than the maximum permissible voltage of the DC-Grid (1), which makes the system efficient in terms of voltage controlling.

## **PHOTOVOLTAIC SYSTEM FOR GENERATING AND SUPPLYING ENERGY TO DC GRID AND ITS CONSUMERS**

### **TECHNICAL FIELD**

Photovoltaic system for generating and supplying energy to DC Grid and its consumers is designed for direct coupling to direct current (DC) grids, for an example as these of public transport – trolley, trams, subway, and it gives opportunity to use it for supplying part of the necessary energy to the existing direct current grids.

### **BACKGROUND ART**

It is known a photovoltaic system, which is used to supply part of the electrical energy to the existing trolleybus grid. It consists photovoltaic field (PV-field), composed from photovoltaic structures, which are single photovoltaic panels (PV-panels) or groups of PV-panels. The location of the photovoltaic structures is defined depending from the specific conditions – climatic, geographic, energy, mounting and others. Each of the photovoltaic structures has (+)output and (–)output, connected in a known manner to the common (+)output line and common (–)output line. Each of these output lines has a first protective block, which consists protection commutative apparatuses, disconnecting the electrical circuit when a higher current flows than the one which is permissible. After the protection commutative apparatuses there is a second protective block, consisting chokes which reduce the pulsation of the direct current from the PV field. After both protective blocks, to each of the common output lines is mounted a bidirectional high speed circuit breaker, which breaks the whole system or part of it in case of voltage increasing. After the high speed circuit breaker there is high frequency filter, which together with the breaker form a control block. There is provided a respectively control for the tripping of the control

block. In the end of the both common lines, before the point of their connection to the direct current grid of the consumers, there are mounted manual breakers. At strongly reduced or zero consumption from the consumers in the grid, the voltage of the PV increase, whereby according to the existing solution, PV structures or whole PV field will be disconnect, in order to protect the grid from the voltage increasing. Disadvantages of the known system are related to the fact, that the provided protection against voltage increasing, actually provides disconnecting of photovoltaic structures or of the whole PV-field from the grid and the increased voltage does not feed the grid, e.g. during the period, when the PV-field or part of it is disconnected, the same disconnected part does not operate. There are problems with the security of the system, manifested in cases such as, denial of high speed circuit breaker or its control, when the increased voltage can be fed to the DC Grid. Moreover in fully operating mode the high speed circuit breakers are working after the event, e.g. once the voltage has already reached the exceeded value. In the existing solution, there is not a system, which can support the operation of the PV-panels in the maximum power point (MPP). It is relying on that they will work during the most of the time "around and close" to MPP, where the losses from inefficiency are not very big. Basically the disadvantages of the existing photovoltaic system are consisting in the following: the electrical scheme is complicated, there are a lot of elements, and it is not possible any unification or use of standard devices and because of that every project needs a personal technical solution; overvoltage protection is not very reliable and safety, and the protection trips after the voltage in the DC Grid is already increased. The provided protection against voltage increasing relies only on the high speed circuit breakers to disconnect the PV system or part of it, once the output voltage is already increased. The system does not work synchronously and safety in parallel in all its modes with the conventional power, and in those modes, in which there is no synchronously and safety work, some measures are undertaken for disconnect the PV system or part of it; PV structures do

not work optimally, e.g. they work without MPPT (maximum power point tracking), as there are no existing standard devices with MPPT, which can be used for connecting the photovoltaic system to DC grids.

#### SUMMARY OF INVENTION

The problem solved by the invention is designing of photovoltaic system for generating and supplying energy to DC Grid and its consumers, in which the PV panels should work in the maximum power point and to secure output voltage corresponding to the nominal voltage of the direct current grid. It should be avoided any unacceptable voltage increasing, which can be caused by the PV system, in case of lower or no consumption from the grid. The system should work absolutely in synchronously in all working modes, and without any disconnecting of the system or part of it.

The problem is solved with photovoltaic system for generating and supplying energy to DC Grid and its consumers, which includes photovoltaic field, composed from at least one photovoltaic structure. Each photovoltaic structure can be single photovoltaic panel or group of panels. The photovoltaic field has its relevant voltage, and each of the photovoltaic structures has (+) output and (-) output. There are also common (+) output line and common (-) output line and a protective block equipped with protection commutative apparatuses. According to the invention, to the outputs of each of the photovoltaic structures forming a photovoltaic field is connected an optimizer. The outputs of the each optimizer are connected to each other and/or in the configuration of the PV-field in the known manner to the common (+) output line and common (-) output line. The protective block is connected to at least one of the common output lines, which are connected to the direct current grid. Each optimizer's type is such that it allows both of conditions to be simultaneously fulfilled during its operation in the photovoltaic field: PV field to have nominal voltage, relevant to the nominal voltage of the direct current grid and PV-field to have maximum limited output voltage lower than the maximum permissible voltage of the direct current grid. The selection of optimizer is defined in a way, that the

input voltage of each optimizer is the voltage of the maximum power point (MPP) of the PV-structure, to which is connected. The output voltage of the optimizer or of the group of serial connected optimizers should be relevant to the nominal voltage of the DC Grid. The output voltage of the optimizers or of the group of serial connected optimizers should be limited in all operating modes to a value, which does not exceed the maximum permissible operating voltage of the DC Grid and its consumers.

The photovoltaic system, as variant, consists a photovoltaic field, formed from a single photovoltaic structure, where single optimizer is connected to their (+)output and (-)output and the outputs of the optimizer are common (+)output line and common (-)output line.

Photovoltaic structure can be group of individual photovoltaic panels, which are connected in series.

It is possible that the photovoltaic structure is a single photovoltaic panel.

Another option is that the photovoltaic field includes at least two photovoltaic structures, which are connected in a known manner.

As appropriate variant it is possible at least one of the group of photovoltaic structures to be a single photovoltaic panel.

It is appropriate at least one of the photovoltaic structures to be "smart photovoltaic panel", in which the optimizer is embedded.

There is also a variant for thereby execution, where at least one of the photovoltaic structures is a group of single photovoltaic panels, and from the connected optimizers to the outputs of the photovoltaic structures is formed a group of serial connected optimizers.

The advantages of the invention are in the achieved possibility for direct supplying the DC Grid with the generated from the photovoltaic system energy, while it works synchronously with conventional power supplies and to replace partially or fully the conventional electrical energy with photovoltaic electrical energy. It has been achieved working synchronization of the safety elements of the system with the work of the photovoltaic field in

the maximum power point (MPP). When we are using it the system remains permanently connected to the direct current grid even if the consumption from the DC Grid is very low or zero, while the output voltage is limited at the predefined level of the optimizers. Generally the system is efficient in terms of voltage controlling during operation. Furthermore it is achieved the possibility to use this technical solution in application for reconstruction of the existing photovoltaic field by connecting the optimizers to their photovoltaic structures according to the invention.

#### BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 a principal block diagram of photovoltaic system for generating and supplying electrical energy to the direct current grid and its consumers;

Fig. 2 – block diagram, according to first embodiment of the photovoltaic system;

Fig. 3 – block diagram, according to the second embodiment of the photovoltaic system;

Fig. 4 – block diagram, according to another embodiment of the photovoltaic system;

Fig. 5 – block diagram, according to next embodiment of photovoltaic system for generating and supplying electrical energy to the direct current grid and its consumers;

#### DESCRIPTION OF EMBODIMENTS

Photovoltaic system for generating and supplying electrical energy to the direct current grid and its consumers is illustrated on the attached figures by its application for power supplying of the direct current grid 1 of the public transport, especially of the trolleybus grid. Photovoltaic system includes photovoltaic field (PV-field) 2, composed from at least one photovoltaic structure 3. The photovoltaic structure 3 is a single photovoltaic panel (PV-panel) 4 or group of PV-panels 5. As the direct current (DC) grid 1 of the trolleybus transport requires nominal voltage of 660V, on the figures it is not shown the use of a photovoltaic field 2, consisting only one photovoltaic

structure 3, which constitutes single PV-panel, although for another types of DC grids of consumers, which are working with lower voltages, this is possible. The current technical solution can be used for direct current grids 1 with voltage from 25V to 1000V. The configuration and location of the photovoltaic structures 3, either single photovoltaic panels 4 or group of photovoltaic panels 5, and combination of both, as it is shown on Fig.1, depends on the specific conditions – climate, geographic, energy, installation and other. The composing and the specific location of the photovoltaic structures 3 in the photovoltaic field 2 is not the subject of the current technical solution. Each photovoltaic field 2 has relevant voltage. Moreover each of the photovoltaic structures 3, included in the photovoltaic field 2, has (+)output 7 and (-)output 8. The photovoltaic field 2 has also common (+)output line 9 and common (-)output line 10. There is also protective block 11, which consists standard protection commutative apparatuses with circuit breakers and fuses. According to the invention, as it is shown of the each attached figures, there is an optimizer 12 which is connected to the outputs of each of the photovoltaic structures 3.

The outputs of each optimizer 12 are connected to each other and/or in the configuration of the PV-field in the known manner to the common (+)output line 9 and (-)output line 10. The specific connection depends from the configuration of each photovoltaic field 2 and from the specific location and type of the photovoltaic structures 3, which are included. The protective block 11 is connected to one of the common output lines 9, 10, which are connected to the direct current grid 1. On the figures the protective block 11 is shown as connected to the common (+)output line 9, but its position depends from the application of the invention for the specific grid and consumers. The protective block 11 can be connected to the both common output lines 9, 10, and also only to the common (-)output line 10. The number and the specific choice in terms of the protective block 11 depends from the application of the solution to the specific direct current grid.

It is shown on fig. 1 one configuration of the photovoltaic field, where the

connection of the optimizer's output 12 is more detailed illustrated. For illustrating the different options, the PV-field is compiled from different configuration of the PV structures 3 and of the optimizers 12 which are connected to them. To one of the common output lines are connected: one of the outputs of each optimizer 12, which is self-connected to a photovoltaic structure 3 and one of the outputs of the first optimizer 12 from a group of serial connected optimizers 12. In this case the common output line is (-)output line 10. The second output of each optimizer 12, which is self-connected to a photovoltaic structure 3 and the output of the last optimizer 12 from the group of serial connected optimizers 12 are connected to the other common output line – shown on fig. 1 as (+) output line 9.

Each optimizer 12 is selected from a type which allows by the simultaneous operation in the photovoltaic field 2, the following conditions to be simultaneously fulfilled for the whole configured system with optimizers:

- The nominal voltage of the PV-field is relevant to the operating voltage of the DC grid and its consumers.
- The input voltage of each optimizer, which is the voltage of maximum power point (MPP) of the connected to the optimizer 12 PV-structure 3, to be higher than the output voltage of the this optimizer 12. The output voltage of each optimizer 12 has the voltage relevant to the nominal voltage of the DC grid and to the scheme of the composing of the group of optimizers 12.
- The input voltage of each optimizer 12, defined by the voltage of maximum power point (MPP) of the PV-Structure 3, which is connected to it, should be lower than the maximum output voltage of each relevant optimizer.
- The maximum output voltage of the PV-field, which is defined by the maximum output voltages of the group of optimizers 12, depending on that how they are composed – to be lower than the maximum permissible operating voltage of the DC grid and its consumers.

The current technical solution can be used as complementing power supply to the direct current grid 1, which is powered by conventional rectifiers 14



from the alternative current grid. This is well illustrated on the attach figures. With other words, the selection of optimizer is defined so that the input voltage to each optimizer to be the relevant voltage of the maximum power point (MPP) of the PV-structure, to which is connected, and the output voltage of the optimizer or group of serial connected optimizers to be relevant to the nominal voltage of the DC grid. Moreover the output voltage of the optimizers or of the group of serial connected optimizers should be limited in all operating modes to a value, which does not exceed the maximum permissible working voltage of the DC Grid and its consumers. The limitation of output voltage in all operating modes is a function of the optimizers.

In the relation with the above requirements it is intended to be used PV-optimizers which are available on the market. The optimizers should be able to limit the output voltage. The set limit value (limitation value) should fulfill the above condition in terms of maximum output voltage of the optimizer and of the whole PV-field. That limit value is set during the production of optimizers or to be a factory preset voltage limits by the manufacturer or can be achieved by entering the appropriate setting by the user, by providing rights and access of settings of optimizers by the producer.

The photovoltaic system for generating and supplying electrical energy to the direct current grid and its consumers is illustrated by several embodiments. One of them is shown of the fig.2, where the PV-field includes single photovoltaic structure 3 with a connected optimizer 12 to (+) output 7 and (-)output 8 of the PV-structure 3. The outputs of this optimizer 12 are the common (+)output line 9 and the common (-)output line 10 of the PV-field 2. In this case the photovoltaic structure 3 is a group 5 of single serial connected PV-panels. The optimizer 12 is selected in a way, so that can fulfill the above mentioned conditions, and as more precisely – PV-field 2 to have nominal voltage relevant to the operating voltage of the direct current grid 1 and maximum output voltage of the PV-field to be lower than the maximum permissible voltage of the direct current grid 1. Moreover the

optimizer 12 has input voltage relevant to the voltage of the maximum power point (MPP) of the PV-structure 3 and output voltage relevant to the nominal voltage of the DC grid. Moreover the output voltage of the optimizer 12 is limited in all operating modes to a value, which not exceeds the maximum permissible operating voltage of the DC grid and its consumers. As the example is related to supplying part of the energy of the direct current grid 1 of the public transport, which is a trolleybus in the current situation, on the fig. 2 is shown the rectifier 14, which is supplying the main part of the needed energy of the direct current grid 1. The example on the fig.2 illustrates the protective block 11, which is connected to the common (+)output line 9.

Similarly, the photovoltaic structure 3 can be only single photovoltaic panel 4, so the optimizer 12 is only one connected between (+)output 7 and (-)output of this photovoltaic panel 4. The outputs of the optimizer 12 are the common (+)output line 9 and the common (-)output line 10. This embodiment is not shown separately on the figures, as all the connections and selected conditions are identical with those which are already explained on fig.2.

On the fig.3 is shown an embodiment of the photovoltaic system according to the invention, where the PV-field 2 is composed from some, at least two, photovoltaic structures 3, where each one is so called "smart photovoltaic panel" 6. They are serial connected and have an integrated optimizers 12, responding to the above mentioned conditions. This realization is equivalent to the realization of the PV-field from several photovoltaic structures 3, each of them represents single PV-panel 4, with connected optimizer 12 as it is shown on fig.4. According the both equivalent realization the optimizers 12, integrated or additional mounted, are serial connected to each other and form a group of serial connected optimizers, whereupon one of the outputs of the first and the last from serial connected optimizers 12 are the common (+)output line 9 and the common (-)output line 10.

On the fig.5 is shown next embodiment of the PV-field 2, formed from several photovoltaic structures 3 representing a group 5 of single PV-panels

4. The number of PV-panels 4 included in the group 5 can be equal or different, for example similarly on the shown on fig. 2 photovoltaic structure. The number of the PV-panels 4 in the group 5 is defined from the conditions at which is set this group 5. In this embodiment there is connected optimizer 12 between the (+)output 7 and (-)output 8 of each photovoltaic structure 3. It is formed a group of serial connected optimizers 12, whereupon one of the outputs of the first and the last from serial connected optimizers 12 are the common (+)output line 9 and the common (-)output line 10. The optimizers 12 are selected in a way, so that can fulfill the above mentioned conditions.

#### INDUSTRIAL APPLICABILITY

When using the invention, incoming on the PV-panels solar radiation is converted into direct current (DC) electrical energy. The energy, coming out of the outputs of any photovoltaic structure 3, formed by the PV-panels 4, enters at the input of each optimizer 12. It converts the electrical values of the PV-panels 4-voltage and current ( $U$ ,  $I$ ), which are input parameters for optimizer 12. On output of the optimizer are obtained other electrical ratio ( $U$ ,  $I$ ), but keeping the same power (the multiplication of  $U$  and  $I$ ), except for the losses in the optimizer. This is due to the conditions on the basis of which the selection of optimizer or the group of optimizers is made. The common output lines 9 and 10 of the optimizer 12, respectively of the group of optimizers 12 are connected directly to the DC grid, through at least one protective block 11 depending on the necessity.

In general, the voltage at the maximum power point (MPP) of the panels is variable depending on the temperature, radiation, shading, aging and degradation of the panel, etc., and the voltage of the grid can be also variable depending on the load tolerance and varying the voltage in electricity transmission and distribution grid, recuperation of vehicles energized by DC grid and others. By specified conditions for selecting optimizer, each optimizer keeps the voltage of PV- panels and/or photovoltaic structures 3 exactly at the maximum power point (MPP), regardless of DC grid voltage. So the optimizer or group of optimizers

provides operation of the photovoltaic panels on each photovoltaic structure in optimum working point, although the voltage of the panels and the voltage of the DC grid are not the same.

To reduce or, in the case of dropping consumption and/or emergency modes of exclusion of consumers, photovoltaic panels from PV- structures 3 of photovoltaic field 2 remain at open circuit mode and the voltage increase on their outputs. At this point, every optimizer 12, limit the voltage regardless of the higher value of the voltage from the PV structure, which is an input voltage for optimizer, it has the output voltage, which is not higher than the pre-set value in the selection and configuration of the optimizer. This limited value of the output voltage does not change, regardless of the higher input voltage of the panels. This is a solution of the problem of voltage regulation, not allowed to supply higher voltage from PV field in the DC grid and the whole system works with high security. The photovoltaic system according to the invention, supplying DC grid with the generated energy, while operating synchronously with conventional power sources and thus replace partially or entirely conventional electrical energy with photovoltaic energy.

## CLAIMS

1. Photovoltaic system for generating and supplying energy to DC grid and its consumers, including photovoltaic field, composed of at least one photovoltaic structure representing a single PV-Panel or group of PV panels, which photovoltaic field has a relevant voltage, and each of the photovoltaic structures has the (+)output and (-)output, as there are also common (+)output line and common (-)output line, as well as a protective block with a protection commutative apparatuses, **characterized by that** to the outputs (7, 8) on each of the photovoltaic structures (3), forming a photovoltaic field (2) is connected an optimizer (12), whose outputs are connected to each other and/or in the configuration of the PV-field in the known manner to the common (+)output line (9) and common (-)output line (10) and the protective block (11) is mounted to at least one of the common output lines (9, 10), which are connected to the DC grid (1) while each optimizer's type is such that it allows both of conditions to be simultaneously fulfilled during its operation in the photovoltaic field – photovoltaic field to have nominal voltage, relevant to the nominal voltage of the DC Grid (1) and photovoltaic field (2) to have maximum limited output voltage lower than the maximum permissible voltage of the DC Grid (1).
2. Photovoltaic system according to claim 1, **characterized by that** the photovoltaic field (2) is formed from a single photovoltaic structure (3), as the connected optimizer (12) between its (+)output (7) and (-)output (8) is one, and its outputs are common (+)output line (9) and common (-)output line (10).
3. Photovoltaic system according to claim 2, **characterized by that** the photovoltaic structure (3) is a group (5) of individual photovoltaic panels (4), connected in series.
4. Photovoltaic system according to claim 2, **characterized by that** the photovoltaic structure (3) is a single photovoltaic panel (4).

5. Photovoltaic system according to claim 1, **characterized by that** the photovoltaic field (2) includes at least two photovoltaic structures (3) which are connected in a known manner.
6. Photovoltaic system according to claim 5, **characterized by that** at least one of the photovoltaic structures (3) is a single photovoltaic panel (4).
7. Photovoltaic system according to claim 5, **characterized by that** at least one of the photovoltaic structures (3) is a "smart photovoltaic panel" (6), in which the optimizer (12) is embedded.
8. Photovoltaic system according to claim 5, **characterized by that** at least one of the photovoltaic structures (3) is a group (5) of a single photovoltaic panels (4), and from the connected optimizers (12) to the outputs of the photovoltaic structures (3) is formed a group of serial connected optimizers (12).

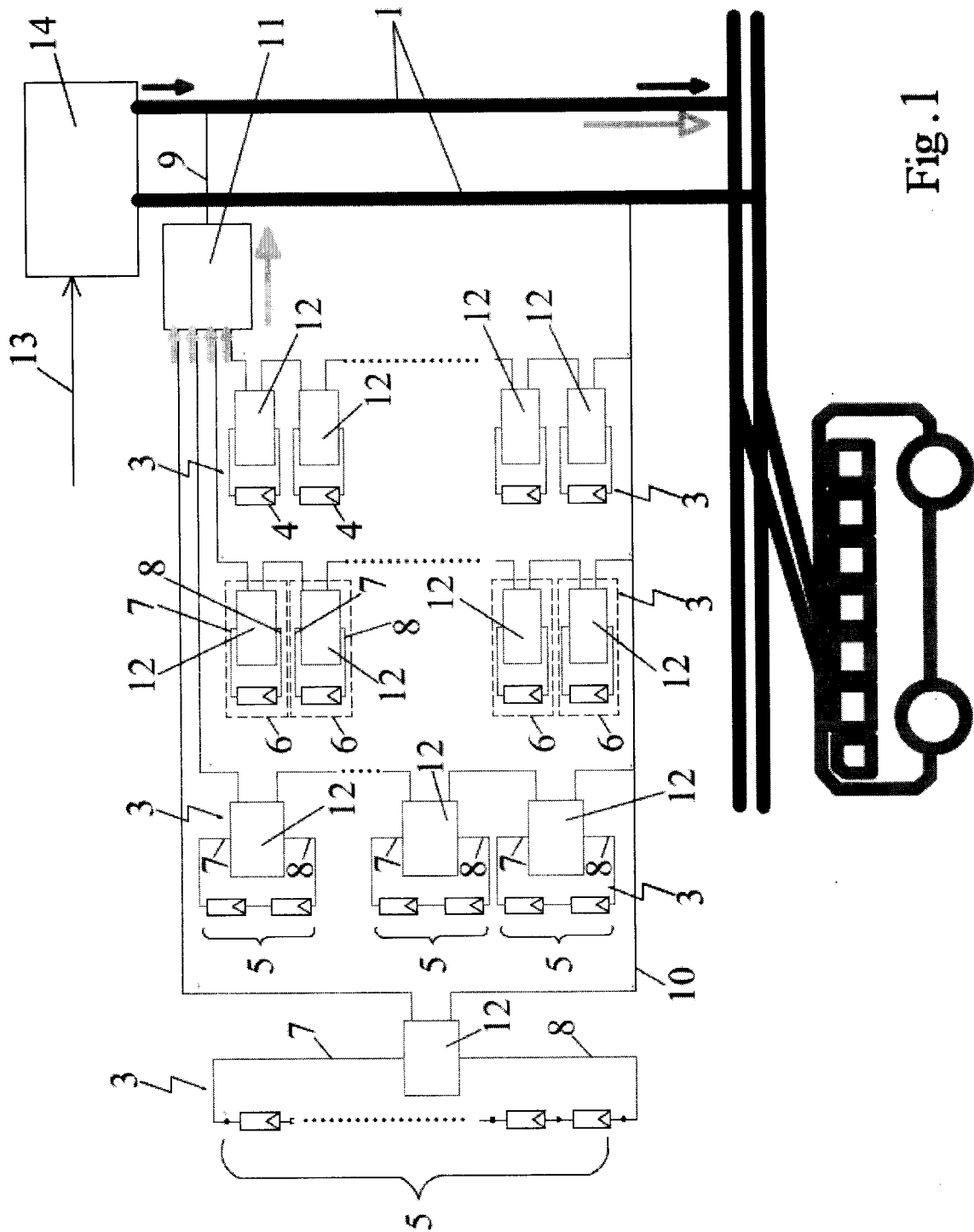


Fig. 1

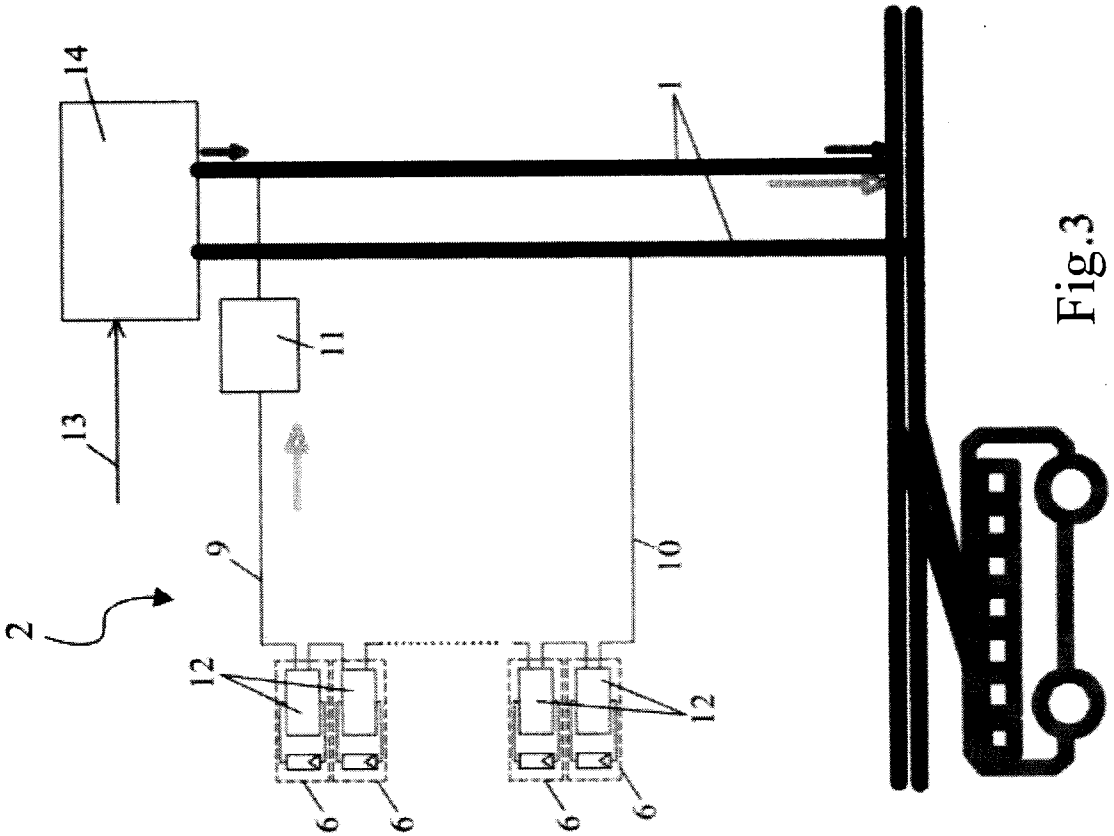


Fig.3

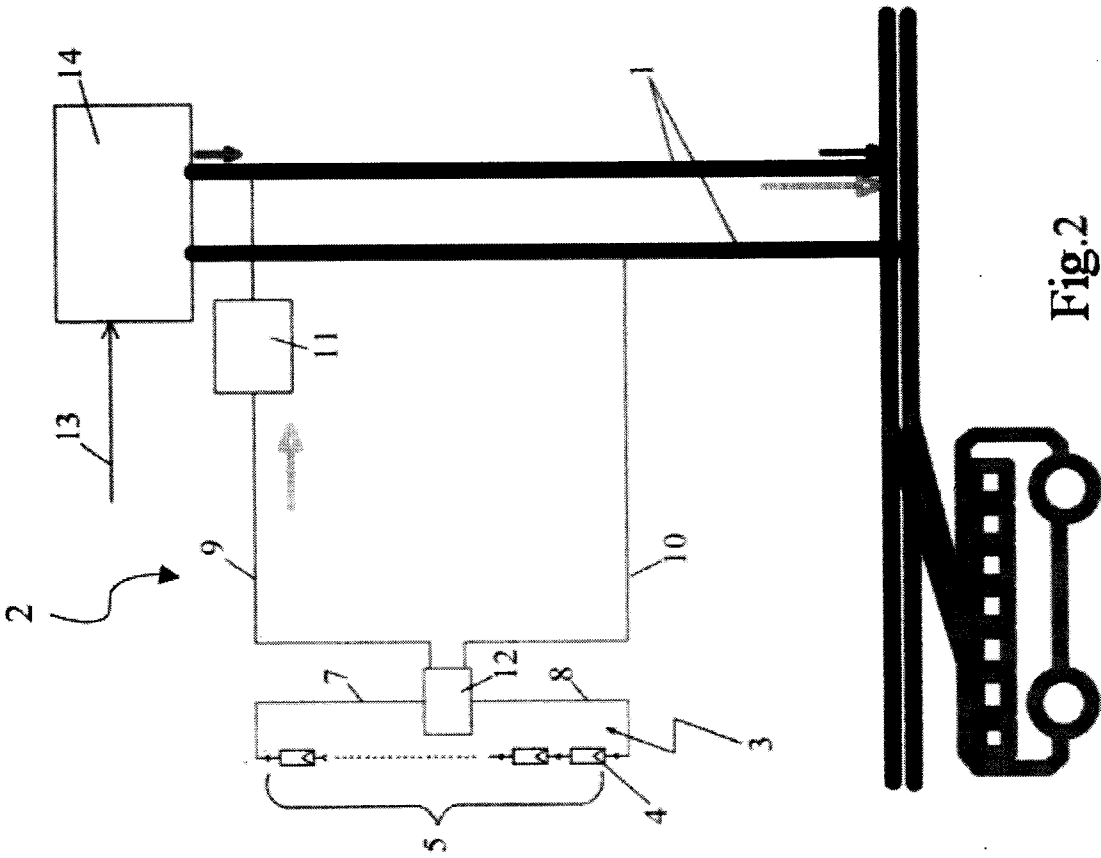
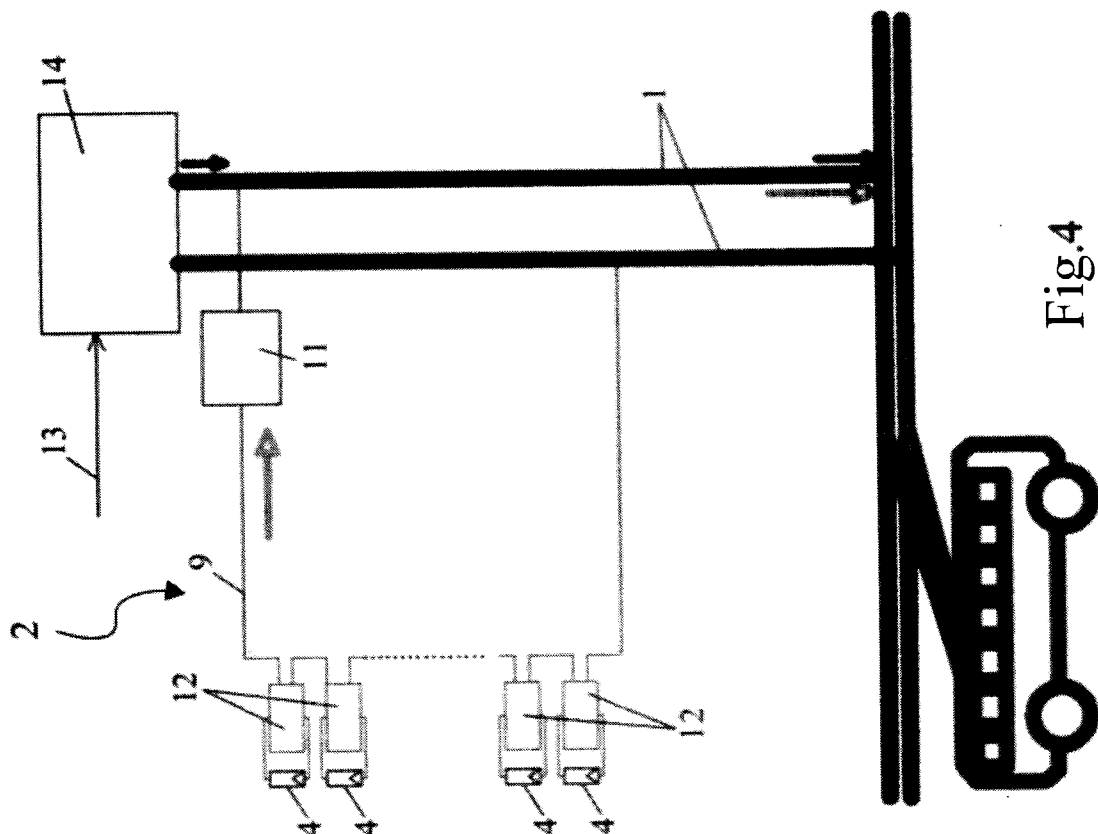
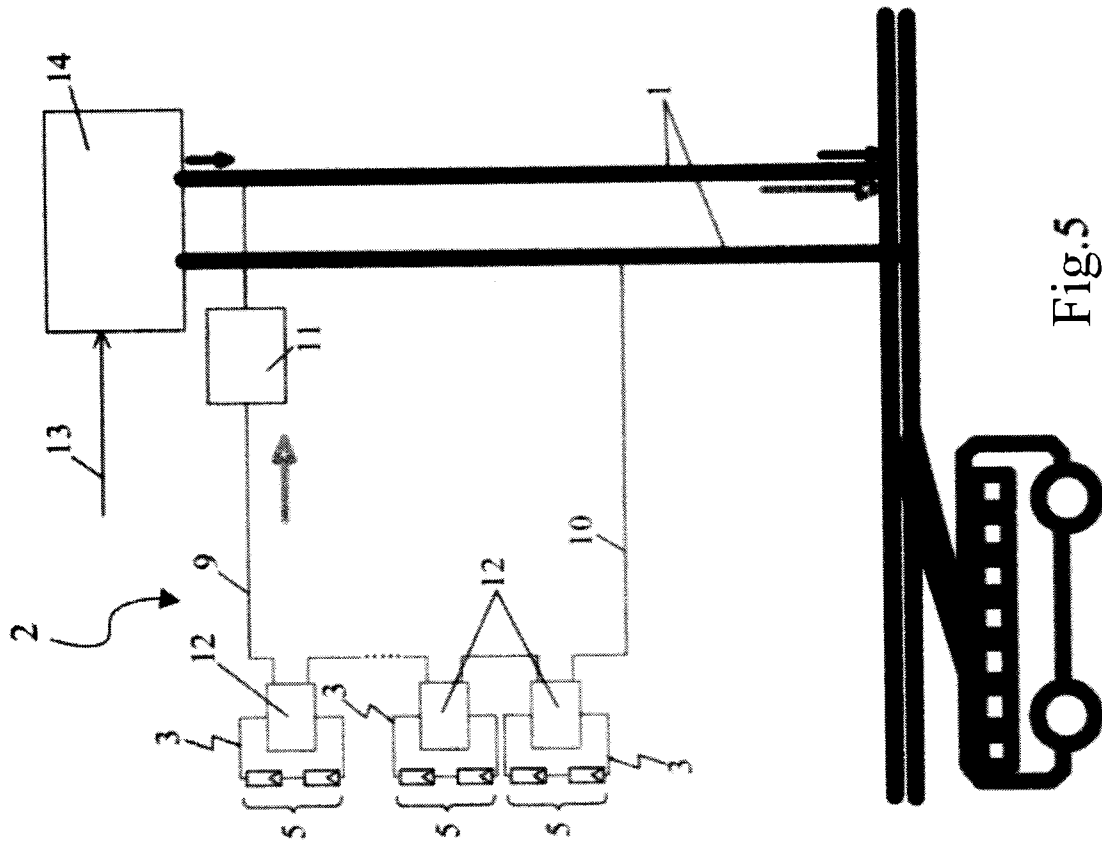


Fig.2





## INTERNATIONAL SEARCH REPORT

International application No  
PCT/BG2015/000022

A. CLASSIFICATION OF SUBJECT MATTER  
INV. H02J1/10 B60L8/00  
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)  
H02J B60L

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, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                      | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 2014/159763 A1 (LUO YUHAO [CN] ET AL)<br>12 June 2014 (2014-06-12)<br>abstract<br>paragraphs [0005] - [0049], [0055] -<br>[0070]; claims 1,2; figures 1,2,3<br>----- | 1-8                   |
| Y         | US 2012/212066 A1 (ADEST MEIR [IL] ET AL)<br>23 August 2012 (2012-08-23)<br>paragraph [0051]; figure 4b<br>-----                                                        | 1-8                   |
| Y         | US 2010/001587 A1 (CASEY LEO FRANCIS [US]<br>ET AL) 7 January 2010 (2010-01-07)<br>paragraphs [0033] - [0051]; figure 2<br>-----                                        | 7                     |
| A         | US 2013/307342 A1 (NIEMELA VAN [US])<br>21 November 2013 (2013-11-21)<br>the whole document<br>-----<br>-/-                                                             | 1-8                   |



Further documents are listed in the continuation of Box C.



See patent family annex.

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5 February 2016

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| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                             |                       |
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