

CONFIGURATION METHOD OF AN ELECTRIC POWER CONVERSION INSTALLATION AND INSTALLATION IMPLEMENTING ONE SUCH METHOD.

BACKGROUND OF THE INVENTION

5 The present invention relates to a configuration method of an electric power conversion installation. It also relates to an electric power conversion installation implementing one such method. It finally relates to a computer program comprising computer program encoding means suitable for execution of steps of the method.

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STATE OF THE ART

The invention applies in particular to electric power supply of ships at quay.

Depending on their type, ships present electric equipment operating in 50 or 60Hz.

15 Thus, when a ship is at quay and its electricity generating set is not operating, an installation enabling its equipment to be supplied with an adequate electric power source, at a frequency of 50 Hz or 60 Hz, has to be available on the quay.

In known manner, ships are equipped with low-voltage electric power systems.

20 Nowadays, electric power requirements have considerably increased and the electric power systems implemented on ships are generally of the medium-voltage type. The use of medium voltage enables cables of smaller cross-sections to be used and power losses in supply of power systems of ships to be reduced .

25 Installations enabling electric power supply of ships at quay with a suitable electric power source (50 Hz or 60 Hz) are based on the frequency converter technology. Existing solutions on the market use a medium-voltage or low-voltage technology with a unitary conversion installation. Control (of conventional type in droop mode or of PQ type) of such an installation involves connection between the conversion
30 installation and the ship. With such an installation, redundancy is not ensured and

during maintenance operations, the ships may no longer be supplied with power unless two conversion installations are provided.

Ships supplied at quay require high powers ranging for example from 1MVA up to 20MVA according to their type (bulk carrier, ferry, container carrier, passenger ships, etc.). According to the type of ship, frequency conversion may be required, in which case the major problem is to ensure a sufficient short-circuit current with a conversion installation to be able to guarantee selectivity of the protections, on the quay and on the ship, in case of a short-circuit. In current solutions where solid-state converters (semi-conductors) are used, this capacity is given only by the thermal characteristics of the static power switch used in design of converters and it is not sufficient. This problem is a major one for the supplied ships, isolation of the faulty feeder being one of the major constraints imposed on electric power supply systems of ships at quay.

The ships further require a good continuity of the electric power supply while they are alongside quay. Depending on the type of ship, the constraints are variable. In this context, it is necessary to provide installation architectures capable of providing a good level of redundancy and a good level of power supply continuity even after a fault has occurred in the installation.

SUMMARY OF THE INVENTION

One object of the invention is to provide a configuration method of an electric power conversion installation enabling the problems brought up in the foregoing to be remedied and improving known installations of the prior art. In particular, the invention proposes a configuration method that is simple, economical and efficient, in particular rendering the conversion installation capable of providing a short-circuit power necessary for selectivity of protections, capable of managing faults and improving the conversion efficiency. The invention further relates to a conversion installation implementing such a configuration method.

A configuration method of an electric power conversion installation according to the invention, the installation comprising several converters, comprises a step of determining a set of converters to be activated and an activation step of this set of converters.

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In a particular embodiment, the method comprises an interconnection step of at least certain of the converters of the set.

Preferably, in the determination step of the converters to be activated, the following are used:

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- information on the rated power of the installation, and/or
- information on the unitary rated power of a converter, and/or
- information on the number of electric power systems to be supplied by means of the installation, and/or
- information on the power required by each electric power system to be supplied, and/or
- information on the rated short-circuit current of a converter, and/or
- information on the maximum short-circuit current required by an electric power system to be supplied.

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Advantageously, for an electric power system to be supplied, the number of converters to be activated can be determined according to the following formulas:

$$N_{FC} = \text{rounded.up} (S_t / S_{FC}) \text{ with } S_t = \min [m/k \times S_{\text{ship}}, S_n] \text{ and } I_{sc FC} = k \times I_n \text{ and } I_{sc max} = m \times I_n,$$

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in which,

S_n : maximum rated power of the conversion installation;

S_t : rated power of the conversion installation after configuration;

S_{FC} : rated power of the converters;

N_{FC} : number of converters activated;

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S_{ship} : rated power of the power system to be supplied;

$I_{sc FC}$: rated short-circuit current of a converter;

k : multiplication factor;

$I_{sc \max}$: maximum short-circuit current demanded by the power system to be supplied;

m : multiplication factor.

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Advantageously, for several electric power systems to be supplied, the number of converters to be activated can be determined according to the following formulas:

$N_{FC} = \text{rounded.up} (S_t / S_{FC})$ with

$$S_t = \max \left[\sum_{i=1}^{N_{ship}} S_{shipi}, \min \left[S_n, \frac{m}{k} \cdot \max [S_{shipi}] \right] \right],$$

10 in which,

S_n : maximum rated power of the conversion installation;

S_t : rated power of the conversion installation after configuration;

S_{FC} : rated power of the frequency converters;

N_{FC} : number of frequency converters activated;

15 $S_{ship i}$: rated power of the power system i to be supplied;

k : multiplication factor;

m : multiplication factor.

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Preferably, the method comprises a step of determining at least one sub-set of converters to be interconnected from among the activated converters and an interconnection step of the converters of this at least one converter sub-set.

Advantageously, interconnection is performed by control of at least one controlled switch.

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In an electric power conversion installation according to the invention comprising several converters, said installation comprises hardware and/or software means for implementing the configuration method as defined above.

Preferably, the hardware and/or software means comprise an element for determining a set of converters to be activated and an activation element of this set of converters.

- 5 Advantageously, the hardware and/or software means comprise an element for determining at least one sub-set of converters to be interconnected from among the set of activated converters and an interconnection element of the converters of this at least one converter sub-set.
- 10 Advantageously, the interconnection element comprises at least one controlled switch.

Advantageously, each converter comprises a frequency conversion element and/or a voltage conversion element.

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A computer program according to the invention comprises computer program encoding means suitable for execution of steps of the method as defined above when the program is executed on a computer.

20 BRIEF DESCRIPTION OF THE DRAWINGS

The appended drawings represent, for example purposes, an embodiment of an installation according to the invention and an execution mode of a configuration method according to the invention.

- 25 Figure 1 is a wiring diagram of an embodiment of an installation according to the invention.

Figure 2 is a diagram representing the ratio of the maximum short-circuit current of a converter over the rated current of the converter versus time.

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Figure 3 is a diagram representing the variation of the short-circuit current intensity of a 20 MVA conversion installation versus the load which this installation has to supply.

- 5 Figure 4 is a table giving the number of converters to be used versus the rated power of an electric power system to be supplied and versus the rated power of each of the converters composing the conversion installation.

- 10 Figure 5 is a table giving the load factor of the converters used versus the rated power of an electric power system to be supplied and versus the rated power of each of the converters composing the conversion installation. A graph represents this load factor versus the rated power of the power system to be supplied for three different converter powers.

- 15 Figure 6A is a table giving the power of the configured installation versus the rated power of a first electric power system to be supplied and versus the rated power of a second electric power system to be supplied.

- 20 Figure 6B is a table giving the number of converters used in the configured installation versus the rated power of a first electric power system to be supplied and versus the rated power of a second electric power system to be supplied.

Figure 7 is a flowchart of an execution mode of a configuration method of an installation according to the invention.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An embodiment of an installation according to the invention is described in the following with reference to figure 1.

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A method according to the invention enables the following problems to be solved:

- Providing a short-circuit power necessary for selectivity of protections; and/or
- Managing default modes.

The installation 1 enables a first input electric voltage of the installation to be converted into a second output electric voltage of the installation. The first electric voltage is provided by a first electric power system 41, in particular a commercial electric power system. The second electric voltage is designed to supply one or more second electric power systems 42 comprising electric equipment, such as electric power systems equipping a ship.

For example, the electric power system 41 provides a first medium-voltage or low-voltage power source. This input voltage is converted into an output voltage of different frequency and/or voltage by means of a converter 2 comprising a frequency conversion element 10 and/or converted into a different voltage by means of a voltage conversion element 11. On output from the converter, an electric power source is obtained with a voltage and frequency matching those of the second electric power system 42.

Load-side from the converters, controlled switches 13 enable connection to be made to electric power distribution conductors 14 or enable each converter to be isolated from these conductors.

The second electric power systems are each connected to a different point of the distribution conductors. The distribution conductors further present controlled switches 12 enabling segments of these conductors to be isolated. This has the result that, depending on the state of the controlled switches 13 and 12, a second electric power system 42 can only be connected to a segment of the distribution conductors 14 and can further only be connected to a part of the converters 2 able to be connected to this segment of the distribution conductor. As a variant, the controlled switches 12 are not present and the second electric power system(s) 42 can be connected to the set of distribution conductors 14.

A control unit 100 performs control of the controlled switches 13 and 12.

The installation, in particular the control unit, comprises all the hardware and/or software means enabling the configuration method that is the object of the invention to be implemented. Thus in particular, the installation comprises hardware and/or software means enabling each of the steps of the method that is the object of the invention to be implemented and enabling each of these steps to be articulated logically and/or temporally. The control unit in particular comprises an element 101 for determining a set of converters to be activated and an activation element 102 of this set of converters. To do this, the activation element is connected with the converters. The control unit also preferably comprises an element 103 for determining at least one sub-set of converters to be interconnected from among the set of activated converters. The installation preferably comprises an interconnection element 12, 13 or coupling cell of the converters of this at least one sub-set of converters.

A method for executing a configuration method of such an installation is described in the following with reference to figure 7.

In a first step 105, the configuration method is initialised.

In a second step 110, data is input. This can be performed by means of sensors detecting the information that is required or by manual input, for example performed by an operator via a man-machine interface. In particular, in the course of this step, the following data is collected:

- S_n : rated power of the installation, and/or
- SFC: unitary power of the converters, and/or
- SFCB: power of a set of converters, and/or
- N_{sh} : number of connected ships, and/or
- $S_{ship\ i}$: power required for ship i , and/or

- $I_{sc FC}$: rated short-circuit current of the frequency converters, and/or
- k : multiplication factor, and/or
- $I_{sc max}$: maximum short-circuit current demanded by a ship, and/or
- m : multiplication factor.

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In a third step 120, it is tested whether there is at least a second electric power system 42 connected load-side from the conversion installation. If this is not the case, we go on to a step 130 in which the conversion installation is switched to standby and, if applicable, a main controlled switch located between the first
 10 electric power system and the conversion installation is opened. If this is the case, we go on to a step 140.

In step 140, it is tested whether there is a single second electric power system 42 connected load-side from the conversion installation. If this is the case, we go on
 15 to a step 160 in which the power S_t that the configured conversion installation has to present and the number N_{FC} of converters that have to be used in this configured conversion installation are calculated or determined. It is therefore determined which of the converters of the conversion installation have to be activated to operate in parallel. A set of converters to be activated is thus defined.
 20 If this is not the case, we go on to a step 150 in which the power S_t that the configured conversion installation has to present and the number N_{FC} of converters that have to be used in this configured conversion installation are calculated or determined. It is therefore determined which of the converters of the conversion installation have to be activated. A set of converters to be activated is
 25 thus defined. Furthermore, the controlled switches 12 that have to be open and the controlled switches 12 that have to be closed are determined. The converters forming interconnected sub-sets in which the converters operate in parallel are thereby determined.

30 In both cases, we then go on to a test step 170 in which it is tested whether the conversion installation was previously active or previously inactive. If the

conversion installation was previously inactive, we go on to a step 180 in which the converters that were determined in the course of step 150 or in the course of step 160 are switched on. In a following step 190, the main switch located between the first electric power system and the conversion installation is closed.

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If the conversion installation was previously active, we go on to a step 200 in which one or more additional converters are switched on if necessary or in which one or more converters that are of no use are switched off. This takes place only if the power demand load-side of the conversion installation has been modified. If the power demand load-side of the conversion installation is unchanged, there is in principle no need to deactivate a converter or to activate a converter.

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In a following step 210, the second electric power system(s) is/are connected to the conversion installation and supplied by the conversion installation.

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In a following step 220, the operating parameters of the installation and the power requirements of the second power systems are monitored.

In a following test step 230, it is tested whether the power requirement at the level of the second electric power systems is modified. If this is not the case, we loop back to step 220. If this is the case, we loop back to step 120.

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The conversion installation according to the invention and the configuration method according to the invention enable a sufficient short-circuit current to be ensured to perform selectivity of the protections. What is meant by selectivity is the ability of a protection system to detect a fault in a determined area of a power system and to cause tripping of suitable circuit breakers to eliminate this fault with a minimum disturbance for the healthy part of the power system.

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The configuration method thus enables converters of the conversion installation to be switched on or off according to the required power. The short-circuit strength of

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the installation can thus be maximised while at the same time minimising the investment cost and preventing downrating of the installation. To do this, as seen in the foregoing, low-power converters are used connected in parallel. For example, 0.5MVA converters or power values ranging between 0.5 MVA and 5MVA are preferably used, as shown in figure 4, to achieve a conversion installation.

From characteristic values for a static frequency converter, for example $2.25I_n$ for 0.8s (rated values), a "Short-circuit current/Rated current versus time" characteristic of a converter is obtained as represented in figure 2. From this characteristic, a control or configuration algorithm of the installation can be defined to ensure a short-circuit current equivalent for example to $3I_n$ for 0.8s in the whole of the conversion installation.

An increase of the short-circuit power is achieved in the scope of the conversion installation by using existing converters in the conversion installation, by switching the latter on. The short-circuit current strength of the conversion installation can thus vary according to the total power supplied.

It is now assumed that a single second electric power system has to be connected to the conversion installation. It is also assumed that the power of the conversion installation is 20MVA. The most constraining case is further considered, i.e. supply of a single second electric power system the power of which varies from 1MVA to 20MVA. In figure 4, according to the power demanded by the load, i.e. the second electric power system (first column of figure 4), one or more unitary power converters (0.5 MVA or 1 MVA or 2 MVA or 3 MVA or 4 MVA or 5 MVA) are switched on to be able to obtain a sufficient short-circuit power. For practical reasons, a maximum overdimensioning limit of 33% is set. Thus, for the example presented, a short-circuit current is ensured equivalent to 1pu up to 15MVA (where 1pu means $3I_n$ for 0.8s). In figure 3, the variation of the short-circuit current is presented versus the load for the 20MVA conversion installation. In the

example $k=2.25$, $m = 3$ and $S_{ship}= 1$ to 20 MVA, the total number of converters in operation N_{FC} is calculated according to the following formulas. It is determined from the power S_t (necessary power to be implemented or configured within the conversion installation to ensure a maximum short-circuit current).

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$$I_{sc\ FC} = k \times I_n$$

$$I_{sc\ max} = m \times I_n$$

$$S_t = \min [m/k \times S_{ship}, S_n]$$

$$N_{FC} = \text{rounded.up} (S_t / S_{FC}) \quad \rightarrow \quad S_t = N_{FC} \times S_{FC}$$

10 with

- S_n : rated power of the conversion installation;
- S_t : power of the configured conversion installation;
- S_{FC} : unitary power of a converter;
- S_{FCB} : power of a set of converters;
- 15 - N_{FC} : number of activated converters;
- N_{sh} : number of second electric power systems to be supplied;
- $S_{ship\ i}$: power required by the second electric power system i ;
- $I_{sc\ FC}$: rated short-circuit current of the converters;
- k : multiplication factor;
- 20 - $I_{sc\ max}$: maximum short-circuit current demanded by a second electric power system;
- m : multiplication factor;
- rounded.up: an application rounding up to the higher integer.

25 These formulas constitute an example of execution of step 160.

The choice of converters to be activated or to be switched on can be random.

Figure 5 presents the results obtained for the example presented in the foregoing where the converters can have powers of 0.5MVA, 1MVA, 2MVA, 3MVA, 4MVA or 5MVA. According to the power of the converters chosen, the global efficiency of

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the installation is different, as the load factor of the converters varies according to the power of the second electric power system connected. A very good efficiency is thus obtained with a constant load factor in the case of use of low-power converters, for example 0.5MVA or 1MVA. The results are recapitulated in figure 5. In the table, each column represents the load factor of the configured conversion installation using converters the power of which determines the column of the table. The first column indicates the power of the second electric power system. The diagram of figure 5 represents the variations of the load factor of three configured installations respectively using converters of 0.5MVA, 3MVA and 5MVA, versus the power of the second electric power system.

In the case of power supply of several second electric power systems at the same time from the conversion installation, the control rules are similar and take account of the power consumed by each second electric power system. It is considered that there cannot be simultaneous short-circuits on two second electric power systems. The short-circuit current required for the faulty second electric power system is provided by the whole of the configured conversion installation. The total number of converters in operation is calculated according to the following formulas:

$$S_t = \max \left[\sum_{i=1}^{N_{shj}} S_{shipi}, \min \left[S_n, \frac{m}{k} \cdot \max [S_{shipi}] \right] \right]$$

$$N_{FC} = \text{rounded.up} (S_t / S_{FC}) \quad \rightarrow \quad S_t = N_{FC} \times S_{FC}$$

These formulas constitute an example of execution of step 150.

The choice of the converters to be activated or switched on can be random.

As an illustration, a case where two second power systems are connected at the same time on a 20MVA conversion installation is presented in figures 6A and 6B.

Thus, according to the power consumed on the two second electric power

systems (Ship 1 and Ship 2), the value S_t of the necessary power to be implemented within the conversion installation to ensure an adequate maximum short-circuit current is determined. The number of converters N_{FC} to be switched on or to be activated is given by the previous formula.

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To ensure a good continuity of power supply of the second electric power systems, in case of a fault both on converters and in the second electric power systems, the electric architecture is preferably of the double antenna type. The electric installation is thus preferably provided with coupling cells 12 on the
 10 secondary busbar 14. As a variant, the electric architecture is of single antenna type, the controlled switches 12 not existing.

There are two possibilities of operation under rated operating conditions of the installation according to the power required by the different second electric power
 15 systems that are connected:

- in the case of use of several second electric power systems of equivalent powers, the controlled switches 12 are normally open. This enables a power supply failure in the other electric power systems to be avoided in case of a fault on a second electric power system,
- 20 - in the case of use of several second electric power systems of very different powers in particular with a second power system the power of which exceeds the power that can be obtained by operation of all the converters able to be connected to a segment of the distribution conductor 14, the installation has to be configured with one or more normally closed controlled switches 12. This
 25 enables supply of second electric power systems of different powers, or supply of a single second electric power system the power of which is equivalent or almost equivalent to the total power of the conversion installation. However, to preserve continuity of service at global level in case of a fault on one of the connected second power systems, controlled switches 12 can be open. Isolation of the power
 30 systems can thus be performed. The choice of the normally open controlled switch

is made according to the power of the connected second electric power systems. The lowest in terms of demanded power is preferably isolated.

In the case where certain controlled switches are open, the choice of the converters to be activated is preferably not random but is made according to the locations of the converters relatively to the open controlled switches 12 and to the conductors 14.

The operation described in the above two cases enables the necessary short-circuit power to obtain selectivity of protection and non-propagation of faults on the feeders of the second electric power systems to be obtained .

In the case of an electric architecture of single antenna type, when the controlled switches 12 do not exist, the installation enables the necessary short-circuit power to obtain selectivity of protection to be ensured.

Another advantage of the conversion installation and of the configuration method is to enable the use of a minimum number of converters to ensure the necessary short-circuit power for the installation. Too great a downgrading of the installation and increased investment costs are thereby avoided. This also enables a good energy efficiency of the conversion installation to be maintained, the load factor of the converters being maintained at values always greater than 65%, with a very good global efficiency. Low load factors for which the efficiency of the converters is less good are in fact avoided by switching the converters on and off.

The configuration method can use an overdimensioning rule. It enables the configured installation to supply a sufficient short-circuit power for selectivity of the protections. It also enables default modes to be managed (abundance of loads when everything is operating normally and isolation of the feeders in case of a short-circuit on a power system). The installation moreover preferably presents means enabling it to be restarted following a fault.

The different controlled switches, in particular controlled switches 12 and 13, are for example circuit breakers.

CLAIMS.

1. A configuration method of an electric power conversion installation (1), the installation comprising several converters (2), the method comprising a step of
 5 determining a set of converters to be activated and an activation step of this set of converters.

2. The configuration method according to claim 1, characterized in that it comprises an interconnection step of at least certain of the converters of the set.

3. The configuration method according to claim 1 or 2, characterized in that, in the step of determining the converters to be activated, the following are used:

- information on the rated power of the installation, and/or
- information on the unitary rated power of a converter, and/or
- 15 – information on the number of electric power systems to be supplied by means of the installation, and/or
- information on the power required by each electric power system to be supplied, and/or
- information on the rated short-circuit current of a converter, and/or
- 20 – information on the maximum short-circuit current required by an electric power system to be supplied.

4. The configuration method according to one of the foregoing claims, characterized in that, for an electric power system (42) to be supplied, the number
 25 of converters to be activated can be determined according to the following formulas:

$$N_{FC} = \text{rounded.up} (S_t / S_{FC}) \text{ with } S_t = \min [m/k \times S_{ship}, S_n] \text{ and } I_{sc FC} = k \times I_n \text{ and } I_{sc max} = m \times I_n,$$

in which,

30 S_n : maximum rated power of the conversion installation;

S_t : rated power of the conversion installation after configuration;

S_{FC} : rated power of the converters;

N_{FC} : number of converters activated;

S_{ship} : rated power of the power system to be supplied;

$I_{sc FC}$: rated short-circuit current of a converter;

5 k : multiplication factor;

$I_{sc max}$: maximum short-circuit current demanded by the power system to be supplied;

m : multiplication factor.

- 10 **5.** The configuration method according to one of the foregoing claims, characterized in that, for several electric power systems (42) to be supplied, the number of converters to be activated can be determined according to the following formulas:

$N_{FC} = \text{rounded.up} (S_t / S_{FC})$ with

$$15 \quad S_t = \max \left[\sum_{i=1}^{N_{ship}} S_{ship i}, \min \left[S_n, \frac{m}{k} \cdot \max [S_{ship i}] \right] \right],$$

in which,

S_n : maximum rated power of the conversion installation;

S_t : rated power of the conversion installation after configuration;

S_{FC} : rated power of the frequency converters;

20 N_{FC} : number of frequency converters activated;

$S_{ship i}$: rated power of the power system i to be supplied;

k : multiplication factor;

m : multiplication factor.

- 25 **6.** The configuration method according to one of the foregoing claims, characterized in that it comprises a step of determining at least one sub-set of converters to be interconnected from among the activated converters and an interconnection step of the converters of this at least one converter sub-set.

7. The configuration method according to the previous claim, characterized in that interconnection is performed by control of at least one controlled switch (12, 13).

5 **8.** An electric power conversion installation (1) comprising several converters (2), the installation comprising hardware means (11, 12, 13, 100) and/or software means for implementing the configuration method according to one of the foregoing claims.

10 **9.** The installation (1) according to the previous claim, characterized in that the hardware and/or software means comprise an element (101) for determining a set of converters to be activated and an activation element (102) of this set of converters.

15 **10.** The installation (1) according to claim 8 or 9, characterized in that the hardware and/or software means comprise an element (103) for determining at least one sub-set of converters to be interconnected from among the set of activated converters and an interconnection element (12, 13, 14) of the converters of this at least one converter sub-set.

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11. The installation (1) according to the previous claim, characterized in that the interconnection element comprises at least one controlled switch (12, 13).

25 **12.** The installation (1) according to one of claims 8 to 11, characterized in that each converter comprises a frequency conversion element (10) and/or a voltage conversion element (11).

30 **13.** A computer program comprising computer program encoding means suitable for execution of steps of the method according to one of claims 1 to 7 when the program is executed on a computer.