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(54) **Title**: CONTROL SYSTEM FOR OVERSPEED REDUCTION IN WATER POWER PLANTS

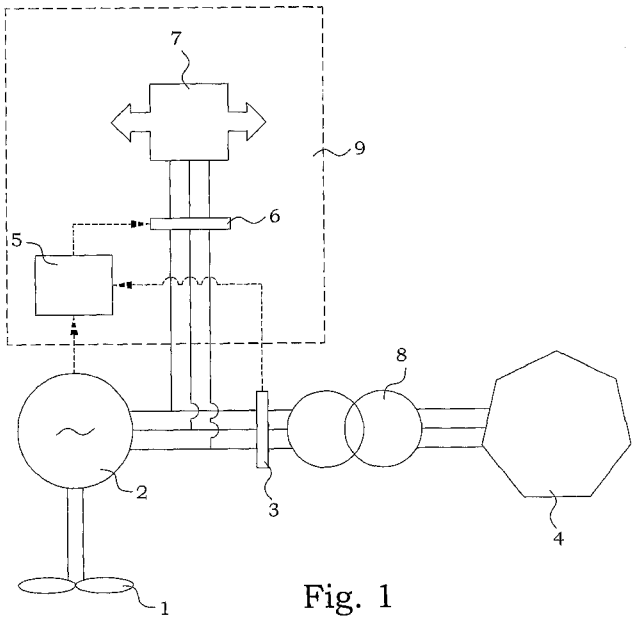

Fig. 1

(57) **Abstract**: A device for redirecting of electrical energy from an electrical generator (2) in a water power plant comprises an electrical load (7), an electrical switch (6) arranged for connecting the electrical load to the generator and a control system (5) for control of the device. The control system is connected to sensor units of the generator, indicating rotational speed of the generator and/or output power of the generator, and within a generator circuit breaker (3), indicating the position of the generator circuit breaker, The control system is arranged for activating the electrical switch to connect the electrical load when it is determined by the sensor units that the generator circuit breaker is open and that an increase in rotational speed in the generator exceeds a first predetermined threshold value, alternatively that the output power of the generator falls below a second predetermined threshold value.

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CONTROL SYSTEM FOR OVERSPEED REDUCTION IN WATER POWER PLANTS

TECHNICAL FIELD

The present invention relates in general to control of hydraulic turbines connected to a generator, and in particular to controlled quick stops of units in a water power plant.

BACKGROUND

In a water power plant intended for production of electricity, a flow of water acts on one or several impellers. A generator, directly or indirectly connected to the turbine shaft, converts the mechanical energy into electrical energy and is connected to a load or to a distribution grid for transmission of electrical energy to consumers.

If events on the electrical grid (for instance any electrical short circuiting) or in the plant (for instance a vibration level guard) and surrounding water conduits initiates a load rejection and need to switch off the generator from the electrical grid by opening a generator circuit breaker, the braking torque on the rotating system from the generator will disappear at the same time as the turbine gives an actuating torque. This may cause an overspeed of the rotating system and hydraulic transients (water hammer or surging) in the water conduits if the guide vane closing time is too short. Depending on the hydraulic circumstances that are present around the turbine at the specific occasion, one may for Kaplan or axial turbines achieve large axial forces which may cause damages on the unit or the station.

If one therefore could reduce the overspeed, and thereby allow a slow closing of the guide vanes directing the water to the turbine, one could avoid hydraulic overpressures and underpressures in the water conduits and reduce the mechanical stress on the rotating system.

RELATED ART

Electrical loads for prohibiting overspeeding at a sudden disconnection of a steam turbine have been proposed in an earlier published international patent application WO 2009/038562. An electrical load is connected when a circuit breaker to the electrical grid is opened. In the published international patent application WO 2011/018404 a system is disclosed, for shortening of the shutdown time of a steam turbine by switching the output connection to an auxiliary load instead of a grid and at the same time shutting the steam supply to the turbine.

Electrical loads for rotating speed control or for controlling power variations are disclosed are disclosed e.g. in the European patent EP 0098047 B1 or the Swedish patent SE 520 399 C2. The loads are there connected during normal operation. Such arrangements are, however, unsuitable for shutdown occasions, since the control strategies are completely different.

SUMMARY

A general object of the present invention is to provide an improved reliability of systems for redirecting of electrical energy in a water power plant in the case of a disconnection of the electrical grid. This object is achieved by a device according to claim1. Advantageous embodiments are defined in the dependent claims.

In general words, a device for redirecting of electrical energy from an electrical generator in a water power plant comprises an electrical load, an electrical switch arranged for connecting the electrical load to the generator and a control system for control of the device. The control system is connected to sensor units of the generator and is arranged for activating the electrical switch to connect the electrical load in response to control signals from the sensor units of the generator and from sensor units within a

generator circuit breaker connecting the generator to an electrical grid. The sensor units of the generator indicate rotational speed of the generator and/or output power of the generator. The sensor units within the generator circuit breaker indicate the position of the generator circuit breaker. The control system is arranged for activating the electrical switch when it is determined by the sensor units of the generator and within the generator circuit breaker that the generator circuit breaker is open and that an increase in rotational speed in the generator exceeds a first predetermined threshold value, alternatively that the output power of the generator falls below a second predetermined threshold value.

One advantage with the present invention is that disconnection of water power plants can be performed in a reliable and lenient manner. This may even allow for an increase in the closing time of the guide vanes which would decrease the risk of potentially harmful hydraulic pressure transients. Additional advantages are discussed in connection with the detailed description further below.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with further objects and advantages thereof, may best be understood by making reference to the following description taken together with the accompanying drawings, in which:
Figure 1 shows schematically an embodiment of a device for redirecting of electrical energy from an electrical generator in a water power plant; and
Figure 2 shows a flow diagram of steps of an embodiment of a method for redirecting of electrical energy from an electrical generator in a water power plant.

DETAILED DESCRIPTION

In a water power plant, it is thus beneficial to allow a slow closing of the guide vanes directing the water to the turbine in order avoid hydraulic

pressure waves in the water conduits and at the same time reduce the overspeed. This can be performed by connecting an external load to the generator after the generator has been disconnected from the electrical grid. The external load (hereinafter called electrical load) prohibits overspeeding of the turbine and one gets more time to control the flow through the unit, which means that one may close the guide vanes as slowly as is needed in order to avoid hydraulic transients without at the same time causing overspeeding of the rotating system provided the electrical load is dimensioned appropriately.

Such connection of an external electrical load may be triggered by the disconnection of the electrical grid. The disconnection of the electrical grid may have different causes and may have differing duration. Load rejection may e.g. be initiated by detection of severe transients in the electrical grid. For very short disturbances, e.g. shorter than 250 ms, it is requested by the system operator in many grids that the generators stay connected, and for faults lasting more than 250 ms one wants to reconnect almost immediately after the fault has been cleared. In such situations, connection of external loads based only on the generator circuit breaker position is not very suitable.

If the external load connection does not react on the re-connection of the electrical grid, the external load will thus be applied in parallel to the loads of the electrical grid. Large amounts of energy will be dissipated through the external load since a large part of the available power will be consumed that way.

There are possibilities to change the parameter on which the connection of the external load is made. For instance, connection of a load may be triggered e.g. on a detected overspeed. However, since moderate overspeed situations may occur also during "normal" operation, c.f. e.g. EP 0098047 B1 or SE 520 399 C2, there are difficulties in determining what is a "normal" overspeed variation and what is an emergency case. Since external loads for

regulating normal power variations for a generator typically is much smaller than preferred external loads for emergency shut-downs, the stabilization equipment may not generally be used for shut-down purposes.

Therefore, according to the present ideas, the control of the connection of the external load is based on two parameters. The first parameter is the position of the generator circuit breaker, which has to indicate that it is open. The other parameter is a parameter concerning the behaviour of the generator, and is according to the present invention either that an increase in rotational speed in the generator exceeds a predetermined threshold value, or alternatively, that the output power of the generator falls below a predetermined threshold value. Short disconnections of the electrical grid will not have time to cause a substantially increased rotational speed, and an external load is thereby not connected until after a certain duration of the electrical grid disconnection. This solution also ensures that a false generator circuit breaker signal could not cause damages to the system.

In other words, an electrical load is connected to the terminals on the generator via an electrical switch. The electrical switch receives a signal from a control system to close the electrical connection between generator and an electrical load. The control system in turn reacts on signals from a generator switch, switching the generator to an electrical grid, and from the generator itself. When the control system detects an increase in rotational speed of the generator, which also can be detected by measuring the electrical frequency, or a low output power and that the generator switch is transferred to an open position, a signal is sent to the electrical switch to connect the electrical load.

Figure 1 schematically illustrates the character of an embodiment of a device 9 for redirecting of electrical energy from an electrical generator 2 in a water power plant. A water power plant comprises one or several turbines 1 connected to the generator 2. Via an electrical circuit breaker or power electronics 3, the electrical power is distributed out to distributed or

localized loads or to the electrically connected electrical grid 4. Typically, a transformer 8 is provided between the circuit breaker 3 and the electrical grid 4. When any incident in the electrical system occurs, it is detected by a protection system (not shown) installed in the power plant. The protection system activates the circuit breaker or power electronics 3 so that the output electrical power to the electrical grid 4 from the generator 2 disappears.

Control signals 10, 11 are sent to a control system 5 in the device 9 for redirecting of electrical energy. The control signals 11 from the generator circuit breaker 3 comprises the position or status of the generator circuit breaker 3. The control signals 10 from the generator 2 comprise delivered active power and/or rotational speed as given from the generator 2. The control signals 10, 11 are not limited to these signals, but may also comprise other control signals. The control system 5 is adapted to receive the control signals 11 about the position of the generator circuit breaker and to receive the control signals 10 about the rotational speed and/or delivered active power of the generator 2.

A device 9 for redirecting of electrical energy from an electrical generator 2 in a water power plant comprises an electrical load 7, an electrical switch 6 arranged for connecting the electrical load 7 to the generator 2 and a control system 5 for control of the device.

A load rejection that is indicated in that the generator circuit breaker 3 is transferred into an open position, and that either the rotational speed increases in the rotating system or that the electrical output power drops to low or almost zero value, is detected by the control system 5. Upon such detection, the control system 5 is adapted to control circuit breakers or power electronics 6 (hereby are both realizations of switches) in order to redirect the electrical power to an equipment, being an electrical load 7, that is intended to take care of the electrical power.

In other words, the control system 5 is connected to sensor units of the generator 2. The sensor units of the generator 2 indicate rotational speed of the generator 2 and/or output power of the generator 2. The control system 5 is further connected to sensor units within the generator circuit breaker 3, connecting the generator 2 to the electrical grid 4. The sensor units within the generator circuit breaker 3 indicate the position of the generator circuit breaker 3. The control system 5 is arranged for activating the electrical switch 6 to connect an electrical load 7 in response to control signals from the sensor units of the generator 2 and from sensor units within the generator circuit breaker 3. The control system 5 is thereby arranged for activating the electrical switch 6 when it is determined, by the sensor units of the generator 2 and within the generator circuit breaker 3, that:

the generator circuit breaker 3 is open, and

an increase in rotational speed in the generator 2 exceeds a first predetermined threshold value, alternatively the output power of the generator 2 falls below a second predetermined threshold value.

The equipment 7 that is intended to take care of the electrical power comprises either an electric load or an energy storage that is able to receive electrical energy. In certain devices, there may also be a transformer (not shown) between generator 2 and the equipment that receives the electrical power 7. The device is designed so that the electrical switch 6 is positioned between the generator 2 and the circuit breaker 3 of the generator.

The device 7 for receiving the electrical power may comprise an electrical load, or a storage system for energy, such as for instance a flywheel, batteries, compressed air, but is not limited to these applications. Therefore, in one embodiment, the electrical load 7 comprises a storage system for electrical energy. In one particular embodiment, the electrical load 7 comprises an electrically connected flywheel. In another particular embodiment, the electrical load 7 is a combination of a storage system and an impedance load. The electrical load comprises in one embodiment an electrical resistance realized in a water bath.

The electrical switch 6 comprises in different embodiments either a circuit breaker or power electronics that electrically connects the external electrical load.

The control system 5 thus makes use of a minimum of two control signals in order to distinguish a normal stop or load rejection and re-closure of the generator circuit breaker 3 from a true load rejection in order to prevent unwanted activation of the installed switch 6 and the risk that the auxiliary equipment 7 absorbs rated power continually. Further it separates normal power oscillations occurring due to load angle oscillations from true load rejections, which the suggested system is designed to handle.

A braking device used for rotating speed control during normal operation can in general not preferably be used as an external electrical load for stop conditions. Such a load is typically very small compared with the nominal power of the power plant, since it should only influence minor fluctuations during normal operation. If systems of these two kinds are to be combined, a preferred embodiment comprises two loads, one for each function. In a preferred embodiment of an external electrical load for stop conditions, the load should consume at least 30% of the nominal power of the water power plant.

Fig. 2 is a flow diagram of steps of an embodiment of a method for redirecting of electrical energy from an electrical generator in a water power plant. The process starts in step 200. In step 210, control signals indicative of a position of a generator circuit breaker are received. The circuit breaker connects the generator to an electrical grid. In step 220, control signals indicative of a rotational speed of the generator and/or an output power of the generator are received. In step 230, two conditions are investigated. It is thereby determined from the received control signals indicative of a position of a generator circuit breaker whether or not the generator circuit breaker is open. Furthermore, it is determining from the received control signals

indicative of a rotational speed of the generator and/or an output power of the generator whether or not an increase in rotational speed in the generator exceeds a first predetermined threshold value, alternatively the output power of the generator falls below a second predetermined threshold value. In step 240 an electrical load is connected to the generator in dependence of the outcome of the determining in step 230. The connection of the electrical load to the generator is performed when it is determined in the step 230 of determining that both conditions are fulfilled, i.e. that the generator circuit breaker is open and that an increase in rotational speed in the generator exceeds a first predetermined threshold value, alternatively the output power of the generator falls below a second predetermined threshold value. The process ends in step 299.

The described device can also be used for normal operation interruptions when the generator is disconnected from the grid and the unit is to be brought to standstill. By maintained rotor magnetization and connection of the electrical load, a braking torque is achieved on the shaft that reduces the rotation speed faster that in a case when no electric load is connected.

The system solution of an embodiment of the present invention is therefore configured in order to allow usage for electrically braking the rotating system also at normal operation stops, i.e. planned stops.

At a normal operation stop, the output power is successively reduced, typically by reducing the flow of water using the guide vanes. When the output power is relatively low, the generator circuit breaker 3 is transferred to an open position. The control system 5 of the external load will then activate the electrical switch 6 to a closed position since the electrical output power is low and since the generator circuit breaker 3 is transferred to an open position.

An embodiment of the described equipment can thus also be used at other stop occasions for turbine 1 and generator 2. At normal stops, or so-called

fast de-loaded stops, when the output power of the generator is almost zero and when the circuit breaker of the generator 3 disconnects the generator 2 from the surrounding electric grid 4, the control system 5 may request the electrical switch 6 to close so that the electrical load 7 receives the rotational energy of the turbine and generator as electrical energy. Thereby, the rotational speed will decrease faster passing critical rotational speeds for the rotating system (consisting of turbine 1, shaft and generator 2) whereby one thereby can avoid vibration problems and wear of bearing components in the water power plant.

The control system 5 is in such an embodiment arranged for activating the electrical switch 6 when it is determined by the sensor units of the generator 2 and the generator circuit breaker 3 that the generator circuit breaker 3 is open and the output power of the generator 2 falls below a second predetermined threshold value. The second predetermined value corresponds to what is induced by as normal stop operation in a turbine generator.

In the case when the described system is used regularly at normal operation stops, the generated energy may be taken care of in the plant or its surroundings, either as local power when the electrical load is arranged as a storage system for electrical power, or for heating of premises when the electrical load is arranged so that the power heats an amount of water. In other words, in one embodiment, the electrical load 7 generates an excess of heat that is used for heating the water power plant. When the load is an electrical load and similar stops occur, a non-insignificant amount of heat will be generated. When the load 7 is a storage system for electrical energy, this may serve as back-up power in the water power plant, and there be used as local power or as emergency power. In other words, in one embodiment the electrical load 7 stores the received energy, which then is used for electrical power generation in the plant.

In one embodiment, a device for redirecting of electrical energy from an electrical generator in a water plant comprises a control system 5 for control

of the device and a generator circuit breaker 3 which connects the generator to the electrical grid 4. The device further comprises an electrical switch 6 arranged for connecting an electrical load 7. The control system 5 is connected to sensor units of generator 2 and generator circuit breaker 3, which indicate rotational speed of the generator and/or output power of the generator and position of the generator circuit breaker 3. The control system 5 is arranged for activating the electrical switch 6 to connect the electrical load 7 after determining from control signals from the sensor units of generator 2 and of generator circuit breaker 3 that the generator circuit breaker 3 is open, and that an increase in rotational speed exceeding a predetermined threshold value occurs in the generator 2, alternatively that the output power of the generator falls below a predetermined threshold value.

In one embodiment, the electrical load 7 consists of an electrically connected flywheel.

In one embodiment, the electrical load 7 consists of a storage system for electrical energy.

In one embodiment, the electrical load is a combination of a storage system and an impedance load.

In one embodiment, the electrical load generates an excess of heat that is used for heating the plant.

In one embodiment, the electrical load stores the received energy, which then is used for electrical power generation in the plant.

In one embodiment, a device for redirecting electrical energy from an electrical generator in a water plant comprises a control system 5 for control of the device and a generator circuit breaker 3, which connects the generator to the electrical grid 4. The device further comprises an electrical switch 6

arranged to connecting an electrical load 7. The control system 5 is connected to sensor units of generator 2 and within generator circuit breaker 3, which indicate rotational speed of the generator and/or output power of the generator and position of the generator circuit breaker 3. The control system 5 is arranged for activating the electrical switch 6 to connect the electrical load 7 after determining from control signals from the sensor units of generator 2 and within generator circuit breaker 3 that the generator circuit breaker 3 is open, and that the output power of the generator falls below a predetermined threshold value, which has been induced by a normal stop operation in a turbine regulator.

CLAIMS

1. A device for redirecting of electrical energy from an electrical generator (2) in a water power plant comprising:

an electrical load (7);

an electrical switch (6) arranged for connecting said electrical load (7) to said generator (2); and

a control system (5) for control of the device;

said control system (5) is connected to sensor units within a generator circuit breaker (3) connecting said generator (2) to an electrical grid (4), which sensor units within said generator circuit breaker (3) indicate the position of said generator circuit breaker (3);

said control system is arranged for activating said electrical switch (6) to connect said electrical load (7) in response to control signals from the sensor units within said generator breaker (3),

characterized in that

said control system (5) is further connected to sensor units of said generator (2);

the sensor units of said generator (2) indicate rotational speed of the generator (2) and/or output power of the generator (2);

whereby said control system (5) is arranged for activating said electrical switch (6) when it is determined by said sensor units of said generator (2) and within said generator circuit breaker (3) that:

said generator circuit breaker (3) is open, and

an increase in rotational speed in the generator (2) exceeds a first predetermined threshold value, alternatively the output power of said generator (2) falls below a second predetermined threshold value.

2. The device according to claim 1, **characterized in that** said control system (5) is arranged for activating said electrical switch (6) when it is determined by said sensor units of said generator (2) and within said generator circuit breaker (3) that said generator circuit breaker (3) is open and the output power of said generator (2) falls below a second

predetermined threshold value, which second predetermined value corresponds to what is induced by as normal stop operation in a turbine generator.

3. The device according to claim 1 or 2, **characterized in that** said electrical load (7) comprises a storage system for electrical energy.

4. The device according to claim 3, **characterized in that** said electrical load (7) comprises an electrically connected flywheel.

5. The device according to claim 3 or 4, **characterized in that** said electrical load (7) is a combination of said storage system and an impedance load.

6. The device according to any of the claims 3 to 5, **characterized in that** said electrical load (7) stores the received energy, which then is used for electrical power generation in the plant.

7. The device according to claim 1 or 2, **characterized in that** said electrical load (7) generates an excess of heat that is used for heating the plant.

8. A method for redirecting of electrical energy from an electrical generator in a water power plant comprising the steps of:

receiving (210) control signals indicative of a position of a generator circuit breaker connecting said generator to an electrical grid;

determining (230) from said received control signals indicative of a position of a generator circuit breaker whether or not:

a) said generator circuit breaker is open; and

connecting (240) an electrical load to said generator in dependence of said step of determining (230),

characterized in that

receiving (220) control signals indicative of a rotational speed of said generator and/or an output power of said generator;

said step of determining (230) further comprises determining from said received control signals indicative of a rotational speed of said generator and/or an output power of said generator whether or not:

b) an increase in rotational speed in the generator exceeds a first predetermined threshold value, alternatively the output power of said generator falls below a second predetermined threshold value;

said step of connecting (240) comprises connecting said electrical load to said generator, when it is determined in the step of determining (230) that both a) and b) are fulfilled.

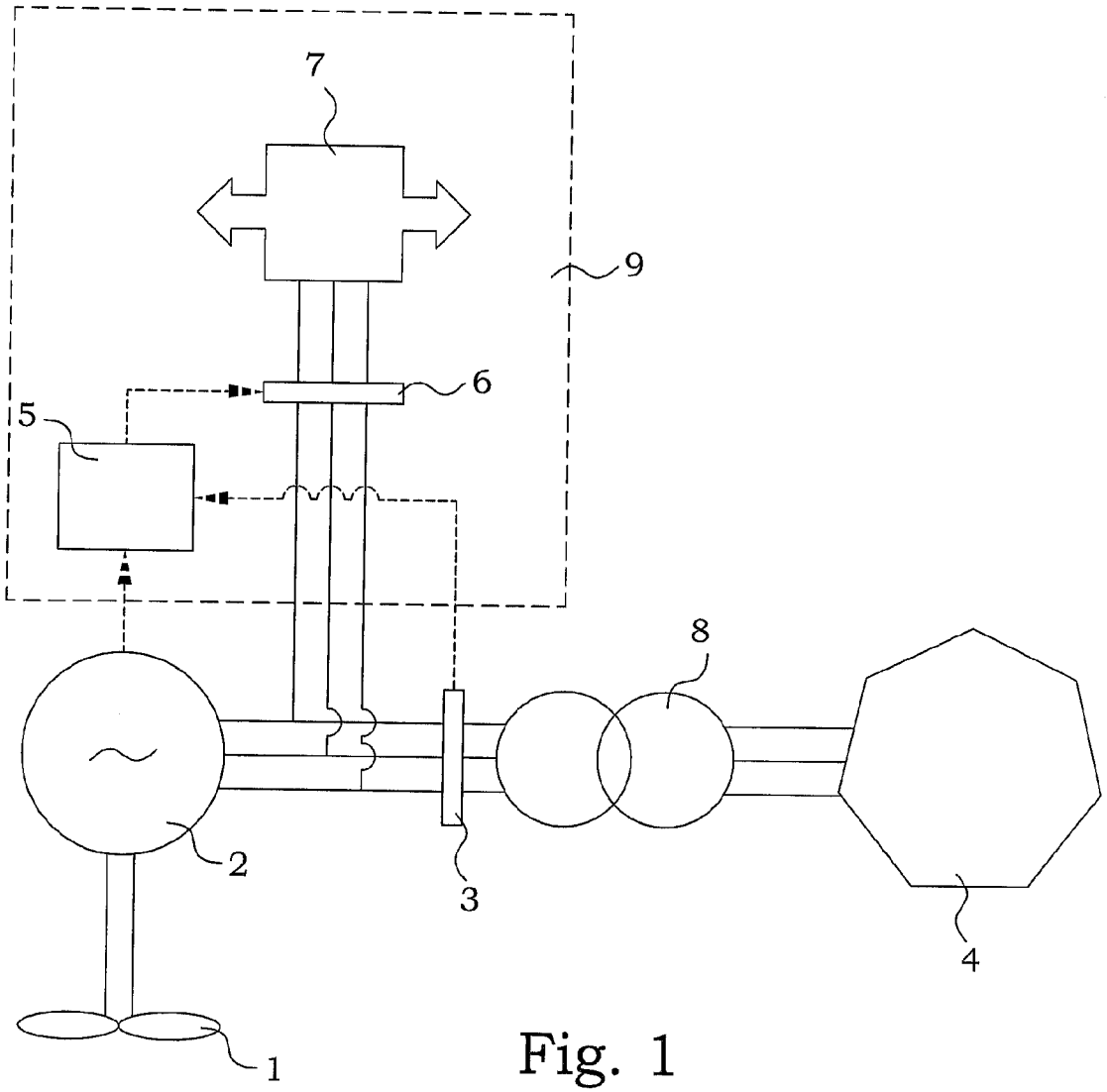

Fig. 1

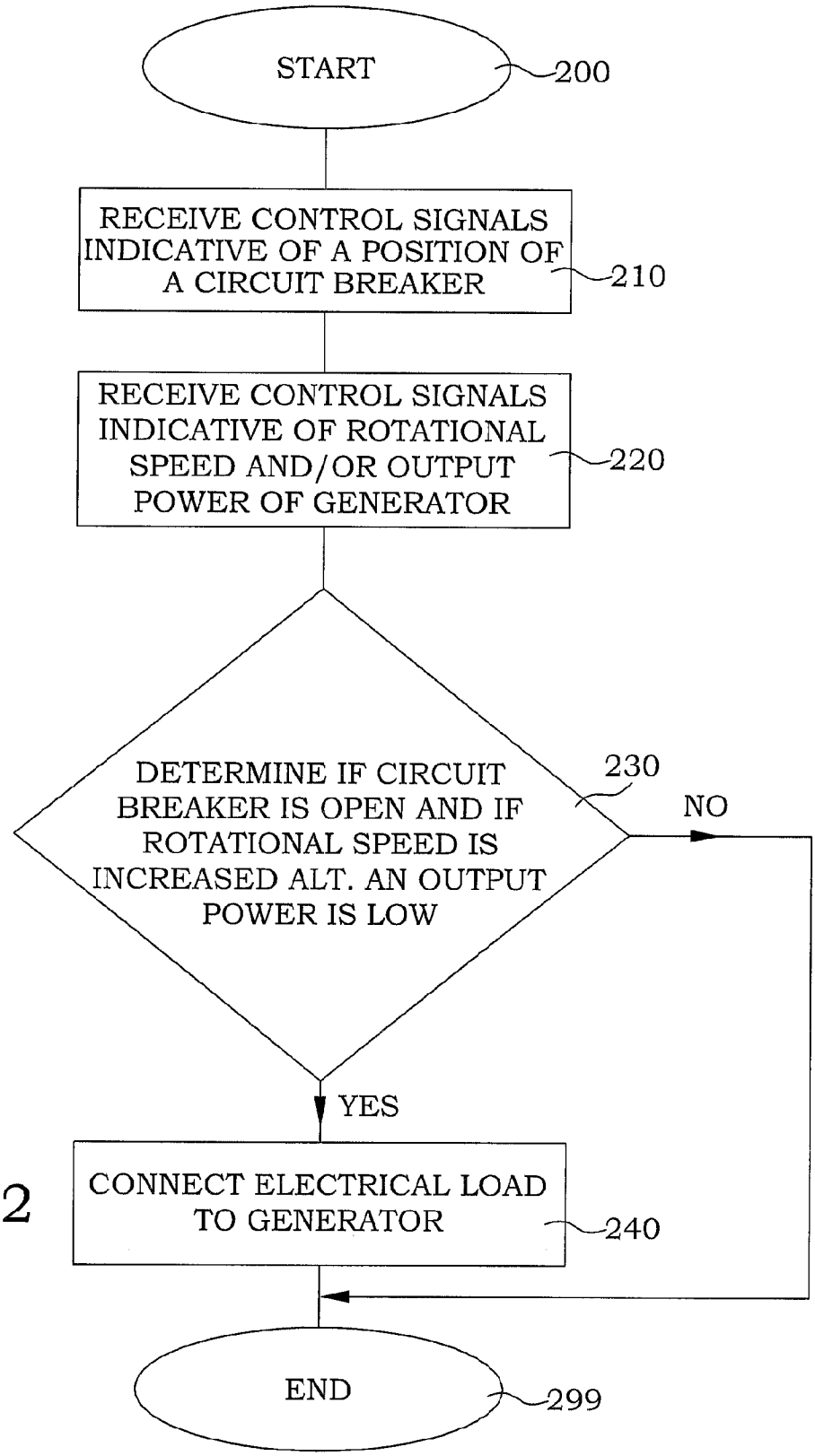
START
200
RECEIVE CONTROL SIGNALS INDICATIVE OF A POSITION OF A CIRCUIT BREAKER
210
RECEIVE CONTROL SIGNALS INDICATIVE OF ROTATIONAL SPEED AND/OR OUTPUT POWER OF GENERATOR
220
DETERMINE IF CIRCUIT BREAKER IS OPEN AND IF ROTATIONAL SPEED IS INCREASED ALT. AN OUTPUT POWER IS LOW
230
NO
YES
CONNECT ELECTRICAL LOAD TO GENERATOR
240
END
299

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2013/050971

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: H02H, H02J

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SE 520399 C2 (ABB AB), 24 September 2002 (2002-09-24); whole document --	1-8
A	Andreica M et al 'Cross-flow water turbines control under grid disturbances' PowerTech, 2009 IEEE Bucharest, 20090628, IEEE, Piscataway, NJ, USA; ISBN 978-1-4244-2234-0 ; ISBN 1-4244-2234-5; whole document --	1-8
A	US 7276807 B2 (LUETZE HENNING ET AL), 19 July 2007 (2007-07-19); whole document -- --------	1-8

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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Continuation of: second sheet

International Patent Classification (IPC)

H02H 7/06 (2006.01)
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/SE2013/050971

SE	520399	C2	24/09/2002	SE	0101061	L	24/09/2002
				WO	02078147	A1	03/10/2002
US	7276807	B2	19/07/2007	CN	101009475	B	25/05/2011
				EP	1819023	A2	15/08/2007
				US	20070164567	A1	19/07/2007