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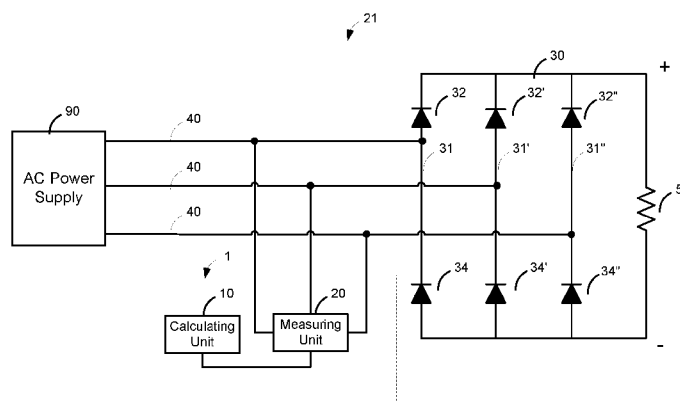


Fig. 1b

(57) Abstract: The present invention relates to a device (1) for detecting a failed rectifier in three-phase AC/DC converter having its AC side connected to a three-phase AC source (90) and its DC side connected to a DC load (50), the AC/DC converter including a rectifier circuit (30) comprising at least three legs (31, 31', 31''), each of the legs (31, 31', 31'') connected to a corresponding AC phase (40) and including at least one rectifier (32, 34, 32', 34', 32'', 34''), the device (1) including a measuring unit (20) for measuring and sampling AC current for each of the phases and a calculating unit (10) configured to estimate an instantaneous DC current based on the measured instantaneous AC currents during one period of the power supply frequency. The calculating unit (10) is further configured to calculate a ripple value of the estimated instantaneous DC current, determine if the calculated ripple value exceeds a pre-defined threshold value, initiate an alarm accordingly, calculate a rectifier status value based on a maximum instantaneous AC phase current and a minimum instantaneous AC phase current during the same one period, and determine, for each of the legs, if the rectifier in the leg has a non-conducting fault based on the calculated rectifier status value.

## METHOD AND SYSTEM FOR DETECTING A FAILED RECTIFIER IN AN AC/DC CONVERTOR

### FIELD OF THE INVENTION

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The present invention relates to the field of detecting a failed rectifier in an AC/DC converter for converting three-phase AC power to DC power. The AC/DC converter including a rectifier circuit that has its AC side connected to an AC source for power supply and its DC side connected to a DC load and includes at least three legs, wherein each of the legs is connected to a corresponding AC phase and including at least one rectifier. The present invention relates also to an excitation system used in a synchronous rotating electrical machine for exciting the rotor of the synchronous rotating electrical machine, wherein the excitation system comprises an exciter including an AC/DC converter and a device for detecting a malfunctioned rectifier in the rectifier circuit of the AC/DC converter.

### PRIOR ART

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An AC/DC converter converts alternating current (AC), which periodically reverses direction, to direct current (DC) which flows in only one direction. It is typically used in DC power supplies and high-voltage direct current power transmission systems. For example, in a power generator the voltage on the stator is built up on the terminal side by injecting a DC excitation current into the rotor windings while the rotor is rotating. The rotor winding is provided with DC excitation current through an AC/DC converter including a rectifier circuit and a power transformer. The rectifier circuit may comprise three legs, each of the legs connected to a corresponding AC phase and including at least one rectifier which is an essential component in the rectifier circuit for converting an AC voltage to a DC voltage. A rectifier may be either a diode or a thyristor.

In case of a rectifier fails in the rectifier circuit, e.g. a short-circuited or non-conductive diode/thyristor, the rotor system is extremely endangered.

Therefore, there is a need to detect a malfunctioned rectifier when the AC/DC converter is in operational.

5 US 2010/0066551 A1 describes a controller for diagnosing a power generation failure for a power circuit in an electric drive. The power circuit includes a rectifier circuit. To determine a failure of one of the diodes in the rectifier circuit that converts a three-phase AC power to DC power, it calculates the RMS phase current values of each of the 3-phases and then compares the ratio of the RMS phase current values of the phases. When  
10 the ratio exceeds a threshold, the controller determines that one of the current phases is unbalanced. This determination may be indicative that one of the diode legs of the rectifier circuit has malfunctioned. Additionally, the controller may attempt to isolate the particular diode that has failed. To perform such diagnosis, the controller determines in which  
15 of the legs of the rectifier current flow is in an opposite direction as compared to the remaining legs. The controller may perform other permutations of the three phase currents to make this determination. Using this approach, a short-circuited diode can be detected, whilst another type of fault, i.e. a non-conductive diode cannot be detected.

20

US 5,508,601 discloses a shorted rectifying diode protection system which monitors the exciter field peak current protection circuit and the output generator voltage to sense the presence of the shorted rectifying diode. Using this solution, a non-conductive diode cannot be detected either.

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## OBJECTS AND SUMMARY OF THE INVENTION

The object of the present invention is to detect a malfunctioned rectifier in an AC/DC converter and determine the type of malfunction in the rectifier.

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This object is achieved by the method according to claim 1.

Such a method comprises measuring instantaneous AC currents of each of the phases, estimating an instantaneous DC current based on the  
35 measured instantaneous AC currents during one period of the power

supply frequency, calculating a ripple value of the estimated instantaneous DC current, determining when the calculated ripple value exceeds a pre-defined threshold value, initiating an alarm upon the calculated ripple value exceeding the pre-defined threshold value, upon the calculated  
5 ripple value exceeding the pre-defined threshold value, for each of the legs calculating a rectifier status value based on a maximum instantaneous AC phase current and a minimum instantaneous AC phase current during the same one period, and determining for each of the legs if the rectifier in the leg has a non-conducting fault based on the calculated  
10 rectifier status value.

By non-conduction of a rectifier, it means that the rectifier prohibits electric current from flowing through the circuit. Such faults result in unbalanced voltages which consequently lead non-conduction of other  
15 rectifiers in the circuit. As such a fault accumulates the risk for serious damage in the vicinity increases.

When the calculated ripple value of an estimated instantaneous DC current exceeds a predefine threshold, there is an indication that there  
20 may be a faulty rectifier in the rectifier circuit. Type of the fault is either non-conductive or short-circuited. The estimated instantaneous DC is based on an instantaneous AC current of each of the phases during one period of the power supply frequency. To determine the fault type, a rectifier status value is calculated based on a maximum instantaneous AC  
25 phase current and a minimum instantaneous AC phase current during the same one period, the invention is able to detect if there is a non-conductive rectifier in the rectifier circuit.

Depending on circumstances, in the case that a non-conductive rectifier is  
30 detected, an operator/user may stop the operation and repair the circuit or he may alternatively run the operation under certain restrictions or switch to a reserve rectifier if available.

In one embodiment of the invention, in the case of the calculated ripple value exceeding the pre-defined threshold value and a non-conducting  
35 rectifier is not detected, for each of the legs, a DC component in the AC

current is calculated based on measured instantaneous AC value of the phase and a short-circuited rectifier is determined and identified thereon.

5 In another embodiment of the invention, the method further comprises calculating a maximum DC current and a minimum DC current during the same one period and calculating the ripple value in percent of the estimated DC current based on the calculated maximum and minimum instantaneous DC currents.

10 Alternatively, the method further comprises calculating an average DC current based on the measured instantaneous AC currents during the same one period and calculating the ripple value in percent of the estimated DC current based on the calculated maximum and minimum instantaneous DC currents and the calculated average DC current.

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This object is achieved by a device as defined in claim 5.

Such a device includes a measuring unit for measuring and sampling AC currents for each of the phases and a calculating unit. The calculating unit  
20 is configured to, estimate an instantaneous DC current based on the measured instantaneous AC currents during one period of the power supply frequency, calculate a ripple value of the estimated instantaneous DC current, determine if the calculated ripple value exceeds a pre-defined threshold value, initiate an alarm upon the calculated ripple value  
25 exceeding the pre-defined threshold value, upon the calculated ripple value exceeding the pre-defined threshold value, for each of the legs, calculate a rectifier status value based on a maximum instantaneous AC phase current and a minimum instantaneous AC phase current during the same one period, and determine, for each of the legs, if the rectifier in the  
30 leg has a non-conducting fault based on the calculated rectifier status value.

According to one embodiment of the invention, the calculating unit is further configured to upon the calculated ripple value exceeding the pre-  
35 defined threshold value and no non-conducting rectifier detected, for each

of the legs, calculate an DC component in the AC current based on measured instantaneous AC value of the phase, and determine and identify, for each of the legs, if the rectifier is short-circuited based on the calculated DC component.

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According to one embodiment of the invention, the calculating unit is further configured to calculate a maximum DC current and a minimum DC current during the same one period and calculate the ripple value in percent of the estimated DC current based on the calculated maximum and minimum instantaneous DC currents.

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Alternatively, the calculating unit is further configured to calculate an average DC current based on the measured instantaneous AC currents during the same one period and calculating the ripple value in percent of the estimated DC current based on the calculated maximum instantaneous and minimum instantaneous DC currents and the calculated average DC current.

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Such a device may be used in an excitation system for exciting a synchronous rotating electrical machine, wherein the synchronous rotating electrical machine has a rotor, wherein the excitation system comprises a transformer having a primary winding and a secondary winding and an exciter for exciting the rotor of the synchronous rotating electrical machine and comprising an AC/DC converter including at least three legs and each of the legs has an AC input connected to the secondary winding and an DC output connected to the rotor and, each of the legs includes at least one rectifier. The excitation system further comprises a device according to any one of claims 5 to 8 for detecting a malfunctioned rectifier in the AC/DC converter.

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According to one embodiment of the invention, the measuring unit of the device is further configured to measure instantaneous AC current at either the primary winding or the secondary winding.

In a case that the transformer further comprises a tertiary winding and each of three additional legs of the rectifier circuit has an AC input connected to the tertiary winding and the DC output connected to the rotor. The measuring unit is further configured to measure instantaneous  
5 AC current at both the secondary winding and the tertiary winding. Alternatively, the measuring unit may be configured to only measure instantaneous AC current at the primary winding.

According to another embodiment of the invention, the excitation system  
10 may comprise a second transformer having a primary winding and a secondary winding, wherein each of three additional legs of the rectifier circuit has an AC input connected to the secondary winding of the second transformer and an DC output connected to the rotor, and each of the additional three legs comprises at least one rectifier, and the measuring  
15 unit is further configured to measure instantaneous AC current flowing through the winding of the second transformer at the same side as the first transformer.

## BRIEF DESCRIPTION OF THE DRAWINGS

20 The invention will now be explained more closely by the description of different embodiments of the invention and with reference to the appended figures.

25 Fig.1a-b show schematic diagrams of the invention, according to a first and a second embodiments of the invention, wherein rectifier circuits are a three-phase half-wave three pulse and a three-phase full-wave 6 pulse respectively.

30 Fig.2 illustrates a schematic diagram of an excitation system for exciting a synchronous rotating electrical machine including an exciter as shown in Fig. 2a, according to a third embodiment of the invention, wherein the exciter includes a device of the present invention.

Fig.3 illustrates a schematic diagram of an excitation system for exciting a synchronous rotating electrical machine including an exciter as shown in Fig. 3a, according to a fourth embodiment of the invention, wherein the transformer is a three winding transformer.

5

Fig.4 shows a flow chart of the invention, according to an embodiment of the invention.

## 10 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

The invention may be applied in AC/DC rectifier circuits having different rectifier configuration.

15 Fig.1a-b show two configurations of an AC/DC converter. Fig. 1a shows a three-phase half-wave rectifier circuit 30 having its AC side connected to a AC power source 90 with three phases 40, wherein each of the legs 31, 31', 31'' of the circuit is connected to a corresponding AC phase and including at least one rectifier 32, 32', 32''. The DC side of the circuit is  
20 connected to a DC load impedance 50. In Fig. 1b two rectifiers, a positive 32, 32', 32'' diode and a negative 34, 34', 34'' diode are arranged in each of the legs 31, 31', 31''. The corresponding AC phase 40 is connected in between the positive 32, 32', 32'' diode and a negative 34, 34', 34'' diode of the leg. Therefore, it is a three-phase full wave 6 pulse converter.

25

Regardless of the configuration of a converter, a device 1 of the present invention may be adapted for detecting a malfunctioned rectifier in the circuit. The device 1 comprises a measuring and sampling unit 20 and a  
30 calculating unit 10.

30

With reference to Fig. 4, the measuring and sampling unit 20 is configured for measuring and sampling AC current for each of the phases, step 100. The measured values are communicated to the calculating unit 10. The calculating unit 10 is configured to estimate an instantaneous DC current  
35 based on the measured instantaneous AC currents during one period of



the power supply frequency, step 110. The instantaneous DC current may be estimated as follows,

$$i_{DC} = \frac{|i_1| + |i_2| + |i_3|}{2}$$

- 5 wherein,  $|i_1|$ ,  $|i_2|$  and  $|i_3|$  are absolute values of the measured samples of the instantaneous AC currents measured in of each of the phases 40 respectively.

- To be able to detect a malfunctioned rectifier, the calculating unit 10 is further configured to calculate a ripple value of the estimated instantaneous DC current, step 120 and thereon determine whether the calculated ripple value exceeds a pre-defined threshold value, step 130. Because a non-conductive rectifier may not always result in asymmetry in phase currents, the ripple value in percent of the estimated DC current is calculated, which may be based on a maximum DC current  $i_{DC\_MAX}$  and a minimum DC current  $i_{DC\_MIN}$  during the same one period at which AC current of each of the phases are measured and an instantaneous DC current are calculated thereof, wherein the maximum DC current  $i_{DC\_MAX}$  and the minimum DC current  $i_{DC\_MIN}$  may be respectively determined as follows,

$$i_{DC\_MAX} = \max_n \{i_{DC}\}$$

$$i_{DC\_MIN} = \min_n \{i_{DC}\}$$

- wherein  $n$  corresponds the number of instantaneous AC current samples during one period of the power supply frequency.

- Preferably, the ripple value may be calculated in percentage. There are several ways to calculate the ripple value in percent of the estimated DC current based on the maximum DC current  $i_{DC\_MAX}$  and the minimum DC current  $i_{DC\_MIN}$ . For example, one way may be as follows,

$$rippleValuePercent = 100 * \frac{(i_{DC\_MAX} - i_{DC\_MIN})}{0.5 * (i_{DC\_MAX} + i_{DC\_MIN})}$$

It may be alternatively calculated as follows,

$$rippleValuePercent = 100 * \frac{(i_{DC\_MAX} - i_{DC\_MIN})}{\bar{i}_{DC}}$$

- 5 wherein,  $\bar{i}_{DC}$  is an average DC current of the instantaneous DC current in the same one period.

Upon the calculated ripple value exceeding the pre-defined threshold value, an alarm is initiated, step 140.

10

Further on, for each of the legs/phase, a rectifier status value based on a maximum instantaneous AC phase current and a minimum instantaneous AC phase current during the same one period is calculated, step 150 to determine whether the rectifier in the leg has a non-conducting fault based on the calculated rectifier status value, step 160.

15

An example of such calculations is demonstrated as follows. Assuming that  $i_1, i_2, i_3$  represent samples of instantaneous phase current, a maximum instantaneous phase current value for each of the phases in the same one period is determined as follows,

20

$$i_{MAX\_Lk} = \max_n \{i_k\}$$

wherein  $n$  is the number of the instantaneous AC current samples during the same one period of the power supply frequency,  $k = 1, 2, 3$  represents one of the three phases. Therefore,  $i_{MAX\_Lk}$  represents the maximum instantaneous phase current sample value in the period of the phase  $k$ . Analogously, the minimum instantaneous phase current sample value  $i_{MIN\_Lk}$  in the period of the phase  $k$  can be determined.

25

Based on the maximum and the minimum instantaneous phase current sample values, a rectifier status value for each phase is then determined as follows,

30

$$rectifierStatusValue_k = \frac{i_{MAX\_L_k}}{(i_{MAX\_L_k} - i_{MIN\_L_k})}$$

wherein  $k = 1, 2, 3$ .

- 5 In principle, a non-conductive rectifier will result in a missing pulse in a failed phase.

For the configuration of the rectifier circuit shown in Fig. 1b, if the rectifierStatusValue is in a range of 0.75 to 1.25, then the negative  
10 rectifier has a non-conductive fault, whereas if it is in a range of -0.25 to 0.25, the positive rectifier has a non-conductive fault, step 190. This is because that in a non-faulty circuit,

$$i_{MIN\_L_k} = -i_{MAX\_L_k}$$

which leads to rectifierStatusValue = 0.5. If a negative rectifier has a non-conductive fault, the minimum phase current will be zero, which leads that  
15 rectifierStatusValue of the negative rectifier will be one. Similarly, if a positive rectifier has non-conductive fault, the maximum phase current will be zero, which leads that rectifierStatusValue will be zero.

20 In the case that if a rectifier has a non-conductive fault, a signal may set and a counter measure may be taken, for example, one may then stop and repair, run under restrictions or switch to a reserve rectifier, if available.

Upon the calculated ripple value exceeding the pre-defined threshold value and no non-conducting rectifier detected, for each of the legs, a DC  
25 component in AC current based on measured instantaneous AC values of the phase is calculated, step 170. A short-circuited rectifier of the leg is thereof determined and identified based on the calculated DC component. The DC component in the AC current of a leg/phase may be an average value of the sampled AC instantaneous current values in the same period,  
30 as calculated as follows,

$$i_{AVE\_L_k} = \text{ave}_n\{i_k\}$$

With reference to Fig. 1b, if the DC component of one phase is positive and the other two are negative, a short-circuited fault occurs in the negative rectifier of the leg connected to the phase that has a positive DC component. If the DC component of one phase is negative and the other two are positive, a short-circuited fault occurs in the positive rectifier of the leg connected to the phase that has a negative DC component, step 190. In the case that if a rectifier has a short-circuited fault, a signal may set and a similar counter measure may be performed as for a non-conductive rectifier.

The rectifiers shown in Fig.1a and 1b are diodes; they may however be thyristors. Furthermore, the rectifier circuits may have other configurations, for example, a three-phase full-wave 12 pulse circuit.

The calculating unit 10 can be, for example, a micro-computing processor, a digital signal processor, a field-programmable gate array, or a standard computer.

The present invention may be applied in an excitation system for exciting a synchronous rotating electrical machine including a rotor 70 and a stator 60. The synchronous rotating electrical machine may be a synchronous generator or a synchronous motor.

Fig.2 illustrates a schematic diagram of such an application, wherein the excitation system comprises a transformer 80 having a primary winding 82 and a secondary winding 84 and an exciter 22 for exciting the rotor 70 of the synchronous rotating electrical machine. Furthermore, an AC power supply 90 is configured to supply AC power with a frequency to the exciter 22. The transformer is connected between the AC power supply 90 and the exciter 22 for transforming the supplied AC power. With reference to Fig. 2a, the exciter 22 comprises an AC/DC converter including a rectifier circuit 30 having three legs, each of the legs has an AC input 40 connected to the secondary winding 84 of the transformer and the DC output of the circuit connected to the rotor 70, each of the legs 31, 31', 31"

includes a positive diode 32, 32', 32" and a negative diode 34, 34', 34". A DC load impedance 50 is connected to the positive output and negative output of the circuit, which is further connected to the rotor. The positive diodes 32, 32', 32" are connected to the positive output of the rectifier circuit at one end and the negative diodes 34, 34', 34" are connected to the negative output of the circuit at the other end. Two ends are further connected to the rotor. The excitation system further comprises a device 1 for detecting a malfunctioned rectifier in the rectifier circuit. In this example, the measuring unit 20 is connected to the secondary winding 84 for measuring instantaneous AC phase currents. It is however possible to perform measurement at the primary winding 82 of the transformer 80.

With reference to Fig. 3 and Fig. 3a, the transformer 80 may further comprise a tertiary winding 86. The rectifier circuit 30 includes three additional legs 41, 41', 41" which have their AC inputs connected to the tertiary winding and the DC output connected to the rotor. Each of the additional legs includes a positive diode 42, 42', 42" and a negative diode 44, 44', 44". The positive diodes 42, 42', 42" are connected to the positive output of the rectifier circuit at one end and the negative diodes 44, 44', 44" are connected to the negative output of the circuit at the other end. Therefore, if the tertiary winding is connected to obtain a suitable ( $\pm 30^\circ$ ) phase shift to the secondary winding, the AC/DC converter has a three-phase full-wave 12 pulse rectifier circuit. The measuring unit 20 is further configured to measure instantaneous AC current at the tertiary winding 86 if it is configured to measure instantaneous AC current at the secondary winding 84. Alternatively, the measuring unit 20 may be arranged to measure the AC phase current at the primary winding 82.

It is also possible that such an excitation system may have a second transformer having a primary winding and a secondary winding, with a suitable phase shift to the first transformer, wherein each of three additional legs of the AC/DC converter has an AC input connected to the secondary winding of the second transformer and an DC output connected to the rotor, and each of the additional three legs comprises at least one rectifier, and the measuring unit is further configured to measure

instantaneous AC current flowing through the winding of the second transformer at the same side as the first transformer.

**CLAIMS**

1. A method for detecting a failed rectifier in an AC/DC converter for converting three-phase AC power to DC power and having its AC side connected to an AC source for power supply and its DC side connected to a DC load, the AC/DC converter including a rectifier circuit comprising at least three legs, each of the legs connected to a corresponding AC phase and including at least one rectifier, the method comprises
- measuring instantaneous AC currents of each of the phases (100),
  - estimating an instantaneous DC current based on the measured instantaneous AC currents during one period of the power supply frequency (110),
- characterized in** that the method further comprises
- calculating a ripple value of the estimated instantaneous DC current (120),
  - determining if the calculated ripple value exceeds a pre-defined threshold value (130),
  - initiating an alarm upon the calculated ripple value exceeding the pre-defined threshold value (140),
  - upon the calculated ripple value exceeding the pre-defined threshold value, for each of the legs, calculating a rectifier status value based on a maximum instantaneous AC phase current and a minimum instantaneous AC phase current during the same one period (150), and
  - determining, for each of the legs, if the rectifier in the leg has a non-conducting fault based on the calculated rectifier status value (160, 190).
2. Method according to claim 1, further comprising,
- upon the calculated ripple value exceeding the pre-defined threshold value and a non-conducting rectifier not detected, for each of the legs, calculating a DC component in AC current based on measured instantaneous AC value of the phase (170), and
  - determining and identifying, for each of the legs, if the rectifier in the leg is short-circuited based on the calculated DC component (180, 190).

3. Method according to claim 1, further comprising calculating a maximum DC current and a minimum DC current during the same one period and calculating the ripple value in percent of the estimated DC current based on the calculated maximum instantaneous and minimum instantaneous DC currents.

4. Method according to claim 3, further comprising calculating an average DC current based on the measured instantaneous AC currents during the same one period and calculating the ripple value in percent of the estimated DC current based on the calculated maximum instantaneous and minimum instantaneous DC currents and the calculated average DC current.

5. A device (1) for detecting a failed rectifier in an AC/DC converter for converting three-phase AC power to DC power and having its AC side connected to a three-phase AC source (90) and its DC side connected to a DC load (50), the AC/DC converter including a rectifier circuit (30) comprising at least three legs (31, 31', 31''), each of the legs (31, 31', 31'') connected to a corresponding AC phase 40 and including at least one rectifier (32, 34, 32', 34', 32'', 34''), the device (1) including a measuring unit (20) for measuring and sampling AC current for each of the phases and a calculating unit (10) configured to estimate an instantaneous DC current based on the measured instantaneous AC currents during one period of the power supply frequency,

**characterized in** that the calculating unit (10) is further configured to,

- calculate a ripple value of the estimated instantaneous DC current,
- determine if the calculated ripple value exceeds a pre-defined threshold value,
- initiate an alarm upon the calculated ripple value exceeding the pre-defined threshold value,
- upon the calculated ripple value exceeding the pre-defined threshold value, for each of the legs, calculate a rectifier status value based on a maximum instantaneous AC phase current and a minimum instantaneous AC phase current during the same one period, and



- determine, for each of the legs, if the rectifier in the leg has a non-conducting fault based on the calculated rectifier status value.

5 6. Device according to claim 6, wherein the calculating unit is further configured to,

- upon the calculated ripple value exceeding the pre-defined threshold value and a non-conducting rectifier not detected, for each of the legs, calculate a DC component in the AC current based on measured instantaneous AC value of the phase, and
- 10 – determine and identify, for each of the legs, if the rectifier is short-circuited based on the calculated DC component.

15 7. Device according to claim 6, wherein the calculating unit is further configured to calculate a maximum DC current and a minimum DC current during the same one period and calculate the ripple value in percent of the estimated DC current based on the calculated maximum and minimum instantaneous DC currents.

20 8. Device according to claim 7, wherein the calculating unit is further configured to calculate an average DC current based on the measured instantaneous AC currents during the same one period and calculating the ripple value in percent of the estimated DC current based on the calculated maximum instantaneous and minimum instantaneous DC currents and the calculated average DC current.

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9. An excitation system for exciting a synchronous rotating electrical machine (60), wherein the synchronous rotating electrical machine has a rotor (70), the excitation system comprising,

- a transformer (80) having a primary winding (82) and a secondary winding (84) and,
- 30 – an exciter (22, 23) for exciting the rotor (70) of the synchronous rotating electrical machine and comprising an AC/DC converter including a rectifier circuit (30) comprising at least three legs (31, 31', 31''), wherein each of the legs has an AC input (40) connected to the secondary

winding (84) and an DC output connected to the rotor (70) and, each of the legs includes at least one rectifier (32, 34, 32', 34', 32'', 34''), wherein the excitation system further comprises a device (1) according to any one of claims 5 to 8 for detecting a failed rectifier in the rectifier circuit.

10. Excitation system according to claim 9, wherein the measuring unit of the device is further configured to measure instantaneous AC current at either the primary winding or the secondary winding.

11. Excitation system according to any of claims 9 or 10, comprising a second transformer having a primary winding and a secondary winding, wherein each of three additional legs of the rectifier circuit has an AC input connected to the secondary winding of the second transformer and an DC output connected to the rotor, and each of the additional three legs comprises at least one rectifier, and the measuring unit is further configured to measure instantaneous AC current flowing through the winding of the second transformer at the same side as the first transformer.

12. Excitation system according to any of claims 9 or 10, wherein the transformer further comprises a tertiary winding (86) and each of three additional legs (41, 41', 41'') of the rectifier circuit (30) has an AC input connected to the tertiary winding (86) and the DC output connected to the rotor (70) and the measuring unit (20) is further configured to measure instantaneous AC current at the tertiary winding in case that the measuring unit has configured to measure the secondary winding.

30

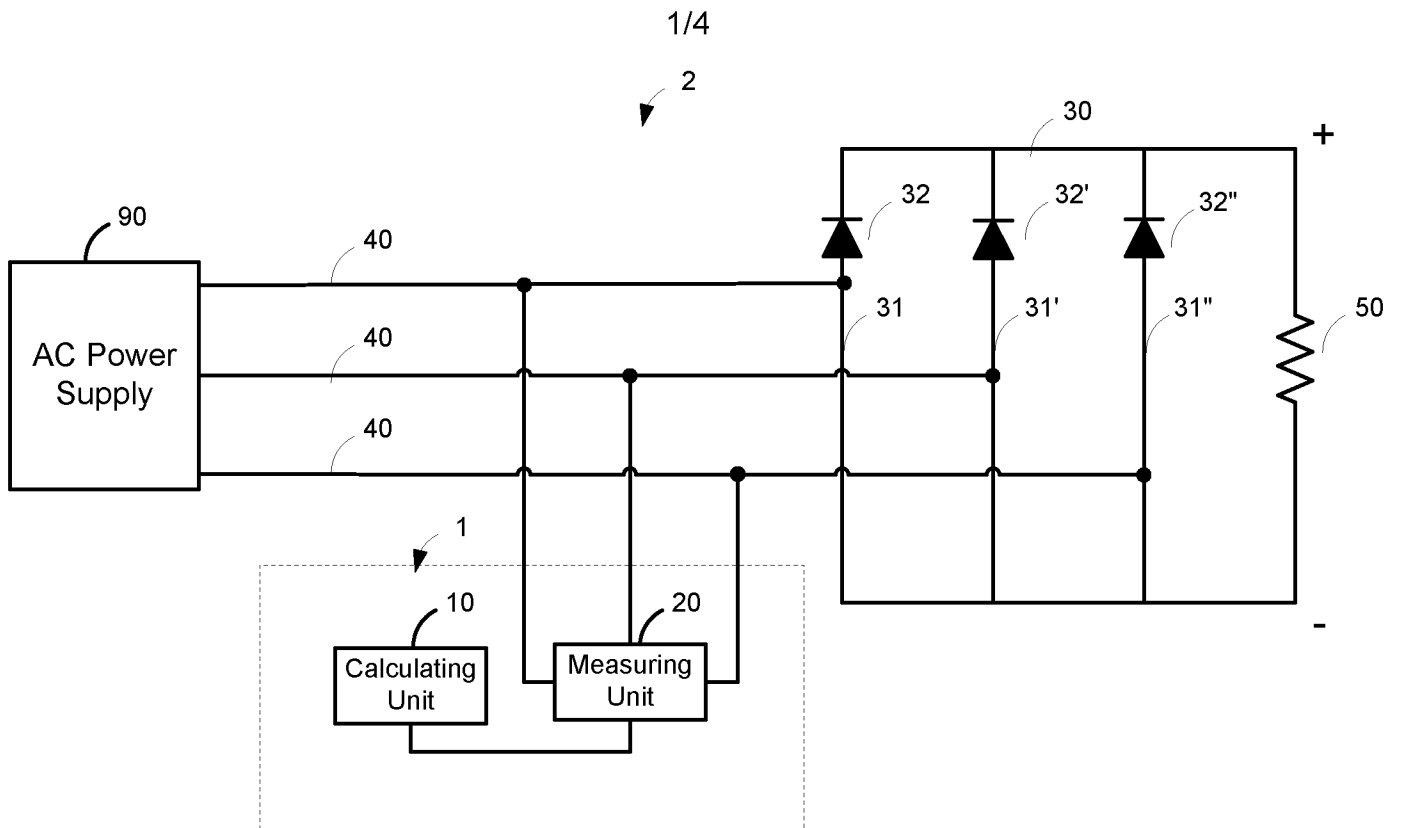


Fig. 1a

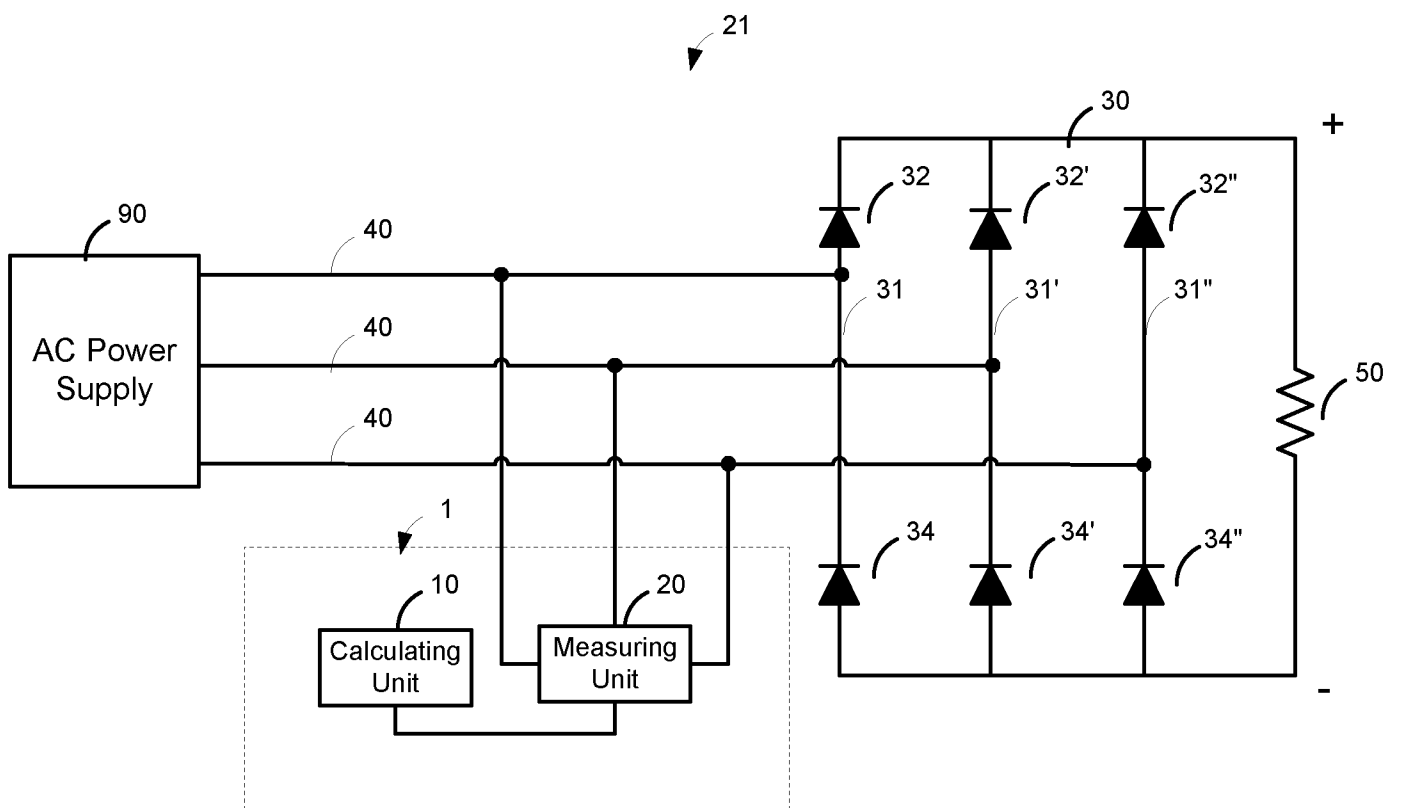
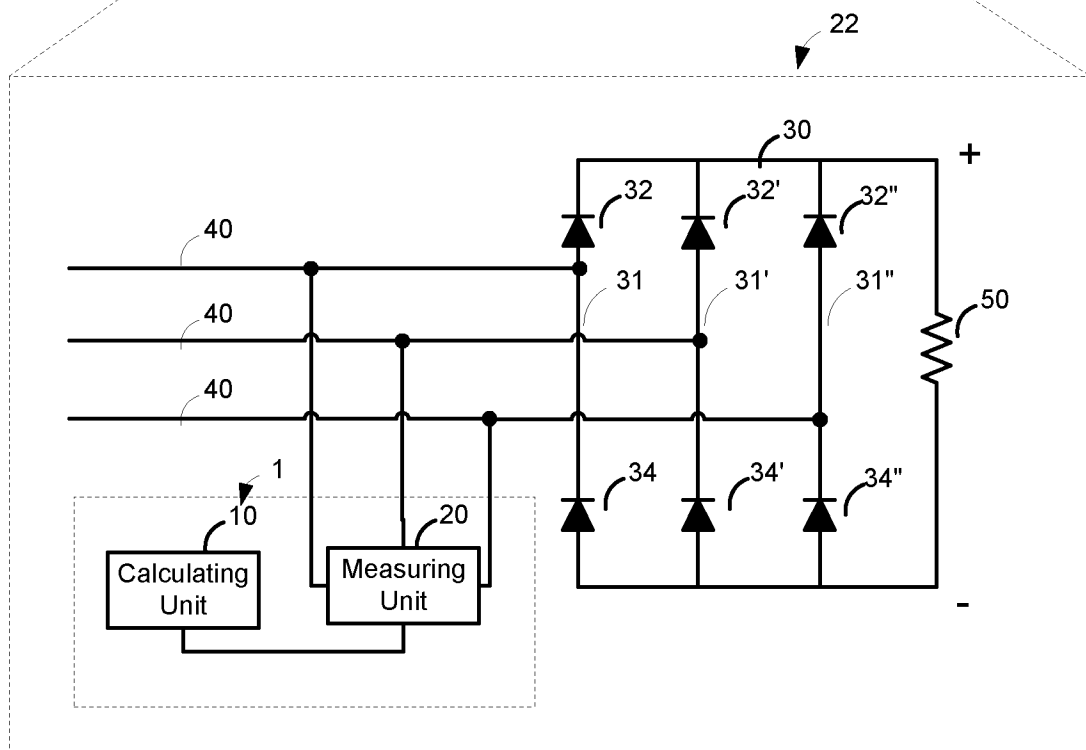
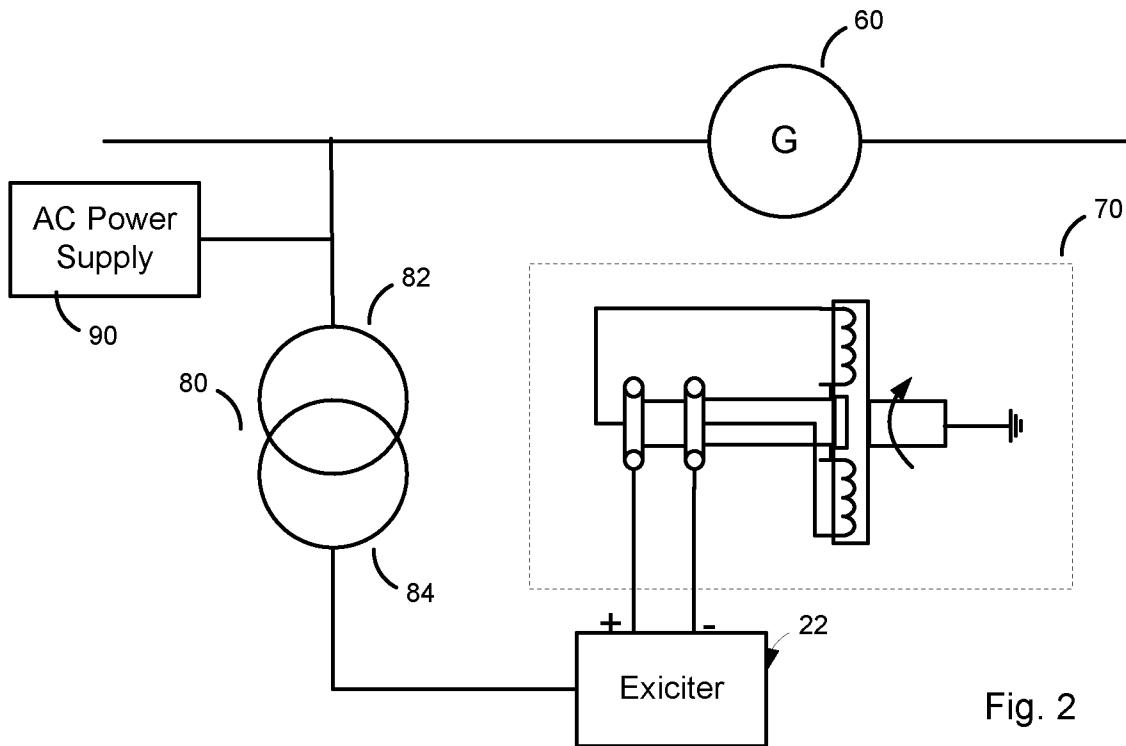
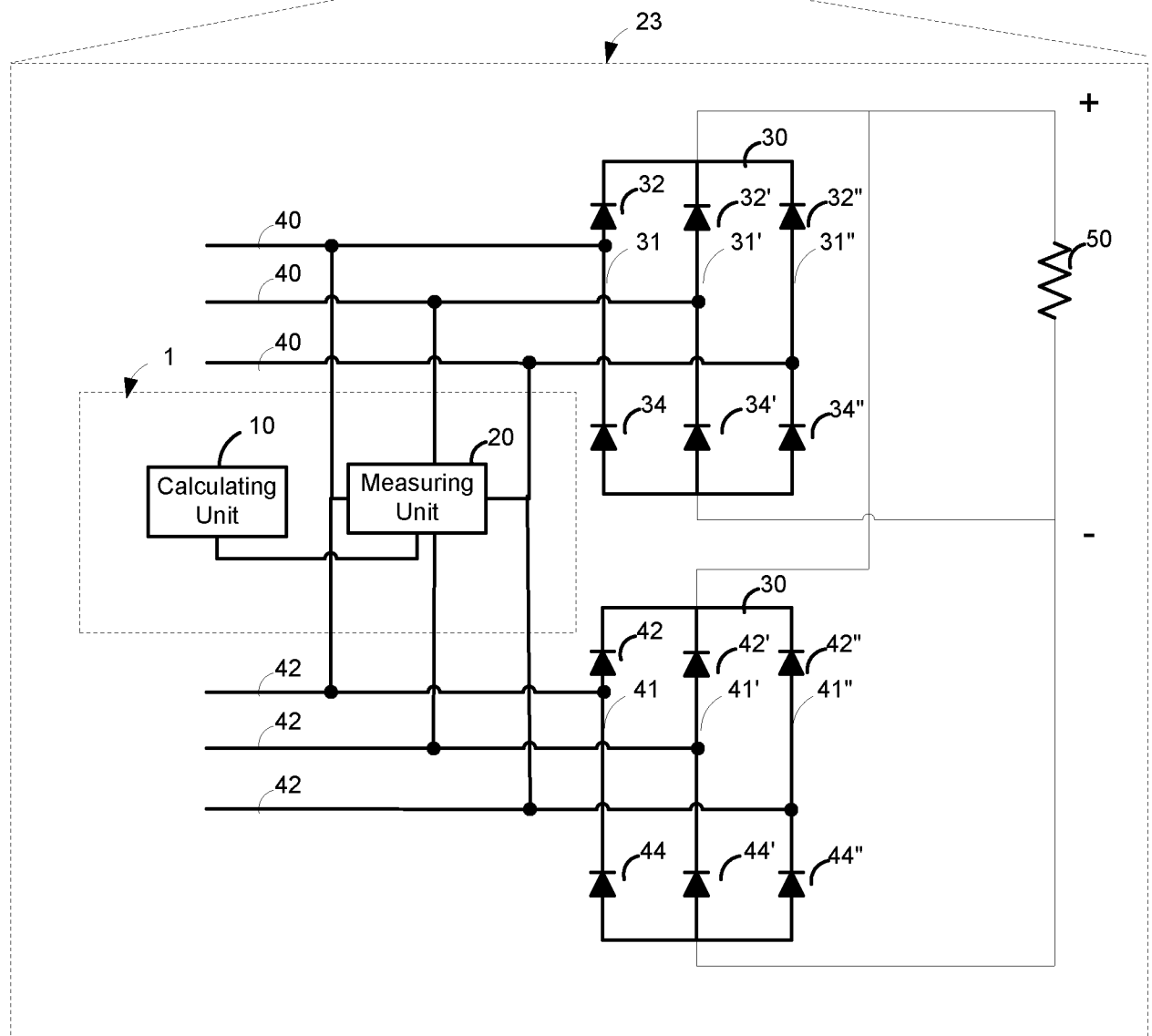
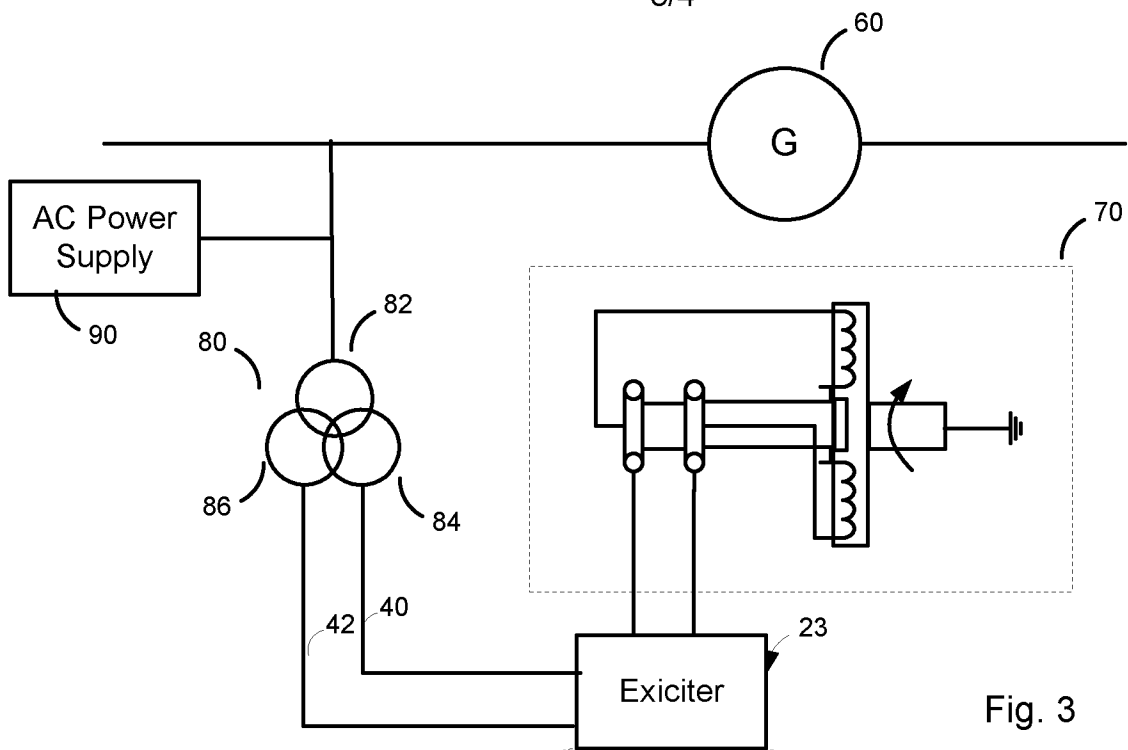


Fig. 1b



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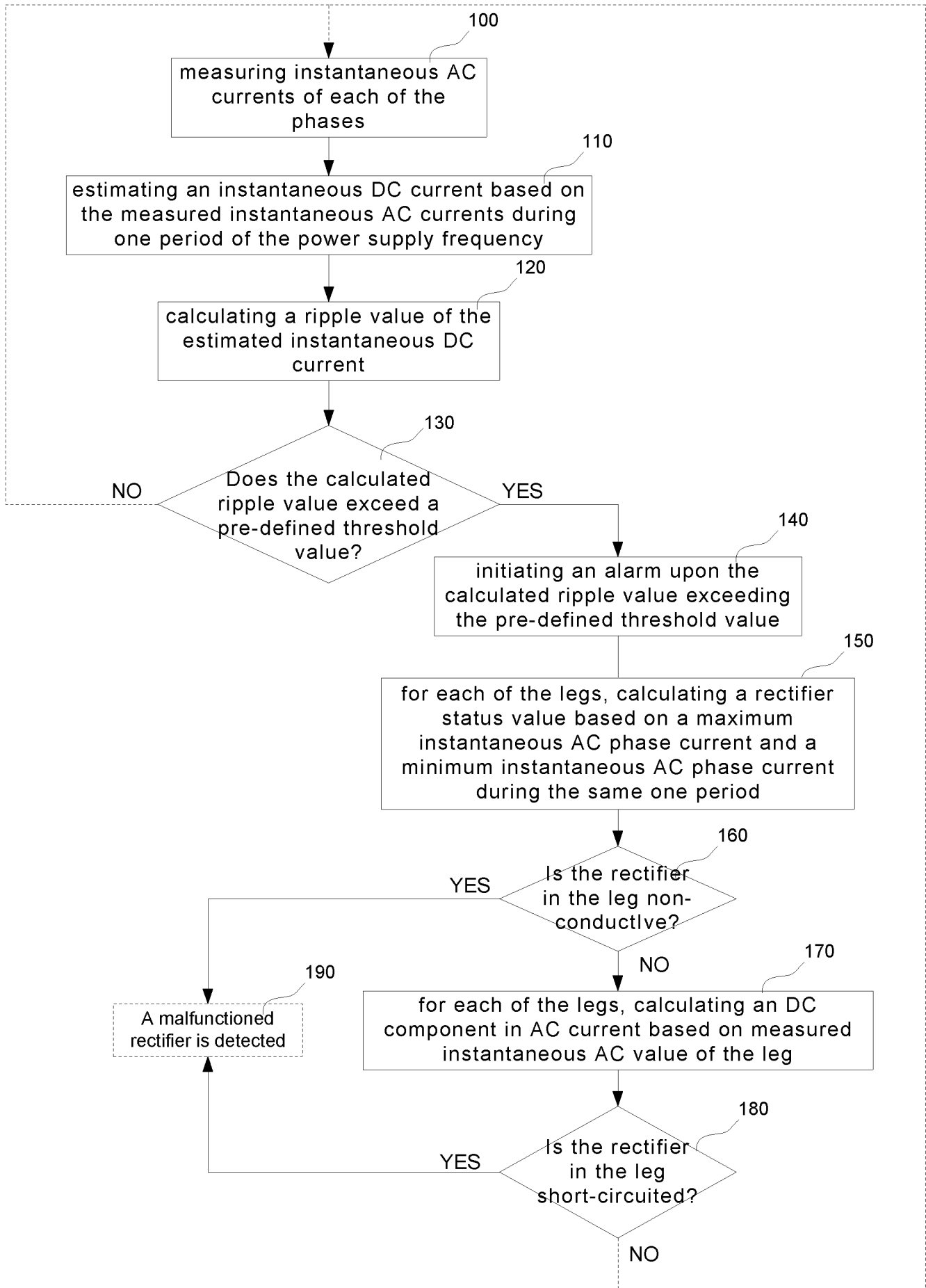


Fig. 4

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2011/068486

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> INV. H02M7/06 H02M7/162 H02H7/125 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) H02M H02H H02P G01R		
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, COMPENDEX, INSPEC		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2001 275247 A (NISSIN ELECTRIC CO LTD) 5 October 2001 (2001-10-05) abstract paragraph [0018] - paragraph [0026]; figures 1,2,4,5 -----	1-12
A	US 5 523 938 A (WAGNER CARL [US] ET AL) 4 June 1996 (1996-06-04) abstract column 3, line 31 - line 53; figure 2 column 4, line 18 - column 5, line 10 -----	1-12
A	EP 0 388 850 A2 (HITACHI LTD [JP]; KANSAI ELECTRIC POWER CO [JP]) 26 September 1990 (1990-09-26) abstract column 8, line 48 - column 10, line 4; figure 1 ----- -/--	1-12
<div style="display: flex; justify-content: space-between;"> <span><input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C.</span> <span><input checked="" type="checkbox"/> See patent family annex.</span> </div>		
<div style="display: flex;"> <div style="flex: 1;"> <p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="flex: 1;"> <p>"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</p> <p>"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</p> <p>"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</p> <p>"&amp;" document member of the same patent family</p> </div> </div>		
Date of the actual completion of the international search  <div style="text-align: center; font-size: 1.2em;">10 September 2012</div>		Date of mailing of the international search report  <div style="text-align: center; font-size: 1.2em;">19/09/2012</div>
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer  <div style="text-align: center; font-size: 1.2em;">Braccini, Roberto</div>

## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/068486

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/066551 A1 (BAILEY BRADLEY [US] ET AL) 18 March 2010 (2010-03-18) cited in the application paragraph [0021] - paragraph [0059]; figures 3-6 -----	1-12



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