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(54) **A METHOD FOR DETERMINING THE LOCATION OF AN OPEN-CIRCUIT FAULT IN AN ELECTRICAL CIRCUIT AND AN ELECTRICAL CIRCUIT**

(57) The present invention provides a method for determining the location of an open-circuit fault in an electrical circuit that comprises a plurality of transformers (101), each transformer (101) having a primary winding (102) and a secondary winding (103), the primary windings (102) being electrically connected in series and each secondary winding (103) being electrically connected to a light-emitting diode (104). In the method, a con-

stant-current regulator (105) is used to supply electric power to the primary windings (102), and the alternating voltage supplied by the constant-current regulator (105) is changed so that the light-emitting diodes (104) light up, the open-circuit fault being located between the transformers (101) that are electrically connected to the light-emitting diodes (104) having the smallest light intensities. The invention also relates to an electrical circuit.

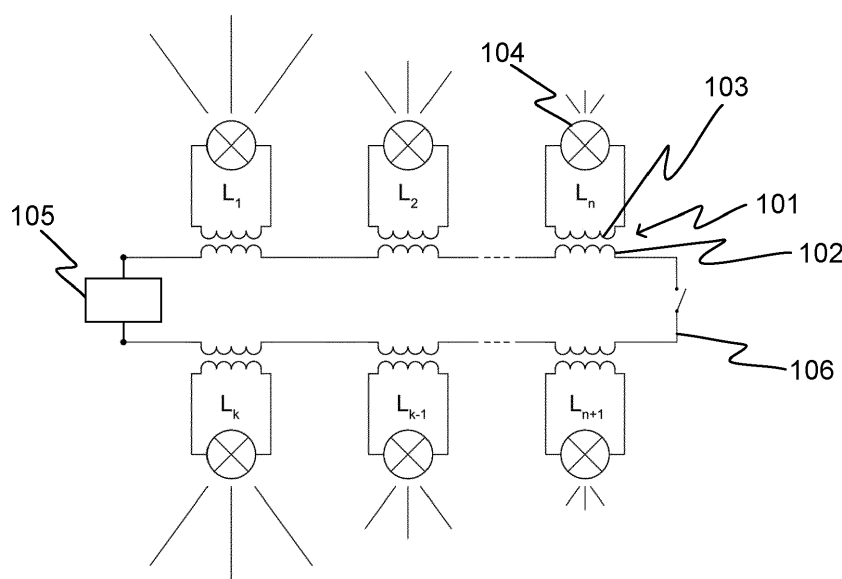


Fig. 1

Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to a method for determining the location of an open-circuit fault in an electrical circuit and to an electrical circuit according to the preambles of the appended independent claims.

BACKGROUND OF THE INVENTION

[0002] Aeronautical ground lighting (AGL) systems provide visual cues in runways and taxiways to help aircraft pilots during approach, landing and taxiing. A conventional AGL system comprises a constant-current regulator (CCR) that supplies electric power through series-connected transformers to luminaires, such as halogen lamps or light-emitting diodes (LEDs). The CCR is a variable voltage source, which provides an adjustable current according to luminaire brightness requirements. The series-connected transformers separate the CCR and the luminaires into primary and secondary circuits. The transformers isolate the luminaires from the high operating voltage of the primary circuit and ensure the circuit continuity in case of a luminaire failure.

[0003] An open-circuit fault may occur in an AGL system, for example, due to a break in an electrical cable that is connected between primary windings of two transformers. The locating of such a fault can be difficult and time-consuming because the electrical circuit of the AGL system is typically very long and the electrical cables are mostly buried underground. The known AGL systems do not have any built-in functionalities to determine the location of an open-circuit fault.

OBJECTIVES OF THE INVENTION

[0004] It is the main objective of the present invention to reduce or even eliminate the prior art problems presented above.

[0005] It is an objective of the present invention to provide a method for determining the location of an open-circuit fault in an electrical circuit. In more detail, it is an objective of the invention to provide a method for determining the location of an open-circuit fault in an electrical circuit that comprises a plurality of transformers, whose primary windings are electrically connected in series and secondary windings are electrically connected to light-emitting diodes.

[0006] It is also an objective of the present invention to provide an electrical circuit comprising a plurality of transformers, whose primary windings are electrically connected in series and secondary windings are electrically connected to light-emitting diodes, and having a built-in functionality to determine the location of an open-circuit fault in the electrical circuit.

[0007] In order to realise the above-mentioned objectives, the method and the electrical circuit according to

the invention are characterised by what is presented in the characterising portions of the appended independent claims. Advantageous embodiments of the invention are described in the dependent claims.

DESCRIPTION OF THE INVENTION

[0008] A method according to the invention for determining the location of an open-circuit fault in an electrical circuit that comprises a plurality of transformers, each transformer having a primary winding and a secondary winding, the primary windings being electrically connected in series and each secondary winding being electrically connected to a light-emitting diode, comprises using a constant-current regulator to supply electric power to the primary windings, and changing the alternating voltage supplied by the constant-current regulator so that the light-emitting diodes light up, the open-circuit fault being located between the transformers that are electrically connected to the light-emitting diodes having the smallest light intensities.

[0009] The method according to the invention is used to determine the location of an open-circuit fault in an electrical circuit. The method is performed after the open-circuit fault in the electrical circuit has been detected.

[0010] The method according to the invention is applied in an electrical circuit that comprises a plurality of transformers whose primary windings are electrically connected in series and secondary windings are electrically connected to light-emitting diodes (LEDs). The series-connected primary windings of the transformers form a primary circuit to which a constant-current regulator (CCR) is electrically connected for supplying electric power (AC power) to the primary windings. The CCR is a variable voltage source, which can provide an adjustable constant current, typically over a wide voltage range. The current supplied by the CCR can be adjusted, for example, according to brightness requirements of the LEDs. The CCR can be configured to provide, for example, a plurality of discrete brightness levels for the LEDs. Each of the secondary windings of the transformers forms a secondary circuit with one of the LEDs.

[0011] During normal operation of the electrical circuit, the CCR supplies electric power through the transformers to the LEDs, which then emit light. The transformers isolate the LEDs from the high operating voltage of the primary circuit and ensure the circuit continuity in case of a LED failure. When an open-circuit fault occurs in the primary circuit, for example as a result of an electrical cable breakage, the LEDs turn off. The open-circuit fault can be detected, for example, by visually observing the LEDs or by measuring the electrical properties of the electric power supplied by the CCR. In case of the open-circuit fault, the current in the primary circuit decreases significantly and its phase shift compared to the voltage becomes positive.

[0012] The location of an open-circuit fault can be determined by using the CCR, which is electrically connect-

ed to the primary windings of the transformers, i.e. to the primary circuit. It has now been found that even in case of an open-circuit fault in the primary circuit, the LEDs can be turned on by supplying with the CCR an alternating voltage having specific characteristics, which typically differ from those used during normal operation of the CCR. The alternating voltage supplied by the CCR can be changed, for example, by adjusting one or more of the following parameters: the waveform, the amplitude (voltage level) and the frequency of the alternating voltage. In the method according to the invention, the alternating voltage supplied by the CCR is changed until the LEDs light up. The light intensities of the LEDs differ from each other in such a manner that the light intensities decrease towards the location of the open-circuit fault. The open-circuit fault is located between the transformers that are electrically connected to the LEDs having the smallest light intensities. The light intensities of the LEDs can be observed, for example, visually. The reason that the LEDs, which are closest to the open-circuit fault, have the smallest light intensities is that the current tends to pass through the capacitance of the broken electrical cable to the ground.

[0013] An advantage of the method according to the invention is that the location of an open-circuit fault in an electrical circuit can be determined in a quick and accurate manner.

[0014] According to an embodiment of the invention the step of changing the alternating voltage supplied by the constant-current regulator comprises changing at least one of the following parameters: the waveform, the amplitude and the frequency of the alternating voltage. Preferably, at least two of these parameters, such as the amplitude and the frequency, are changed during the search of the alternating voltage that can light up the LEDs.

[0015] According to an embodiment of the invention the step of changing the alternating voltage supplied by the constant-current regulator comprises changing the amplitude within a predefined amplitude range and changing the frequency within a predefined frequency range. The predefined amplitude range and the predefined frequency range define the area inside which the amplitude and the frequency of the alternating voltage can be changed when finding the alternating voltage that can light up the LEDs.

[0016] According to an embodiment of the invention the lower limit of the predefined amplitude range is larger than the sum of the threshold voltages of the light-emitting diodes. Preferably, in this case, the predefined frequency range is close to the maximum frequency of the CCR. The upper limit of the predefined amplitude range can be a value between 600 V and 1200 V, such as 800 V, 900 V or 1000 V. The lower limit of the predefined frequency range can be a value between 100 Hz and 450 Hz, such as 200 Hz, 300 Hz or 400 Hz. The upper limit of the predefined frequency range can be a value between 500 Hz and 1000 Hz, such as 600 Hz, 700 Hz or 900 Hz.

[0017] According to an embodiment of the invention the upper limit of the predefined amplitude range is smaller than the sum of the threshold voltages of the light-emitting diodes. Preferably, in this case, the predefined frequency range covers most of the frequency range of the CCR. The lower limit of the predefined amplitude range can be a value between 0 V and 50 V, such as 5 V, 10 V or 20 V. The lower limit of the predefined frequency range can be a value between 50 Hz and 100 Hz, such as 60 Hz, 70 Hz or 80 Hz. The upper limit of the predefined frequency range can be a value between 500 Hz and 1000 Hz, such as 600 Hz, 700 Hz or 900 Hz.

[0018] According to an embodiment of the invention the step of changing the alternating voltage supplied by the constant-current regulator comprises setting the frequency of the alternating voltage to a predefined frequency value and changing the amplitude within a predefined amplitude range.

[0019] According to an embodiment of the invention the predefined frequency value is close to the maximum frequency of the constant-current regulator, and the lower limit of the predefined amplitude range is larger than the sum of the threshold voltages of the light-emitting diodes. Preferably, the amplitude of the alternating voltage is changed by increasing the amplitude from the lower limit of the predefined amplitude range.

[0020] According to an embodiment of the invention the predefined frequency value is a parallel resonance frequency of the electrical circuit, and the upper limit of the predefined amplitude range is smaller than the sum of the threshold voltages of the light-emitting diodes. Preferably, the amplitude of the alternating voltage is changed by decreasing the amplitude from the upper limit of the predefined amplitude range. The parallel resonance occurs in the electrical circuit between the cable capacitance and the magnetization inductance of the transformers.

[0021] According to an embodiment of the invention the step of changing the alternating voltage supplied by the constant-current regulator comprises setting the amplitude of the alternating voltage to a predefined amplitude value and changing the frequency within a predefined frequency range. The frequency of the alternating voltage can be changed by increasing the frequency from the lower limit of the predefined frequency range, or by decreasing the frequency from the upper limit of the predefined frequency range. If the predefined amplitude value is smaller than the sum of the threshold voltages of the LEDs, the alternating voltage can light up the LEDs when its frequency corresponds to the parallel resonance frequency of the electrical circuit.

[0022] According to an embodiment of the invention the step of changing the alternating voltage supplied by the constant-current regulator comprises changing the waveform by adding harmonics to the alternating voltage. Initially, the waveform of the alternating voltage can be a sinusoidal at a specific fundamental frequency. As described above, both the amplitude and the frequency of

this sinusoidal waveform can be changed during the search of such an alternating voltage that can light up the LEDs in case of an open-circuit fault. Together or separately with these, the alternating voltage can be changed by adding harmonics to the alternating voltage. The harmonic is a sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. Preferably, the alternating voltage can be changed by adding odd harmonics of the fundamental frequency to the alternating voltage.

[0023] The present invention also relates to an electrical circuit. The electrical circuit according to the invention comprises a plurality of transformers, each transformer having a primary winding and a secondary winding, the primary windings being electrically connected in series, a plurality of light-emitting diodes, each light-emitting diode being electrically connected to one of the secondary windings, and a constant-current regulator electrically connected to the series-connected primary windings for supplying electric power to the primary windings. In the electrical circuit according to the invention the constant-current regulator is configured, in case of an open-circuit fault in the electrical circuit, to change the alternating voltage so that the light-emitting diodes light up, the open-circuit fault being located between the transformers that are electrically connected to the light-emitting diodes having the smallest light intensities.

[0024] The electrical circuit according to the invention is a lighting circuit that has a built-in functionality to determine the location of an open-circuit fault in it. The electrical circuit can be used in an aeronautical ground lighting (AGL) system, which provides visual cues in runways and taxiways to help aircraft pilots during approach, landing and taxiing.

[0025] In the electrical circuit according to the invention, the series-connected primary windings of the transformers form a primary circuit. The CCR is electrically connected to the primary circuit for supplying electric power (AC power) to the primary windings. Each of the secondary windings of the transformers forms a secondary circuit with one of the LEDs.

[0026] During normal operation of the electrical circuit, the CCR supplies electric power through the transformers to the LEDs, which then emit light. The transformers isolate the LEDs from the high operating voltage of the primary circuit and ensure the circuit continuity in case of a LED failure. When an open-circuit fault occurs in the primary circuit, for example as a result of an electrical cable breakage, the LEDs turn off. The open-circuit fault can be detected, for example, by visually observing the LEDs or by measuring the electrical properties of the electric power supplied by the CCR.

[0027] The location of an open-circuit fault in the primary circuit can be determined by using the CCR. After the open-circuit fault has been detected, the alternating voltage supplied by the CCR is changed so that the LEDs light up. The alternating voltage can be changed, for example, by adjusting one or more of the following param-

eters: the waveform, the amplitude (voltage level) and the frequency of the alternating voltage. The open-circuit fault is located between the transformers that are electrically connected to the LEDs having the smallest light intensities.

[0028] An advantage of the electrical circuit according to the invention is that the location of an open-circuit fault in the electrical circuit can be determined in a quick and accurate manner.

[0029] According to an embodiment of the invention the constant-current regulator is configured, in case of an open-circuit fault in the electrical circuit, to change at least one of the following parameters: the waveform, the amplitude and the frequency of the alternating voltage. Preferably, the CCR is configured to change at least two of these parameters, such as the amplitude and the frequency, during the search of the alternating voltage that can light up the LEDs.

[0030] The exemplary embodiments of the invention presented in this text are not interpreted to pose limitations to the applicability of the appended claims. The verb "to comprise" is used in this text as an open limitation that does not exclude the existence of also unrecited features. The features recited in the dependent claims are mutually freely combinable unless otherwise explicitly stated.

[0031] The exemplary embodiments presented in this text and their advantages relate by applicable parts to the method as well as the electrical circuit according to the invention, even though this is not always separately mentioned.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032]

Fig. 1 illustrates an electrical circuit according to an embodiment of the invention, and

fig. 2 illustrates exemplary operating areas of the electrical circuit according to fig. 1 during normal operation and during locating of an open-circuit fault.

DETAILED DESCRIPTION OF THE DRAWINGS

[0033] Fig. 1 illustrates an electrical circuit according to an embodiment of the invention. The electrical circuit comprises a plurality of transformers 101, which each have a primary winding 102 and a secondary winding 103. The primary windings 102 are electrically connected in series so that they form a primary circuit. The electrical circuit also comprises a plurality of light-emitting diodes (LEDs) 104, each of which is electrically connected to one of the secondary windings 103. Each of the secondary windings 103 forms a secondary circuit with one of the LEDs 104. The transformers 101 isolate the LEDs 104 from the high operating voltage of the primary circuit

and ensure the circuit continuity in case of the LED 104 failure.

[0034] The electrical circuit of fig. 1 comprises a constant-current regulator (CCR) 105 that is electrically connected to the primary circuit. During normal operation of the electrical circuit, the CCR 105 can supply electric power through the transformers 101 to the LEDs 104, which then emit light.

[0035] In the electrical circuit of fig. 1, an open-circuit fault has occurred due to a break in an electrical cable 106 that is electrically connected between two primary windings 102. The location of this open-circuit fault can be determined by using the CCR 105. To determine the location of the open-circuit fault in the primary circuit, the CCR 105 is configured to change the characteristics of the supplied alternating voltage so that the LEDs 104 light up. The alternating voltage supplied by the CCR 105 can be changed by adjusting one or more of the following parameters: the waveform, the amplitude (voltage level) and the frequency of the alternating voltage. The open-circuit fault is located between the transformers 101 that are electrically connected to the LEDs 104 having the smallest light intensities. The light intensities of the LEDs 104 can be observed by a person.

[0036] Fig. 2 illustrates exemplary operating areas of the electrical circuit according to fig. 1 during normal operation and during locating of an open-circuit fault. During normal operation of the electrical circuit, the amplitude and the frequency of the alternating voltage supplied by the CCR are chosen from an area 201. The area 201 defines the possible values for the amplitude and the frequency of the alternating voltage that enable the LEDs to emit light when the electrical circuit is in order.

[0037] In a case of an open-circuit fault in the primary circuit, the locating of the fault can be carried out by finding such amplitude and frequency values from an area 202 or an area 203 for the alternating voltage that enable the LEDs to light up. The open-circuit fault is located between the transformers that are electrically connected to the LEDs having the smallest light intensities. The area 202 is a so-called voltage detection area. The lower limit of the amplitude range is larger than the sum of the threshold voltages of the LEDs in the electrical circuit, and the upper limit of the amplitude range extends into the maximum amplitude of the CCR. The frequency range is close to the maximum frequency of the CCR. The area 203 is a so-called resonance detection area. The lower limit of the amplitude range is close to zero, and the upper limit of the amplitude range is smaller than the sum of the threshold voltages of the LEDs in the electrical circuit. The frequency range covers most of the frequency range of the CCR.

[0038] Only advantageous exemplary embodiments of the invention are described in the figures. It is clear to a person skilled in the art that the invention is not restricted only to the examples presented above, but the invention may vary within the limits of the claims presented hereafter. Some possible embodiments of the invention are

described in the dependent claims, and they are not to be considered to restrict the scope of protection of the invention as such.

Claims

1. A method for determining the location of an open-circuit fault in an electrical circuit that comprises a plurality of transformers, each transformer having a primary winding and a secondary winding, the primary windings being electrically connected in series and each secondary winding being electrically connected to a light-emitting diode, **characterised in that** the method comprises:
 - using a constant-current regulator to supply electric power to the primary windings, and
 - changing the alternating voltage supplied by the constant-current regulator so that the light-emitting diodes light up, the open-circuit fault being located between the transformers that are electrically connected to the light-emitting diodes having the smallest light intensities.
2. The method according to claim 1, **characterised in that** the step of changing the alternating voltage supplied by the constant-current regulator comprises changing at least one of the following parameters: the waveform, the amplitude and the frequency of the alternating voltage.
3. The method according to claim 1 or 2, **characterised in that** the step of changing the alternating voltage supplied by the constant-current regulator comprises changing the amplitude within a predefined amplitude range and changing the frequency within a predefined frequency range.
4. The method according to claim 3, **characterised in that** the lower limit of the predefined amplitude range is larger than the sum of the threshold voltages of the light-emitting diodes.
5. The method according to claim 3, **characterised in that** the upper limit of the predefined amplitude range is smaller than the sum of the threshold voltages of the light-emitting diodes.
6. The method according to claim 1 or 2, **characterised in that** the step of changing the alternating voltage supplied by the constant-current regulator comprises setting the frequency of the alternating voltage to a predefined frequency value and changing the amplitude within a predefined amplitude range.
7. The method according to claim 6, **characterised in that** the predefined frequency value is close to the

maximum frequency of the constant-current regulator and the lower limit of the predefined amplitude range is larger than the sum of the threshold voltages of the light-emitting diodes.

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8. The method according to claim 6, **characterised in that** the predefined frequency value is a parallel resonance frequency of the electrical circuit and the upper limit of the predefined amplitude range is smaller than the sum of the threshold voltages of the light-emitting diodes. 10
9. The method according to claim 1 or 2, **characterised in that** the step of changing the alternating voltage supplied by the constant-current regulator comprises setting the amplitude of the alternating voltage to a predefined amplitude value and changing the frequency within a predefined frequency range. 15
10. The method according to any of the preceding claims, **characterised in that** the step of changing the alternating voltage supplied by the constant-current regulator comprises changing the waveform by adding harmonics to the alternating voltage. 20
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11. An electrical circuit, comprising:
 - a plurality of transformers, each transformer having a primary winding and a secondary winding, the primary windings being electrically connected in series, 30
 - a plurality of light-emitting diodes, each light-emitting diode being electrically connected to one of the secondary windings, and
 - a constant-current regulator electrically connected to the series-connected primary windings for supplying electric power to the primary windings, 35

characterised in that the constant-current regulator is configured, in case of an open-circuit fault in the electrical circuit, to change the alternating voltage so that the light-emitting diodes light up, the open-circuit fault being located between the transformers that are electrically connected to the light-emitting diodes having the smallest light intensities. 40
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12. The electrical circuit according to claim 11, **characterised in that** the constant-current regulator is configured, in case of an open-circuit fault in the electrical circuit, to change at least one of the following parameters: the waveform, the amplitude and the frequency of the alternating voltage. 50
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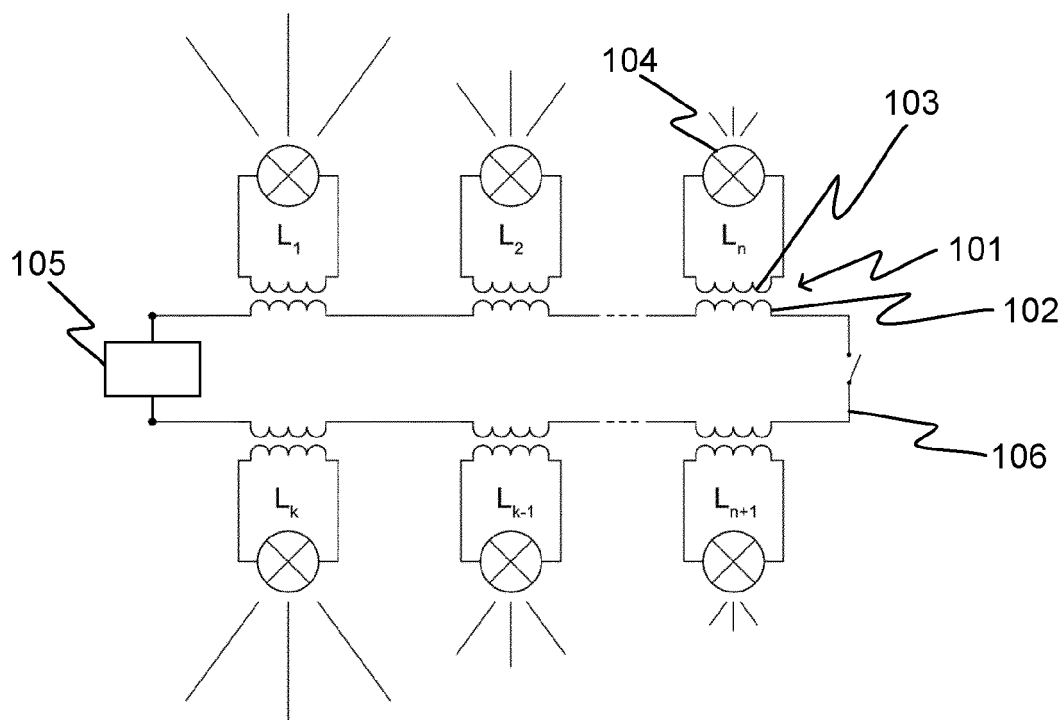


Fig. 1

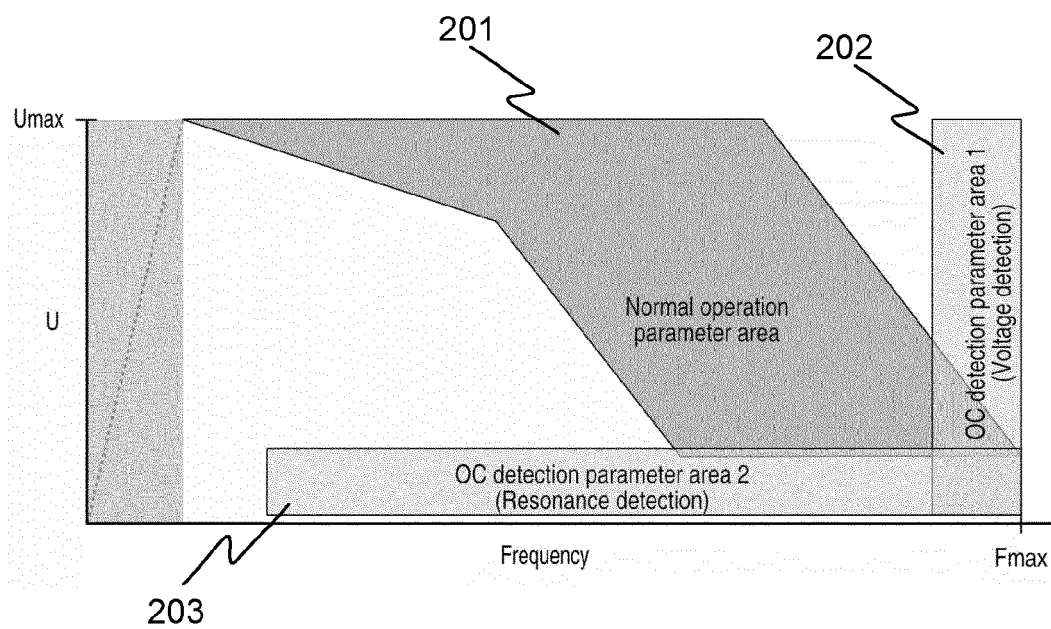


Fig. 2



EUROPEAN SEARCH REPORT

Application Number
EP 20 17 9536

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EPO FORM 1503 03.82 (P04C01)

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			TECHNICAL FIELDS SEARCHED (IPC)
			H05B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 18 September 2020	Examiner Morrish, Ian
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 20 17 9536

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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18-09-2020

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