PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference SE-16099WO-PCT	**FOR FURTHER ACTION** See Form PCT/IPEA/416	
International application No. PCT/EP2016/062391	International filing date *(day/month/year)* 01.06.2016	Priority date *(day/month/year)*
International Patent Classification (IPC) or national classification and IPC INV. H05K7/20		
Applicant ABB SCHWEIZ AG		

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 5 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. ☒ *(sent to the applicant and to the International Bureau)* a total of 18 sheets, as follows:
      - ☒ sheets of the description, claims and/or drawings which have been amended and/or sheets containing rectifications authorized by this Authority, unless those sheets were superseded or cancelled, and any accompanying letters (see Rules 46.5, 66.8, 70.16, 91.2, and Section 607 of the Administrative Instructions).
      - ☐ sheets containing rectifications, where the decision was made by this Authority not to take them into account because they were not authorized by or notified to this Authority at the time when this Authority began to draw up this report, and any accompanying letters (Rules 66.4bis, 70.2(e), 70.16 and 91.2).
      - ☐ superseded sheets and any accompanying letters, where this Authority either considers that the superseding sheets contain an amendment that goes beyond the disclosure in the international application as filed, or the superseding sheets were not accompanied by a letter indicating the basis for the amendments in the application as filed, as indicated in item 4 of Box No. I and the Supplemental Box (see Rule 70.16(b)).

   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing, in the form of an Annex C/ST.25 text file, as indicated in the Supplemental Box Relating to Sequence Listing (see paragraph 3*ter* of Annex C of the Administrative Instructions).

4. This report contains indications relating to the following items:
   - ☒ Box No. I Basis of the report
   - ☐ Box No. II Priority
   - ☐ Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - ☐ Box No. IV Lack of unity of invention
   - ☒ Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - ☐ Box No. VI Certain documents cited
   - ☐ Box No. VII Certain defects in the international application
   - ☐ Box No. VIII Certain observations on the international application

Date of submission of the demand	Date of completion of this report
27.03.2018	17.08.2018
Name and mailing address of the international preliminary examining authority: European Patent Office P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk - Pays Bas Tel. +31 70 340 - 2040 Fax: +31 70 340 - 3016	Authorized officer Seifert, Frank Telephone No. +31 70 340-3620

Box No. I Basis of the report

1. With regard to the **language**, this report is based on

☒ the international application in the language in which it was filed

☐ a translation of the international application into , which is the language of a translation furnished for the purposes of:

☐ international search (under Rules 12.3(a) and 23.1(b))
☐ publication of the international application (under Rule 12.4(a))
☐ international preliminary examination (under Rules 55.2(a) and/or 55.3(a) and (b))

2. With regard to the **elements*** of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report)*:

Description, Pages

1-12	filed with the letter of	25-06-2018

Claims, Numbers

1-13	filed with the letter of	25-06-2018

Drawings, Sheets

1, 2	as originally filed

☐ a sequence listing - see Supplemental Box Relating to Sequence Listing.

3. ☒ The amendments have resulted in the cancellation of:

☐ the description, pages
☒ the claims, Nos. 9,13
☐ the drawings, sheets/figs
☐ the sequence listing *(specify)*:

4. ☐ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since either they are considered to go beyond the disclosure as filed, or they were not accompanied by a letter indicating the basis for the amendments in the application as filed, as indicated in the Supplemental Box (Rules 70.2(c) and (c-*bis*)):

☐ the description, pages
☐ the claims, Nos.
☐ the drawings, sheets/figs
☐ the sequence listing *(specify)*:

5. ☐ This report has been established:

☐ taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91 (Rules 66.1(d-*bis*) and 70.2(e)).

☐ without taking into account the **rectification of an obvious mistake** authorized by or notified to this Authority under Rule 91(Rules 66.4*bis* and 70.2(e)).

6. ☒ With regard to top-up searches (Rules 66.1*ter* and 70.2(f)):
   - ☒ A top-up search was carried out by this Authority on 03.08.2018 (all discovered documents are listed in the Supplemental Box Relating to Top-up Search).
     - ☐ Additional relevant documents have been discovered during the top-up search.
   - ☐ No top-up search was carried out by this Authority because it would serve no useful purpose.

7. ☐ Supplementary international search report(s) from Authority(ies) has/have been received and taken into account in establishing this report (Rule 45bis.8(b) and (c)).

* *If item 4 applies, some or all of those sheets may be marked "superseded".*

Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-13
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-13
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-13
	No:	Claims	

2. Citations and explanations (Rule 70.7):

see separate sheet

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1 Reference is made to the following documents:

D1 EP 1 637 020 A1 (RITTAL GMBH & CO KG [DE]) 22 March 2006 (2006-03-22)

D2 US 4 047 561 A (JASTER HEINZ ET AL) 13 September 1977 (1977-09-13)

D3 EP 2 790 480 A2 (VACON OYJ [FI]) 15 October 2014 (2014-10-15)

2 D1 is regarded as being the prior art closest to the subject-matter of claim 1, and discloses

Liquid cooling system (Paragraph [0009]; Claim 1) for cooling at least one electrical component (Paragraph [0001] "Wärmeerzeugende Einbauten eines Schaltschrankes", Fig. 1 (11)), the liquid cooling system (Paragraph [0009]; Claim 1) comprising:
- a cooling circuit (Paragraph [0014]; Fig. 1 (20)) having an inlet flow line (Fig. 1, Inlet flow line (33)), a return flow line (Fig. 1, Inlet flow line (34)), and at least one supply branch (Fig. 1 (21), (22)) for supplying liquid coolant to an electrical component (Fig. 1 (11)); and
- at least one deaeration line (Paragraph [0014]; Fig. 1 (24), (25)) to provide a connection between a high point (High point: Fig. 1 Upper end from (21)) and a junction point (Fig. 1 (23) -> (22)) of the cooling circuit (Paragraph [0014]; Fig. 1 (20)) to bypass a part of the cooling circuit; wherein the high point (Fig. 1: Upper end of (21)) constitutes a geodetically or locally highest point of at least one supply branch (Fig. 1, (21), (22));

~~characterized in that the junction point is provided on the return flow line downstream of the at least one supply branch; wherein the pressure of the liquid coolant is lower in the junction point than in the high point during circulation of the liquid coolant in the liquid cooling system.~~

The subject-matter of claim 1 therefore differs from this known liquid cooling system in that that the junction point is provided on the return flow line downstream of the at least one supply branch; wherein the pressure of the liquid coolant is lower in the junction point than in the high point during circulation of the liquid coolant in the liquid cooling system and is therefore new (Article 33(2) PCT).

The problem to be solved by the present invention may be regarded as to provide a liquid cooling system with a simple and user-friendly setup that provides increased deaeration efficiency and safety and avoids the risk of leaking or spilled cooling liquid during deaeration.

The solution to this problem proposed in claim 1 of the present application is considered as involving an inventive step (Article 33(3) PCT) for the following reasons:

None of the cited prior art documents D1-D3 neither discloses nor an combination of prior art is obvious to form the claimed subject-matter of a liquid cooling system with a deaeration system featuring a deaeration line between a geodetically or locally highest point of at least one supply branch and a junction point on the return flow line downstream of the at least one supply branch, wherein the pressure of the liquid coolant is lower in the junction point than in the high point during circulation of the liquid coolant in the liquid cooling system, and enabling a continuous and leak/spill save deaeration of the supply branch toward the return flow line by avoiding trapped air at the high point of the brach.

3 Independent method claim 13 represents the liquid cooling method corresponding to the liquid cooling system so the argumentation for the liquid cooling system applies mutatis mutandis to this method claim which therefore is considered to be new (Article 33(2) PCT) and to involve an inventive step (Article 33(3) PCT).

4 Claims 2-12 are dependent on independent claim 1 whose subject-matter is considered as being new and inventive, as discussed above, and as such said dependent claims also meet the requirements of the PCT with respect to novelty and inventive step.

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OUR REF. NO. SE-16099-WO-PCT
DATE June 25, 2018

International Patent Application No.: PCT/EP2016/062391
Applicant: ABB Schweiz AG

This is in response to the written opinion issued by the International Preliminary Examining Authority on 24 April 2018.

In case the Examiner is not in a position to issue an International Preliminary Examination Report without any objections, a telephone consultation with the Examiner pursuant to Art. 34(2)(a) PCT is respectfully requested.

Cited documents

D1: EP 1637020 B1;
D2: US 4047561 A;
D3: EP 2790480 A2;

Amendments, Art. 34(2)(b) PCT

Independent claim 1 has been amended by the addition of the features of dependent claim 9.

Claim 1 has further been amended by defining that the high point constitutes *"a geodetically or locally highest point of the at least one supply branch (20)"*, substantially as suggested by the Examiner at point 2.2.

Support for the definition that the high point may constitute a geodetically highest point of the at least one supply branch can for example be found at page 3, lines 28-30, where it is stated that *"In case the high point is a high point of the at least one supply branch, the high point may be the highest point of the at least one supply branch"*, at page 8, lines 15-16, where it is stated that *"a high point 32 constituting a geodetically highest point of each supply branch 20 is connected to the deaeration line 28"*, and in original 2, where it is defined that *"the high point (32) is a high point (32) of the at least one supply branch (20)"*.

Support for the definition that the high point may constitute a locally highest point of the at least one supply branch can for example be found at page 2, lines 29-30, where it is referred to *"accumulation of gas and air in high points (and/or local high points)"*, at page 3, line 30 to page 4, line 2, where it is stated that *"This highest point may or may not be the highest point of the cooling circuit. In other words, this highest point may or may not be a locally highest point"*, at page 5, line 26, where it is stated that *"The at least one high point may be a local high point"*, and by the combination of original claims 2 and 12.

Claim 1 has further been amended by defining that the junction point is provided on the return flow line *"downstream of the at least one supply branch (20)"*. Support for this definition can for example be found at page 5, lines 16-19, where it is stated that *"In case several supply branches provide connections between the inlet flow line and the return flow line, several junction points may be provided immediately downstream of each supply branch"*, at page 8, lines 20-21, where it is stated that *"the junction point 34 is positioned downstream of the first supply branch 20"*, and at page 10, lines 12-24.

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The language in each of dependent claims 2 and 11 has been brought into conformity with claim 1.

The now redundant features in dependent claim 8 have been deleted.

Previous claim 9 has consequently been deleted without prejudice. Also previous claim 13 has been deleted. The numbering and dependencies of the remaining claims have been adjusted accordingly.

Independent claim 13 has been amended in the corresponding manner as claim 1.

Each of claims 1 and 13 has further been drafted in the two-part form with respect to document D1 having features alleged by the Examiner to be disclosed by document D1 in the preamble, in accordance with Rule 6(3)(b) PCT. The objection raised under point 8 should therefore no longer apply.

Documents D1 and D2 have been identified in the description in accordance with Rule 5.1(a)(ii) PCT. The objection raised at point 9 should therefore no longer apply.

Clarity, Art. 6 PCT

Notwithstanding our previously submitted arguments, the following is submitted in regard to clarity of the amended claims.

Amended claim 1 now contains the definition that the high point constitutes *"a geodetically or locally highest point of the at least one supply branch"*, substantially as suggested by the Examiner at point 2.2. The only difference from the wording suggested by the Examiner is the use of *"the at least one"* instead of *"each"* in line with *"at least one supply branch"* in the preamble of claim 1.

Amended claim 1 also defines that the dearation line is connected to the return flow line at a junction point, as requested by the Examiner at point 2.3. This is unambiguous since claim 1 defines that the deaeration line provides a connection to the junction point and defines that the junction point is provided on the return flow line.

The same applies to independent claim 13.

Since claims 1 and 13 have been amended as requested by the Examiner in this regard, the lack of clarity objection raised at point 2 should be overcome.

The claims meet the requirements of Art. 6 PCT.

Novelty, Art. 33(2) PCT

Regarding document D1, the Examiner considered the forward-flow line 21 and the return-flow line 22 to constitute a branch, the connecting line 25 having a manually operated venting device 24 to constitute a deaeration line, and the junction between the supply line 23 and the return-flow line 22 to constitute a junction point according to claim 1.

However, document D1 fails to disclose a deaeration line that provides a connection between the connecting line 25 and a junction point, downstream of a supply branch, and that bypasses a part of a cooling circuit, according to claim 1. At least for this reason, claim 1 is novel over document D1.

Regarding document D2, the Examiner seems to interpret the upper end of the inlet duct 17 to constitute a high point according to claim 1. It is not immediately apparent which part the Examiner considers to constitute a supply branch according to claim 1.

Should the inlet duct 17 and the outlet duct 18 be considered to constitute a supply branch, and the upper end of the inlet duct 17 be considered to constitute a high point according to claim 1, document D2 does not disclose a deaeration line that provides a connection between the high point and a junction point, downstream of the supply branch, and that bypasses a part of the cooling circuit. At least for this reason, claim 1 is novel over document D2.

Inventive Step, Art. 33(3) PCT

D1 may be considered to represent the closest prior art. As mentioned above, D1 fails to disclose a deaeration line that provides a connection between the connecting line 25 and a junction point, downstream of a supply branch, and that bypasses a part of a cooling circuit, according to claim 1.

D1 comprises a manually operated venting device 24. This adds costs, both for the venting device 24 as such, and for any potential equipment needed to supervise the position of the venting device 24. Venting devices typically also requires maintenance.

Furthermore, the venting device 24 in D1 is also associated with safety risks. For example, when opening the venting device 24, coolant may be sprayed along with the air. An additional safety issue is when an operator forgets to close the venting device 24.

In contrast to D1, the liquid cooling system according to claim 1 comprises at least one deaeration line that provides a connection between a high point (constituted by a geodetically or locally highest point of the at least one supply branch) and a junction point, provided downstream of the at least one supply branch, to bypass a part of the cooling circuit. By deviating a part of the liquid coolant flow through the deaeration path according to claim 1, accumulation of gas and air in high points (and/or local high points) can be avoided without the use of a venting device, see for example page 2, lines 27-30.

A derived objective technical problem may consequently be formulated as how to modify the cooling system in D1 to provide a simpler structure with a reduced number or components, and to increase deaeration efficiency and safety, see page 1, line 22 to page 2, line 3, of the present application.

Neither D1 nor D2 contains any teaching that would prompt the skilled person, faced with the objective technical problem, to modify the cooling system of D1 into anything falling within the scope of claim 1. Document D3, merely assigned to category "A" in the International Search Report, provides no further relevant disclosure.

Hence, independent claim 1 is inventive over the cited prior art. The above reasoning applies mutatis mutandis to independent claim 13.

Since claim 1 contains the features indicated at points 7.1 and 7.2 a) of the written opinion, it is assumed that this conclusion is shared by the Examiner.

Conclusions and Request

In view of the above, it is respectfully submitted that the claims meet all the requirements of the PCT and hence that this is reflected in the International Preliminary Examination Report, Art 35 PCT.

ABB Schweiz AG

Reino Savela

Enclosures:
Amended Claims, clean and marked up
Amended description, clean and marked up

CLAIMS

1. Liquid cooling system (10) for cooling at least one electrical component (14), the liquid cooling system (10) comprising:
- a cooling circuit (12) having an inlet flow line (18), a return flow line (22), and at least one supply branch (20) for supplying liquid coolant to an electrical component (14); and
- at least one deaeration line (28) to provide a connection between a high point (32) and a junction point (34) of the cooling circuit (12) to bypass a part of the cooling circuit (12);
wherein the high point (32) constitutes a geodetically or locally highest point of the at least one supply branch (20);
characterized in that the junction point (34) is provided on the return flow line (22) downstream of the at least one supply branch (20); wherein the pressure of the liquid coolant is lower in the junction point (34) than in the high point (32) during circulation of the liquid coolant in the liquid cooling system (10).

2. The liquid cooling system (10) according to claim 1, wherein the high point (32) constitutes a geodetically highest point of the at least one supply branch (20).

3. The liquid cooling system (10) according to claim 1 or 2, wherein the junction point (34) is geodetically below the high point (32).

4. The liquid cooling system (10) according to claim 1 or 2, wherein the junction point (34) is geodetically above the high point (32).

5. The liquid cooling system (10) according to claim 1, wherein the liquid cooling system (10) comprises:
- a plurality of supply branches (20) for supplying liquid coolant to a plurality of electrical components (14); and
- at least one deaeration line (28) to provide a connection between each high point (32) of the supply branches (20) and at least one junction

point (34) of the cooling circuit (12);
wherein the pressure of the liquid coolant is lower in the at least one junction point (34) than in the respective high point (32) connected to the junction point (34) by means of the deaeration line (28).

6. The liquid cooling system (10) according to claim 5, wherein the at least one junction point (34) is geodetically below the respective high point (32) connected to the junction point (34) by means of the deaeration line (28).

7. The liquid cooling system (10) according to claim 5 or 6, wherein the at least one deaeration line (28) provides a connection between each high point (32) of the supply branches (20) and one single junction point (34) of the cooling circuit (12).

8. The liquid cooling system (10) according to any of the preceding claims, wherein the at least one supply branch (20) provides a connection between the inlet flow line (18) and the return flow line (22).

9. The liquid cooling system (10) according to any of the preceding claims, further comprising at least one electrical component (14) to be cooled.

10. The liquid cooling system (10) according to claims 8 or 9, wherein the inlet flow line (18) is located geodetically below the at least one electrical component (14).

11. The liquid cooling system (10) according to any of the preceding claims, wherein the at least one high point (32) constitutes a locally highest point of the at least one supply branch (20).

12. The liquid cooling system (10) according to any of the preceding claims, further comprising a valve (36) for closing the deaeration line (28).

13. Method of operating a liquid cooling system (10) for cooling at least one electrical component (14), the method comprising the steps of:
- circulating liquid coolant in a cooling circuit (12) having an inlet flow

line (18), a return flow line (22), and at least one supply branch (20) for supplying liquid coolant to an electrical component (14); and

- connecting at least one high point (32) and a junction point (34) of the cooling circuit (12) to bypass a part of the cooling circuit (12);

wherein the high point (32) constitutes a geodetically or locally highest point of the at least one supply branch (20);

characterized in that the junction point (34) is provided on the return flow line (22) downstream of the at least one supply branch (20); wherein the pressure of the liquid coolant is lower in the junction point (34) than in the high point (32).

LIQUID COOLING SYSTEM AND METHOD

Technical Field

The present disclosure generally relates to a liquid cooling system. In particular, a liquid cooling system for cooling at least one electrical component and a method of operating a liquid cooling system for cooling at least one electrical component are provided.

Background

Various solutions exist in order to deaerate liquid coolants for liquid cooling systems by removing air and gas entrapped in the liquid medium.

US 2012090348 A1 discloses a cooling system having a closed-loop cooling circuit. The system comprises a coolant reservoir, a pump, fluid passages in a battery charging module, fluid passages in a power electronics module and a heat exchanger. The coolant reservoir includes a body portion defining an interior cavity configured to hold a coolant and a barrier wall positioned within the body portion to partition the interior cavity into an upper chamber and a lower chamber where the barrier wall defines an opening therethrough that allows fluid communication between the lower chamber and the upper chamber. The barrier wall prevents the air in the upper chamber from mixing with the coolant in the lower chamber.

EP 1637020 B1 discloses a cooling system for cooling a switchgear cabinet. The cooling system comprises a coolant circuit, having a forward-flow line and a return-flow line, and individual appliance supply lines for supplying coolant to individual cooling bodies. The forward-flow line and the return-flow line are connected via a connecting line having a manually operated venting device.

US 4047561 A discloses a closed loop forced liquid cooling system comprising a main cooling duct loop and a combined gas separator and pressurizer with a heating element mounted in a bypass branch of the main cooling duct loop. The main cooling duct loop is arranged at a single level and comprises a pump 10 for supplying cooling liquid to a network of pipes for circulation in contact with hot surfaces of a heat-producing electronic equipment. The heated coolant is then cooled by a heat exchanger before being returned to the pump inlet.

Summary

One object of the present disclosure is to provide a liquid cooling system having a simple structure and a reduced number of components.

A further object of the present disclosure is to provide a liquid cooling system that provides an effective deaeration of the liquid coolant.

A still further object of the present disclosure is to provide a liquid coolant system that can operate without danger for an operator and without leaking liquid coolant on electrical components.

According to one aspect, there is provided a liquid cooling system for cooling at least one electrical component, the liquid cooling system comprising a cooling circuit having at least one supply branch for supplying liquid coolant to an electrical component; and at least one deaeration line to provide a connection between a high point and a junction point of the cooling circuit to bypass a part of the cooling circuit; wherein the pressure of the liquid coolant is lower in the junction point than in the high point during circulation of the liquid coolant in the liquid cooling system.

In liquid cooling systems, there is a risk that air and gas entrapped in the liquid coolant accumulate in highest points of the system. For example, air may be entrapped in the liquid coolant when filling up the system. Gases may be produced by electrolysis processes or when the liquid coolant temperature is increased.

The at least one deaeration line may thus constitute, or constitute a part or section of, a deaerating path that connects one or more high points of the cooling circuit to a line where the pressure of the liquid coolant is lower, for example an outlet line or return flow line of the cooling circuit. By continuously circulating the liquid coolant in the cooling circuit, a first part of the liquid coolant can flow through the at least one supply branch to cool a respective electrical component.

At the same time, a second part of the liquid coolant flow can be divided from one or several high points of the at least one supply branch and guided through the deaeration line in order to remove the liquid coolant containing (or containing a relatively high amount of) air or gas. By deviating the second part of the liquid coolant flow through the deaeration line and recirculating this part in the liquid cooling system, the accumulation of gas and air in high points (and/or local high points) can be avoided. The second part of the liquid coolant flow guided through the deaeration line may be 0.5-30%, such as 0.5-10%, such as 0.5-5% of the first part of the liquid coolant flow guided through the cooling circuit.

The liquid cooling system may further comprise a deaeration vessel arranged downstream of the junction point, e.g. upstream of a heat exchanger, in order to remove the air and gas entrapped in the liquid coolant. Alternatively, or in addition, a deaeration vessel may be arranged upstream of the junction point to cool the second liquid coolant flow.

Throughout the present disclosure, the cooling circuit may alternatively be referred to as a cooling medium distribution circuit and the deaeration line may alternatively be referred to as a bypass line. The language "to provide a connection" includes both variants where a line constitutes the entire connection as well as variants where the line only constitutes a part of the connection.

The liquid cooling system may comprise more than one deaeration line to provide a connection between a high point and a junction point of the cooling circuit. For example, two or more deaeration lines may provide a connection between one single high point of the cooling circuit and two or more separate junction points of the cooling circuit. Alternatively, two or more deaeration lines may provide a connection between two or more separate high points of the cooling circuit and one single junction point of the cooling circuit. As a further alternative, two or more deaeration lines may provide connections between two or more high points of the cooling circuit and respective two or more junction points of the cooling circuit.

The high point may be a high point of the at least one supply branch. It is however alternatively possible to design the cooling circuit such that the high point is positioned at other locations of the cooling circuit than in the supply branch for supplying liquid coolant to the electrical component. In case the high point is a high point of the at least one supply branch, the high point may be the highest point of the at least one supply branch. This highest point may or may not be the highest point of the cooling circuit. In other words, this highest point may or may not be a locally highest point.

The junction point may be geodetically below the high point. Thus, the junction point may be constituted by a low point. A geodetically higher point is vertically above a geodetically lower point. The at least one supply branch may thus be arranged to elevate liquid coolant to and/or from the electrical component. Thus, at least a part of the supply branch may propagate in a direction having a vertical component. In order to elevate the liquid coolant to the high point, the liquid coolant needs to be sufficiently pressurized in a section of the supply branch upstream of the high point. Once the high point is reached by the liquid coolant, the pressure decreases as the liquid coolant flows downstream from the high point.

However, as long as the pressure of the liquid coolant is lower in the junction point than in the high point during circulation of the liquid coolant in the liquid cooling system, the junction point does not necessarily have to be geodetically below the high point. Thus, according to one variant, the junction point is geodetically above the high point.

The liquid cooling system may comprises a plurality of supply branches for supplying liquid coolant to a plurality of electrical components; and at least one deaeration line to provide a connection between each high point of the supply branches and at least one junction point of the cooling circuit; wherein the pressure of the liquid coolant is lower in the at least one junction point than in the respective high point connected to the junction point by means of the deaeration line.

The at least one junction point may be geodetically below the respective high point connected to the junction point by means of the deaeration line. Each supply branch may thus be arranged to elevate liquid coolant to the respective electrical component.

The at least one deaeration line may provide a connection between each high point of the supply branches and one single junction point of the cooling circuit. Alternatively, the deaeration line may provide several connections between a high point of several separate supply branches and several separate junction points. Thus, the liquid cooling system may comprise several parallel deaeration lines.

The cooling circuit may comprises an inlet flow line and a return flow line wherein the at least one supply branch provides a connection between the inlet flow line and the return flow line.

The liquid cooling system may comprise a pump for circulating the liquid coolant in the cooling circuit. The pump may be arranged to discharge high pressure liquid coolant to the inlet flow line.

Furthermore, the liquid cooling system may comprise a heat exchanger to cool the liquid coolant after circulation through the cooling circuit. The heat exchanger may be provided on the return flow line downstream of the last of the at least one supply branch.

In case the cooling circuit comprises an inlet flow line and a return flow line, the at least one junction point may be provided on the return flow line. In case several supply branches provide connections between the inlet flow line and the return flow line, several junction points may be provided immediately downstream of each supply branch.

The liquid cooling system may further comprise at least one electrical component to be cooled. The at least one electrical component may be constituted by one or more power modules, such as converters.

The inlet flow line may be located geodetically below the at least one electrical component. The at least one supply branch may thus extend substantially vertically to provide liquid coolant to cool a respective electrical component.

The at least one high point may be a local high point. Alternatively, or in addition, the at least one high point may be a geodetically highest point of the cooling circuit.

The liquid cooling system may further comprise a valve for closing the deaeration line. The deaeration line can thereby be closed with the valve when deaeration is not required. For example, a continuous circulation of liquid coolant through the deaeration line may not be necessary at all times. Instead, the deaeration may be carried out at commissioning and/or during scheduled maintenance. The liquid cooling system may comprise more than one valve, for example in case several deaeration lines provide connections to several separate junction points. The one or more valves may be manually operable.

According to a further aspect, there is provided a method of operating a liquid cooling system for cooling at least one electrical component, the method comprising the steps of circulating liquid coolant in a cooling circuit having at least one supply branch for supplying liquid coolant to an electrical component; connecting at least one high point and a junction point of the cooling circuit to bypass a part of the cooling circuit; wherein the pressure of the liquid coolant is lower in the junction point than in the high point. The step of connecting at least one high point and a junction point of the cooling circuit may be constituted by the step of connecting at least one high point of the at least one supply branch and a junction point of the cooling circuit.

The method may further comprise the step of closing or opening a deaeration line connected between the at least one high point and the junction point by means of a valve. The valve may be manually operable.

Brief Description of the Drawings

Further details, advantages and aspects of the present disclosure will become apparent from the following embodiments taken in conjunction with the drawings, wherein:

Fig. 1: schematically represents a liquid cooling system; and
Fig. 2: schematically represents a further liquid cooling system.

Detailed Description

In the following, a liquid cooling system for cooling at least one electrical component and a method of operating a liquid cooling system for cooling at least one electrical component will be described. The same reference numerals will be used to denote the same or similar structural features.

Fig. 1 schematically represents a liquid cooling system 10. The liquid cooling system 10 comprises a cooling circuit 12 for cooling a plurality of electrical components 14. In Fig. 1, the electrical components 14 are constituted by four power modules, such as PEBBs (Power Electronic Building Blocks). The number of power modules is merely an example.

The liquid cooling system 10 comprises a pump 16 for delivering pressurized and cooled liquid coolant to an inlet flow line 18 of the cooling circuit 12. The cooling circuit 12 further comprises four supply branches 20, each for supplying liquid coolant to a respective electrical component 14 to be cooled.

A first supply branch 20 (the leftmost supply branch 20 in Fig. 1) branches off from the inlet inlet flow line 18 and elevates to a first electrical component 14 to cool the same and back to a return flow line 22. Similarly, a second and third supply branch 20 branch off from the inlet flow line 18 and elevate to a respective second and third electrical component 14 to be cooled and back to the return flow line 22. For providing liquid coolant to the last electrical component 14 (here, the fourth electrical component 14), the inlet flow line 18 transitions into the fourth supply branch 20 (i.e. the fourth supply branch 20 does not branch off from the inlet flow line 18) to cool the fourth electrical component 14 and back to the return flow line 22. The supply branches 20 in Fig. 1 thus have a parallel relationship.

In Fig. 1, each electrical component 14 is positioned geodetically above the inlet flow line 18. Thereby, each supply branch 20 may be said to elevate liquid coolant to the respective electrical component 14.

The path of the supply branches 20 in the respective electrical component 14 is merely schematically illustrated. Each supply branch 20 may guide the cooling liquid in a path layout that provides the best cooling for the respective electrical component 14. For example, each supply branch 20 may be laid in a serpentine shape along one or several surfaces of each electrical component 14 to provide a good cooling of the same.

The liquid cooling system 10 further comprises a deaeration vessel 24 to remove the air and gas entrapped in the liquid coolant in the return flow line 22 and a heat exchanger 26 for cooling the liquid coolant, heated when cooling the electrical components 14, before being circulated again in the cooling circuit 12.

The liquid cooling system 10 further comprises a deaeration line 28. A deaeration conduit 30 associated with each supply branch 20 connect a geodetically high point 32 to the deaeration line 28. In the implementation of Fig. 1, a high point 32 constituting a geodetically highest point of each supply branch 20 is connected to the deaeration line 28. The high points 32 of the supply branches 20 are substantially horizontally aligned and also constitute the vertically highest points of the cooling circuit 12.

The deaeration line 28 is connected to the return flow line 22 at a junction point 34. More specifically, the junction point 34 is positioned downstream of the first supply branch 20 (i.e. the left supply branch 20 in Fig. 1). Thus, the deaeration line 28 functions as a bypass line that bypasses a part of the main flow through the cooling circuit 12. Moreover, the deaeration line 28 provides a connection between the high points 32 of the supply branches 20 and the junction point 34 of the cooling circuit 12.

When the liquid coolant is circulated in the cooling circuit 12 and reaches a high point 32, the pressure in the liquid coolant will decrease downstream of the high point 32. Since the junction point 34 is geodetically below each high point 32 of the respective supply branch 20 in Fig. 1, also the gravity force will contribute to a decreasing liquid coolant pressure downstream of each high point 32 of the respective supply branch 20. Thus, the pressure is lower in the junction point 34 than in each high point 32 of the supply branches 20.

The liquid cooling system 10 further comprises a valve 36. The valve 36 is arranged on the deaeration line 28 and is moveable between a closed position and an open position (optionally also to any intermediate position) in order to close and open the deaeration line 28 (or restrict the flow in the deaeration line 28). In this implementation, the valve 36 is manually operable.

When the valve 36 adopts the closed position and the pump 16 is running, the entire flow of liquid coolant is circulated in the cooling circuit 12. In this mode of operation, air and gas entrapped in the liquid coolant might accumulate in the high points 32 of the supply branches 20. As a consequence, the cooling provided by the cooling circuit 12 might be deteriorated.

In order to remove the air and gas entrapped in the liquid coolant and accumulated in the high points 32 of the supply branches 20, the valve 36 may be opened. This may be done while the liquid cooling system 10 is operating, i.e. as the liquid coolant circulates in the cooling circuit 12. When the valve 36 adopts the open position, the flow of liquid coolant is divided into a first part circulating in the cooling circuit 12, i.e. from the inlet flow line 18, through the supply branches 20 and to the return flow line 22, and a second part constituting a bypass flow. This second part of the liquid coolant flow is guided from the inlet flow line 18, to a respective supply branch 20, to a high point 32 of the respective supply branch 20, to a deaeration conduit 30 connected to a respective high point 32, to the deaeration line 28, through the valve 36 and to the junction point 34 where the first and second flows of liquid coolant are joined. In the implementation of Fig. 1, the second flow may constitute, for example, approximately 2% of the first flow.

In this manner, any air and gas entrapped at the high points 32 are removed with the second liquid coolant flow. More specifically, liquid coolant containing the air and gas (or containing a high amount of air and gas), i.e. "low quality" liquid coolant, is transported away from the respective high point 32. The air and gas may then be removed from the liquid coolant by means of the deaeration vessel 24. The liquid coolant purified by the deaeration vessel 24 may then be circulated anew in the liquid cooling system. Since air and gas is removed from the high points 32, the cooling effect is improved. More specifically, the liquid coolant approaching the high points 32 is not blocked by air and gas (or is blocked to a reduced extent).

The valve 36 may be left open to continue bypassing a partial flow (i.e. the second flow) through the deaeration line 28 during further operation of the liquid cooling system 10. Alternatively, the valve 36 may be closed again to circulate all liquid coolant in the cooling circuit 12.

As an alternative design, the liquid cooling system 10 may comprise a deaeration line 28 associated with each high point 32. A fourth deaeration line 28 may provide a connection between the fourth high point 32 (i.e. the rightmost high point 32 in Fig. 1) and a junction point 34 on the return flow line 22 downstream of the fourth supply branch 20 but upstream of the third supply branch 20. A third and second deaeration line 28 associated with the respective third and second high point 32 may provide a connection between the respective third and second high point 32 and a respective junction point

34 on the return flow line 22 downstream of the third and second supply branch 20, respectively, but upstream of the second and first supply branch 20, respectively. A first deaeration line 28 may provide a connection between the first high point 32 and a junction point 34 on the return flow line 22 downstream of the first supply branch 20.

Fig. 2 schematically represents a further liquid cooling system 10. Mainly differences with respect to the liquid cooling system 10 of Fig. 1 will be described.

The liquid cooling system 10 of Fig. 2 comprises nine electrical components 14 to be cooled. Also in Fig. 2, the electrical components 14 are constituted by power modules. A first set of three electrical components 14 are cooled by a first supply branch 20, a second set of three electrical components 14 are cooled by a second supply branch 20 and a third set of three electrical components 14 are cooled by a third supply branch 20. The supply branches 20 of the cooling circuit 12 have a parallel relationship.

Each supply branch 20 comprises three sub-branches 38 where one sub-branch 38 is associated with each electrical component 14. Each sub-branch 38 is connected to a point on the supply branch 20 upstream of the high point 32 and to a point on the supply branch 20 downstream of the high point 32. For each supply branch 20, the sub-branches 38 thus have a parallel relationship. The high points 32 of the supply branches 20 are connected to the return flow line 22 in the same manner as in Fig. 1.

In Fig. 2, each sub-branch 38 diverts in a substantially horizontal direction from a portion of the supply branch 20 upstream of the high point 32 and to a respective electrical component 14 to be cooled. Any air or gas in the liquid coolant in the inlet flow line 18 is therefore less likely to be circulated in a sub-branch 38 to an electrical component 14. Instead, any air or gas in the liquid coolant in the inlet flow line 18 is more prone to rise (due to its lower weight) directly to a respective high point 32 without being introduced in a sub-branch 38. Also in this manner, the cooling effect of the liquid cooling system 10 is improved.

While the present disclosure has been described with reference to exemplary embodiments, it will be appreciated that the present invention is not limited to what has been described above. For example, it will be appreciated that the dimensions of the parts may be varied as needed. Accordingly, it is intended that the present invention may be limited only by the scope of the claims appended hereto.