



Capacitive power transfer system and method for controlling capacitive power transfer system

Dou, Yi; Ouyang, Ziwei; Chen, Xu

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Dou, Y., Ouyang, Z., & Chen, X. (2021). Capacitive power transfer system and method for controlling capacitive power transfer system. (Patent No. WO2021144255).

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



(51) International Patent Classification:
H02J 50/05 (2016.01)

(21) International Application Number:
PCT/EP2021/050471

(22) International Filing Date:
12 January 2021 (12.01.2021)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
20151498.1 13 January 2020 (13.01.2020) EP

(71) Applicant: DANMARKS TEKNISKE UNIVERSITET
[DK/DK]; Anker Engelunds Vej 101A, 2800 Kgs. Lyngby
(DK).

(72) Inventors: DOU, Yi; c/o Danmarks Tekniske Universitet,
Anker Engelunds Vej 101A, 2800 Kgs. Lyngby (DK).
OUYANG, Ziwei; c/o Danmarks Tekniske Universitet,
Anker Engelunds Vej 101A, 2800 Kgs. Lyngby (DK).
CHEN, Xu; c/o Danmarks Tekniske Universitet, Anker En-
gelunds Vej 101A, 2800 Kgs. Lyngby (DK).

(74) Agent: HØIBERG P/S; Adelgade 12, 1304 Copenhagen K
(DK).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN,
KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD,
ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO,
NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW,

(54) Title: CAPACITIVE POWER TRANSFER SYSTEM AND METHOD FOR CONTROLLING CAPACITIVE POWER TRANSFER SYSTEM

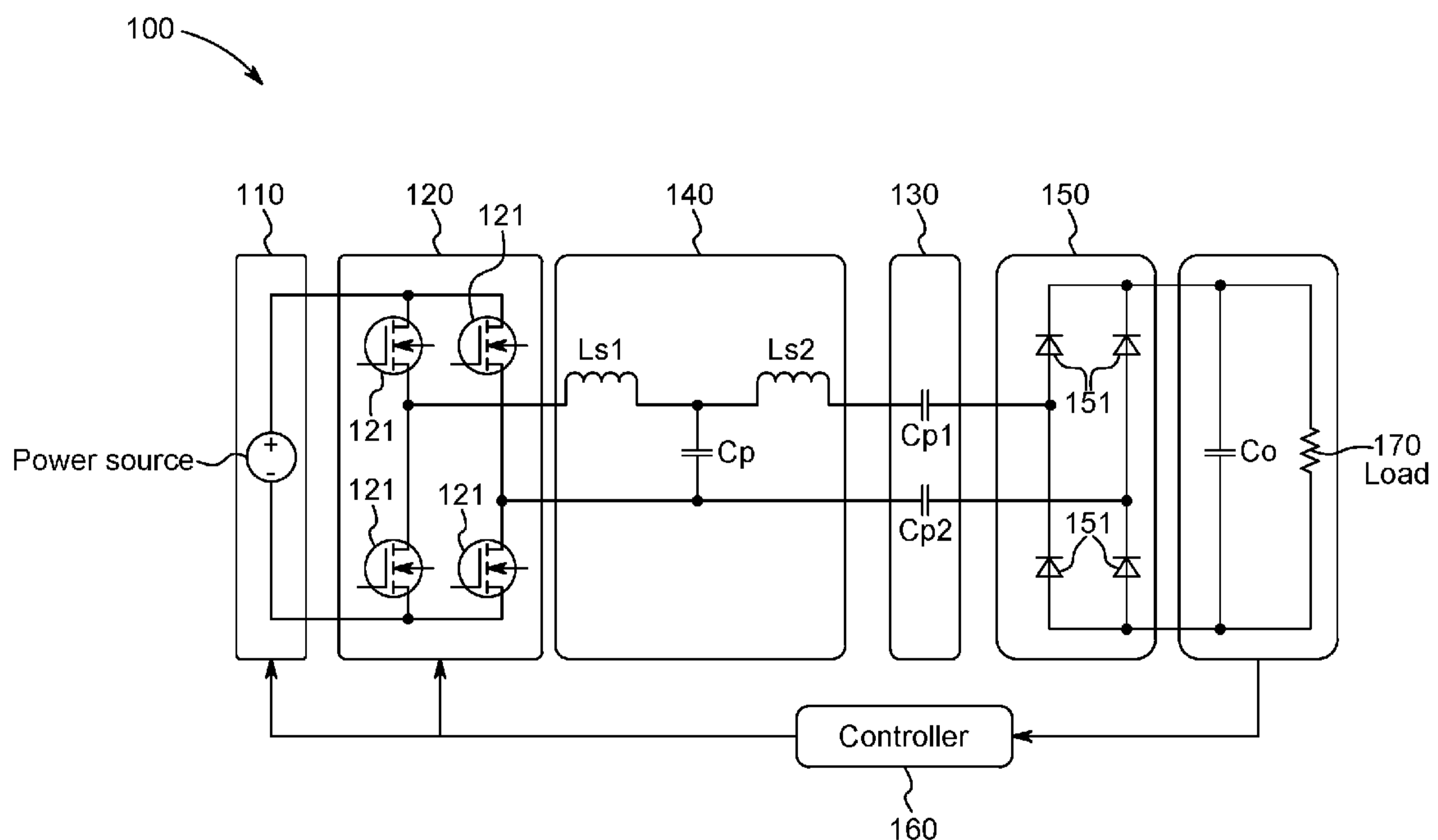


FIG. 1

(57) Abstract: The present disclosure relates to a capacitive power transfer system comprising: a DC power source providing an input DC supply voltage; an inverter configured to convert the DC supply voltage into an AC power; a capacitive coupler configured to transfer the AC power wirelessly; an LCL compensation topology arranged between the inverter and the capacitive coupler; a rectifier configured to convert the wirelessly transferred AC power into a DC output, said DC output connectable to a load; and a control unit configured to control the DC power source and/or the inverter such that the capacitive power transfer system: in a constant current mode, operates at a constant current mode frequency (f_{cc}), wherein a constant current is provided to the load; and in a constant voltage mode, operates at a constant voltage mode frequency (f_{cv}), wherein a constant voltage is provided



SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

Capacitive power transfer system and method for controlling capacitive power transfer system

The present disclosure relates to capacitive power transfer system that can be used for, for example, battery charging. The disclosure further relates to a method for
5 controlling a capacitive power transfer system.

Background

Wireless power transfer (WPT) is the transmission of electrical energy without wires as a physical link. In a wireless power transmission system, a transmitter device, driven by electric power from a power source, generates a time-varying electromagnetic field,
10 which transmits power across space to a receiver device, which extracts power from the field and supplies it to an electrical load.

Inductive Power Transfer (IPT) has been widely applied in the charging of devices. The aim of a charging system based on inductive power transfer is to provide power to a
15 across a gapped magnetic structure. Its theoretical development relies on both magnetic and power electronics together as an integrated system. An inductive power transfer system uses inductive coupling between two circuits as the basis of its operation. The system is effectively a two part transformer - the primary being contained within the power sourcing element, and the secondary being contained
20 within the item in which the batteries are to be charged. Both the transmitter and receiver are fitted with electrical coils.

Capacitive Power Transfer (CPT) has been introduced more recently as a promising wireless power transfer technology offering simple and flexible coupling designs, low
25 electromagnetic interference and less critical alignment requirements between the transmitter and receiver and low cost.

Existing CPT based charging systems are, however, typically relatively unstable and complex to control and may require additional compensation and DC-DC conversion on
30 the output. There is thus a need for a solution that is simpler and more stable with respect to implementation and operation.

Summary

A first aspect of the present disclosure relates to a capacitive power transfer system comprising:

- a DC power source providing an input DC supply voltage;
- 5 - an inverter configured to convert the DC supply voltage into an AC power;
- a capacitive coupler configured to transfer the AC power wirelessly;
- an LCL compensation topology arranged between the inverter and the capacitive coupler;
- a rectifier configured to convert the wirelessly transferred AC power into a DC output, said DC output connectable to a load; and
- 10 - a control unit configured to control the DC power source and/or the inverter such that the capacitive power transfer system:
 - o in a constant current mode, operates at a constant current mode frequency (f_{cc}), wherein a constant current is provided to the load;
 - 15 and
 - o in a constant voltage mode, operates at a constant voltage mode frequency (f_{cv}), wherein a constant voltage is provided to the load.

It can be noted that the capacitive power transfer system can be operated using a single LCL compensation on the transmitter side, which may also be referred to as the primary side. By operating the capacitive power transfer system in a constant current mode during a first charging cycle and in a constant voltage mode in a second cycle, a charging profile as shown in fig. 5 can be achieved with a power transfer system as described. Moreover, there is no need for DC-DC conversion on the receiver side, which may also be referred to as the secondary side. The capacitive power transfer system may be used in a battery charging application.

In the constant current mode a constant current is provided to the load, i.e. the load to which the DC output is connected. This load is referred to as 'Load' (170) in the example of fig. 1 and may be a rechargeable battery. In the constant voltage mode a constant voltage is provided to the load, i.e. the load to which the DC output is connected. This load is referred to as 'Load' (170) in the example of fig. 1 and may be a rechargeable battery.

The constant current mode frequency (f_{cc}) and the constant voltage mode frequency (f_{cv}), which are controlled by the controller, may be determined based on the characteristics and selected components of the circuit. The inventors have realized that by controlling the constant current mode frequency (f_{cc}) to be $f_{cc} = \frac{1}{2\pi\sqrt{L_{s1}C_p}}$ in the example of fig. 1, the output current will be load independent and constant. Simulations support this statement. The inventors have also realized that for the same topology, by controlling the constant voltage mode frequency that equals to $f_{cv} = \frac{1}{2\pi\sqrt{L_{s1}C_{pa}}} = \frac{1}{2\pi\sqrt{L_{s2}C_{es}}}$ wherein C_{es} denotes a series equivalence of the two parallel capacitors (C_{pa} and C_{pb}) representing an equivalent of C_p the example of fig. 1, the output voltage will be load independent and constant. Simulations support this statement as well.

Based on the proposed topology and control scheme, a capacitive power transfer system is achieved, which has one constant current output operation point and one constant voltage output operation point that are both load independent. The constant current and constant voltage operations can meet the requirement of a battery charging application without having further compensation or a DC-DC converter on the secondary side.

Constant voltage charging in battery charging allows the full current of the charger to flow into the battery until the power supply reaches its pre-set voltage. This method enables fast charging rates. Constant current is a simple form of charging batteries, with the current level set at, for example, 10% of the maximum battery rating. Charge times are relatively long. Constant current / constant voltage is a combination of the above two methods. The charger limits the amount of current to a pre-set level until the battery reaches a pre-set voltage level. The current then reduces as the battery becomes fully charged. This approach allows fast charging without the risk of over-charging. Fig. 5 shows this typical charging profile of a battery.

The presently disclosed capacitive power transfer system has a constant current mode for operating at a constant current and a constant voltage mode for operating at a constant voltage. The processing unit can therefore be controlled in any suitable way to switch from the constant current mode to the constant voltage mode. As a non-limiting, the processing unit may be configured to change from the constant current mode to the constant voltage mode when a voltage level of the load reaches a predefined or

configurable voltage level. A battery charging process may be started with the capacitive power transfer system in the constant current mode. Any suitable voltage, current or power criteria may be used by the control unit to control the DC power source and/or the inverter such that the capacitive power transfer system operates in the constant current mode or constant voltage mode.

The presently disclosed capacitive power transfer system may be used in a wide range of battery chargers, including, but not limited to, battery chargers for hearing aids, earbuds, shelf labels, smart glasses, mobile phones, tablets, computers, and smart watches.

The present disclosure further relates to a method for controlling a capacitive power transfer system comprising:

- a DC power source providing an input DC supply voltage;
- an inverter configured to convert the supply voltage into an AC power;
- a capacitive coupler comprising two pairs of coupled plates for transferring the AC power wirelessly;
- an LCL compensation topology arranged between the inverter and the capacitive coupler;
- a rectifier configured to convert the wirelessly transferred AC power into a DC output, said DC output connectable to a load;

said method comprising the steps of:

- configuring the inverter to operate at a constant current mode frequency, wherein a constant current is provided to the load; and
- configuring the inverter to operate at a constant voltage mode frequency, wherein a constant voltage is provided to the load.

A person skilled in the art will recognize that the presently disclosed method may be performed using any embodiment of the presently disclosed capacitive power transfer system.

Description of drawings

Fig. 1 shows an embodiment of the presently disclosed capacitive power transfer system.

Fig. 2A shows a simulation of an embodiment of the presently disclosed capacitive power transfer system in the constant current mode.

Fig. 2B shows a simulation of an embodiment of the presently disclosed capacitive power transfer system in the constant voltage mode.

Fig. 3A shows an equivalent of an embodiment of the presently disclosed capacitive power transfer system operating in the constant current mode.

5 Fig. 3B shows an equivalent of an embodiment of the presently disclosed capacitive power transfer system operating in the constant voltage mode.

Fig. 4 shows an embodiment of the presently disclosed method for controlling a capacitive power transfer system.

Fig. 5 shows a charging profile of a battery.

10 Detailed description of the invention

The present disclosure relates to capacitive power transfer system, which is based on the wireless transfer of power using a capacitive coupler configured to transfer the AC power, such as an AC voltage, wirelessly. The capacitive coupler may be implemented by means of two pairs of coupled plates (C_{p1} and C_{p2}). As a person skilled in the art
15 would recognize, the capacitive coupler may comprise, for example, parallel plates with an air gap. On the transmitter side the capacitive power transfer system typically comprises a DC power source providing an input DC supply voltage. The DC supply voltage may then be converted into an AC power, such as an AC voltage, by an inverter. The inverter can be, for example, a full-bridge inverter and can convert the DC
20 supply voltage to a rectangular waveform. The capacitive power transfer system may further comprise an LCL compensation topology arranged between the inverter and the capacitive coupler. The value of the coupling capacitance depends on the plate area, distance between the plates and the dielectric material between the plates. Since the permittivity constant of air is small the value of the coupling capacitance is typically
25 limited. The role of the LCL compensation topology may therefore be to provide resonance such that sufficiently high voltages to generate electric fields between the plates are generated. In one embodiment of the presently disclosed power transfer system, the LCL topology is configured to resonate with the capacitive coupler. On the receiver side, the capacitive power transfer system may further comprise a rectifier
30 configured to convert the wirelessly transferred AC power, such as AC voltage, into a DC output. The DC output can be connected to a load. The capacitive power transfer system may further comprise a control unit configured to control the DC power source and/or the inverter. Preferably, the control unit is configured to control the DC power source and/or the inverter such that the capacitive power transfer system: in a constant
35 current mode, operates at a constant current mode frequency (f_{cc}), wherein a constant

current is provided to the load; and in a constant voltage mode, operates at a constant voltage mode frequency (f_{cv}), wherein a constant voltage is provided to the load. The inventors have realized that by controlling the switching frequency of the inverter at the constant current mode frequency (f_{cc}) and the constant voltage mode frequency (f_{cv}),
5 wherein the frequencies are based on component parameter values of the LCL compensation topology and parameters of the capacitance coupling, load independent output current and output voltage can be achieved. Therefore in one embodiment of the presently disclosed power transfer system, the constant current in the constant current mode and the constant voltage in the constant voltage mode are load
10 independent. The proposed capacitive power transfer system may operate without the need for LCL compensation and DC-DC conversion on the receiver side. Therefore, in one embodiment of the presently disclosed power transfer system, the system is configured to operate without a compensation topology and/or without a DC-DC receiver on a receiving side of the capacitive power transfer system. In the known
15 systems, a DC-DC converter is typically used to regulate the output. In the present system such DC-DC converters can be eliminated.

The control unit may be configured to control the AC power from the inverter by phase-shift control and/or by controlling the DC supply voltage from the DC power source. In
20 one embodiment the DC power source comprises a DC-DC converter. The DC supply voltage can be controlled by controlling the DC-DC converter. The control unit may also control a phase-shifting of the inverter to change the output of the inverter. By using the presently disclosed constant current mode and constant voltage mode, the current and voltage can be kept stable in respective mode.

25 The LCL compensation topology may comprise a first inductor (L_{s1}), a second inductor (L_{s2}) and a first capacitor (C_p). As illustrated in fig. 1, the first inductor (L_{s1}) and second inductor (L_{s2}) may be serially connected, whereas the first capacitor (C_p) is connected to a node on the serial connection between the first inductor (L_{s1}) and second inductor
30 (L_{s2}). The first capacitor (C_p) may thus a parallel component to both the first inductor (L_{s1}) and second inductor (L_{s2}).

In order to achieve constant current, the control unit may be configured to control the DC power source and/or the inverter to maintain a constant current mode frequency
35 (f_{cc}) equal to a resonant frequency between the first inductor (L_{s1}) and the first capacitor (C_p). More specifically, the control unit is configured to control the DC power source

and/or the inverter to maintain a constant current mode frequency (f_{cc}) equal to a resonant frequency between the first inductor (L_{s1}) and the first capacitor (C_p). Fig. 1 shows an embodiment of the presently disclosed capacitive power transfer system. Fig. 3A and 3B show equivalents of the capacitive power transfer system operating in the constant current mode and constant voltage mode, respectively. The inverter can convert DC voltage to a rectangular waveform, whose frequency is the same as the switching frequency f of the inverter. After first harmonic analysis the output of the inverter can be regarded as the an AC voltage source, whose voltage is a complex number V_g and its angular frequency ω corresponds to the switching frequency $\omega = 2\pi f$. Meanwhile the load resistance R_l with diode rectifier can be regarded as a resistive AC load R_e where $R_e = \frac{8}{\pi^2 2\pi} R_l$. Besides, the two capacitances of coupled plates can be simplified to one capacitor C_r where to $C_r = \frac{C_{p1}C_{p2}}{C_{p1} + C_{p2}}$.

In one embodiment of the presently disclosed capacitive power transfer system, the constant current mode frequency (f_{cc}) in the constant current mode is calculated as $f_{cc} = \frac{1}{2\pi\sqrt{L_{s1}C_p}}$. The output current can then be calculated as $i_o = \frac{V_g}{j\omega L_{s1}}$ which is load independent.

In order to achieve constant voltage, the control unit may be configured to control the switching frequency of the inverter in the following way. The AC equivalent circuit model in the constant voltage mode is shown in fig. 3B. The capacitor C_p is electrically equivalent to two parallel capacitors C_{pa} and C_{pb} where $C_p = C_{pa} + C_{pb}$. The series equivalent capacitance C_{es} of C_{pb} and C_r can be defined as $C_{es} = \frac{C_{pb}C_r}{C_{pb} + C_r}$. Therefore, in one embodiment of the presently disclosed capacitive power transfer system, the control unit is configured to control the DC power source and/or the inverter to maintain a constant voltage mode frequency (f_{cv}) that equals to $f_{cv} = \frac{1}{2\pi\sqrt{L_{s1}C_{pa}}} = \frac{1}{2\pi\sqrt{L_{s2}C_{es}}}$ wherein C_{es} denotes a series equivalence of the two parallel capacitors (C_{pa} and C_{pb}), wherein $C_{es} = \frac{C_{pb}C_r}{C_{pb} + C_r}$. The output voltage can then be calculated as $V_o = \frac{V_g}{\omega^2 L_{s1} C_{pb}}$ which is load independent.

As stated above, the capacitive power transfer system may comprise an inverter configured to convert the DC supply voltage into an AC power, such as an AC voltage. The inverter may be any inverter suitable for the purpose. Specifically, the inverter may be, for example, a full-bridge inverter, a half-bridge inverter or a Class-E inverter. The

inverter may be configured to convert the DC supply voltage to the AC voltage having a substantially rectangular waveform having a frequency equal to a switching frequency of the inverter. In a specific embodiment, the inverter is configured to convert the DC supply voltage to a symmetric AC voltage. The AC voltage does not strictly have to be symmetric. As an example, the output of a half-bridge can have a DC bias and an AC voltage,

The rectifier on the receiver side that is configured to convert the wirelessly transferred AC power into a DC output may be any rectifier suitable for the purpose, for example a full-bridge rectifier. The rectifier may further comprise a smoothing circuit.

Moreover, the power transfer system may further comprise an output capacitor (C_o) arranged in parallel with the load. In illustration of an output capacitor (C_o) arranged in parallel with the load can be found in fig. 1. The load of the system is typically a battery or a resistive load. However, the system can also be connected to a cascaded DC-DC converter connected to a load.

The present disclosure further relates to a method for controlling a capacitive power transfer system comprising:

- a DC power source providing an input DC supply voltage;
- an inverter configured to convert the supply voltage into an AC power;
- a capacitive coupler comprising two pairs of coupled plates for transferring the AC power wirelessly;
- an LCL compensation topology arranged between the inverter and the capacitive coupler;
- a rectifier configured to convert the wirelessly transferred AC power into a DC output, said DC output connectable to a load;

said method comprising the steps of:

- configuring the inverter to operate at a constant current mode frequency, wherein a constant current is provided to the load; and
- configuring the inverter to operate at a constant voltage mode frequency, wherein a constant voltage is provided to the load.

As stated above, the LCL compensation topology may comprise a first inductor (L_{s1}), a second inductor (L_{s2}) and a first capacitor (C_p). According to one embodiment, the method may comprise the steps of:

- configuring the control unit to control the DC power source and/or the inverter to maintain a constant current mode frequency (f_{cc}) equal to a resonant frequency between the first inductor (L_{s1}) and the first capacitor (C_p); and
- 5 - configuring the control unit to control the DC power source and/or the inverter to maintain a constant voltage mode frequency (f_{cv}).

The method may further comprise the step of configuring the control unit to any configuration described in the present disclosure. A person skilled in the art will also
10 recognize that the method may be performed using any embodiment of the presently disclosed capacitive power transfer system.

The invention further relates to a computer program having instructions which when executed by a computing device or computing system cause the computing device or
15 system to carry out any embodiment of the presently disclosed method for controlling a capacitive power transfer system. Computer program in this context shall be construed broadly and include, for example, programs to be run as part of a power transfer system or any embedded system.

Detailed description of drawings

20 The invention will in the following be described in greater detail with reference to the accompanying drawings. The drawings are exemplary and are intended to illustrate some of the features of the presently disclosed capacitive power transfer system and method for controlling a capacitive power transfer system, and are not to be construed as limiting to the presently disclosed invention.

25

Fig. 1 shows an embodiment of the presently disclosed capacitive power transfer system (100). The capacitive power transfer system (100) comprises a DC power source (110) providing an input DC supply voltage and an inverter (120) configured to convert the DC supply voltage into an AC voltage. In the example, the inverter (120) is
30 implemented as a full-bridge inverter comprising four power switches (121).

Alternatively, the inverter (120) may be implemented as any other suitable inverter, including, but not limited to, a half-bridge inverter and a Class-E inverter. The capacitive power transfer system (100) further comprises a capacitive coupler (130) configured to transfer the AC power wirelessly. In the example, the capacitive coupler
35 (130) is implemented as two pairs of coupled plates (C_{p1} and C_{p2}). The capacitive

power transfer system (100) further comprises an LCL compensation topology (140) arranged between the inverter (120) and the capacitive coupler (130). On the receiving side, there is a rectifier (150) configured to convert the wirelessly transferred AC power into a DC output. In the example, the rectifier (150) is a full-bridge diode rectifier comprising four diodes (151). Alternatively, the rectifier (150) may be implemented as any other suitable passive or active rectifier. The DC output is connected to a load (170), which has an output capacitor (C_o) arranged in parallel. The capacitive power transfer system (100) further comprises a control unit (170) configured to control the DC power source (110) and/or the inverter (120) to operate the capacitive power transfer system in a constant current mode and in a constant voltage mode.

Fig. 2A shows a simulation of an embodiment of the presently disclosed capacitive power transfer system in the constant current mode. As an example of constant current operation, the current output curve (210), using 10 ohm load, is illustrated. The example simulation is obtained using the following parameters: $L_{s1} = 600$ nH, $C = 422$ pF, $L_{s2} = 1.23$ uH, $C_r = 150$ pF, $f_{cc} = 10$ MHz, $f_{cv} = 15$ MHz.

Fig. 2B shows a simulation of an embodiment of the presently disclosed capacitive power transfer system in the constant voltage mode. As an example of constant voltage operation, the voltage output curves (220), using 5/10/50 ohm load, is illustrated. The example simulation is obtained using the following parameters: $L_{s1} = 600$ nH, $C = 422$ pF, $L_{s2} = 1.23$ uH, $C_r = 150$ pF, $f_{cc} = 10$ MHz, $f_{cv} = 15$ MHz.

Fig. 3A shows an equivalent of an embodiment of the presently disclosed capacitive power transfer system (100) operating in the constant current mode. In the constant current mode, the LCL compensation topology (140) is unchanged, whereas the two pairs of coupled plates (C_{p1} and C_{p2}) are modeled as one capacitor C_r . Fig. 3B shows an equivalent of an embodiment of the presently disclosed capacitive power transfer (100) system operating in the constant voltage mode. In the constant current mode, the first capacitor (C_p) is modeled as two parallel capacitors (C_{pa} and C_{pb}).

Fig. 4 shows an embodiment of the presently disclosed method (300) for controlling a capacitive power transfer system (100). The capacitive power transfer system (100) may be any capacitive power transfer system described in the present disclosure. The method comprises the steps of:

- Providing a capacitive power transfer system according to any embodiment of the present disclosure (optional step); (310)
- configuring the inverter to operate at a constant current mode frequency, wherein a constant current is provided to the load; (320) and
- 5 - configuring the inverter to operate at a constant voltage mode frequency, wherein a constant voltage is provided to the load (330).

Fig. 5 shows a typical charging profile of a battery. During a first period of time, the current is constant. During a second period of time, the voltage is constant. One
10 embodiment of the presently disclosed capacitive power transfer system (100) is configured for delivering the constant current and constant voltage in a charging process according the charging profile shown in fig. 5.

Further details

1. A capacitive power transfer system comprising:
 - 15 - a DC power source providing an input DC supply voltage;
 - an inverter configured to convert the DC supply voltage into an AC power;
 - a capacitive coupler configured to transfer the AC power wirelessly;
 - an LCL compensation topology arranged between the inverter and the capacitive coupler;
 - 20 - a rectifier configured to convert the wirelessly transferred AC power into a DC output, said DC output connectable to a load; and
 - a control unit configured to control the DC power source and/or the inverter such that the capacitive power transfer system:
 - 25 ○ in a constant current mode, operates at a constant current mode frequency (f_{cc}), wherein a constant current is provided to the load; and
 - in a constant voltage mode, operates at a constant voltage mode frequency (f_{cv}), wherein a constant voltage is provided to the load.
- 30 2. The capacitive power transfer system according to item 1, wherein the LCL compensation topology comprises a first inductor (L_{s1}), a second inductor (L_{s2}) and a first capacitor (C_p).
- 35 3. The capacitive power transfer system according to item 2, wherein the control unit is configured to control the DC power source and/or the inverter to maintain

a constant current mode frequency (f_{cc}) equal to a resonant frequency between the first inductor (L_{s1}) and the first capacitor (C_p).

4. The capacitive power transfer system according to item 3, wherein the constant
5 current mode frequency (f_{cc}) is calculated as $f_{cc} = \frac{1}{2\pi\sqrt{L_{s1}C_p}}$.

5. The capacitive power transfer system according to any one of items 2-4,
wherein the first capacitor (C_p) is electrically equivalent to two parallel
capacitors (C_{pa} and C_{pb}).

10

6. The capacitive power transfer system according to item 5, wherein the control
unit is configured to control the DC power source and/or the inverter to maintain
a constant voltage mode frequency (f_{cv}) that equals to $f_{cv} = \frac{1}{2\pi\sqrt{L_{s1}C_{pa}}} =$

$\frac{1}{2\pi\sqrt{L_{s2}C_{es}}}$ wherein C_{es} denotes a series equivalence of the two parallel

15

capacitors (C_{pa} and C_{pb}), wherein $C_{es} = \frac{C_{pb}C_r}{C_{pb} + C_r}$

7. The capacitive power transfer system according to any one of the preceding
items, wherein the control unit controls the AC power from the inverter by
phase-shift control or by controlling the DC supply voltage from the DC power
source.

20

8. The capacitive power transfer system according to any one of the preceding
items, wherein the inverter is a full-bridge inverter, a half-bridge inverter or a
Class-E inverter.

25

9. The capacitive power transfer system according to any one of the preceding
items, wherein the capacitive coupler comprises two pairs of coupled plates
(C_{p1} and C_{p2}).

30

10. The capacitive power transfer system according to any one of the preceding
items, wherein the rectifier is a full-bridge rectifier.

11. The capacitive power transfer system according to any one of the preceding
items, wherein the rectifier further comprises a smoothing circuit.

12. The capacitive power transfer system according to any one of the preceding items, further comprising an output capacitor (C_o) arranged in parallel with the load.
- 5 13. The capacitive power transfer system according to any one of the preceding items, wherein the inverter is configured to convert the DC supply voltage to the AC power having a substantially rectangular waveform having a frequency equal to a switching frequency of the inverter.
- 10 14. The capacitive power transfer system according to any one of the preceding items, wherein the inverter is configured to convert the DC supply voltage to a symmetric AC voltage.
- 15 15. The capacitive power transfer system according to any one of the preceding items, wherein the constant current in the constant current mode and the constant voltage in the constant voltage mode are load independent.
- 20 16. The capacitive power transfer system according to any one of the preceding items, said capacitive power transfer system being configured to operate without a compensation topology and/or without a DC-DC receiver on a receiving side of the capacitive power transfer system.
- 25 17. The capacitive power transfer system according to any one of the preceding items, wherein in the LCL topology is configured to resonate with the capacitive coupler.
- 30 18. A method for controlling a capacitive power transfer system comprising:
- a DC power source providing an input DC supply voltage;
 - an inverter configured to convert the supply voltage into an AC power;
 - a capacitive coupler comprising two pairs of coupled plates for transferring the AC power wirelessly;
 - an LCL compensation topology arranged between the inverter and the capacitive coupler;
 - a rectifier configured to convert the wirelessly transferred AC power into a
- 35 DC output, said DC output connectable to a load;
- said method comprising the steps of:

- configuring the inverter to operate at a constant current mode frequency, wherein a constant current is provided to the load; and
- configuring the inverter to operate at a constant voltage mode frequency, wherein a constant voltage is provided to the load.

5

19. The method for controlling a capacitive power transfer system according to item 18, wherein the LCL compensation topology comprises a first inductor (L_{s1}), a second inductor (L_{s2}) and a first capacitor (C_p), said method further comprising the steps of:

10

- configuring the control unit to control the DC power source and/or the inverter to maintain a constant current mode frequency (f_{cc}) equal to a resonant frequency between the first inductor (L_{s1}) and the first capacitor (C_p); and

15

- configuring the control unit to control the DC power source and/or the inverter to maintain a constant voltage mode frequency (f_{cv}).

20. The method for controlling a capacitive power transfer system according to any one of items 18-19, wherein the capacitive power transfer system is the capacitive power transfer system according to any one of items 1-17.

20

21. A computer program having instructions which, when executed by a computing device or computing system, cause the computing device or computing system to carry out the method for controlling a capacitive power transfer system according to any one of items 18-20.

Claims

1. A capacitive power transfer system comprising:
 - a DC power source providing an input DC supply voltage;
 - 5 - an inverter configured to convert the DC supply voltage into an AC power;
 - a capacitive coupler configured to transfer the AC power wirelessly;
 - an LCL compensation topology comprising a first inductor (L_{s1}), a second inductor (L_{s2}) and a first capacitor (C_p), the LCL compensation topology arranged between the inverter and the capacitive coupler;
 - 10 - a rectifier configured to convert the wirelessly transferred AC power into a DC output, said DC output connectable to a load; and
 - a control unit configured to control the DC power source and/or the inverter such that the capacitive power transfer system:
 - 15 ○ in a constant current mode, operates at a constant current mode frequency (f_{cc}), wherein a constant current is provided to the load; and
 - in a constant voltage mode, operates at a constant voltage mode frequency (f_{cv}), wherein a constant voltage is provided to the load.
- 20 2. The capacitive power transfer system according to claim 1, wherein the control unit is configured to control the DC power source and/or the inverter to maintain a constant current mode frequency (f_{cc}) equal to a resonant frequency between the first inductor (L_{s1}) and the first capacitor (C_p).
- 25 3. The capacitive power transfer system according to claim 2, wherein the constant current mode frequency (f_{cc}) is calculated as $f_{cc} = \frac{1}{2\pi\sqrt{L_{s1}C_p}}$.
4. The capacitive power transfer system according to any one of claims 1-3, wherein the first capacitor (C_p) is electrically equivalent to two parallel
 - 30 capacitors (C_{pa} and C_{pb}).
5. The capacitive power transfer system according to claim 4, wherein the control unit is configured to control the DC power source and/or the inverter to maintain a constant voltage mode frequency (f_{cv}) that equals to $f_{cv} = \frac{1}{2\pi\sqrt{L_{s1}C_{pa}}} =$

$\frac{1}{2\pi\sqrt{L_{S2}C_{es}}}$ wherein C_{es} denotes a series equivalence of the two parallel

capacitors (C_{pa} and C_{pb}), wherein $C_{es} = \frac{C_{pb}C_r}{C_{pb} + C_r}$

- 5 6. The capacitive power transfer system according to any one of the preceding claims, wherein the control unit controls the AC power from the inverter by phase-shift control or by controlling the DC supply voltage from the DC power source.
- 10 7. The capacitive power transfer system according to any one of the preceding claims, wherein the capacitive coupler comprises two pairs of coupled plates (C_{p1} and C_{p2}).
- 15 8. The capacitive power transfer system according to any one of the preceding claims, wherein the inverter is configured to convert the DC supply voltage to the AC power having a substantially rectangular waveform having a frequency equal to a switching frequency of the inverter.
- 20 9. The capacitive power transfer system according to any one of the preceding claims, wherein the constant current in the constant current mode and the constant voltage in the constant voltage mode are load independent.
- 25 10. The capacitive power transfer system according to any one of the preceding claims, wherein the inverter and the LCL compensation topology constitute a transmitting side, wherein the rectifier constitutes a receiving side, and wherein said capacitive power transfer system is configured to operate without a compensation topology and/or without DC-DC conversion on the receiving side.
- 30 11. The capacitive power transfer system according to any one of the preceding claims, wherein the LCL compensation topology is a single LCL compensation topology on a transmitting side of the capacitive power transfer system.
- 35 12. The capacitive power transfer system according to any one of the preceding claims, wherein in the LCL topology is configured to resonate with the capacitive coupler.

13. A method for controlling a capacitive power transfer system comprising:
- a DC power source providing an input DC supply voltage;
 - an inverter configured to convert the supply voltage into an AC power;
 - a capacitive coupler comprising two pairs of coupled plates for transferring the AC power wirelessly;
 - an LCL compensation topology arranged between the inverter and the capacitive coupler;
 - a rectifier configured to convert the wirelessly transferred AC power into a DC output, said DC output connectable to a load;

5

10

said method comprising the steps of:

- configuring the inverter to operate at a constant current mode frequency, wherein a constant current is provided to the load; and
- configuring the inverter to operate at a constant voltage mode frequency, wherein a constant voltage is provided to the load.

15

14. The method for controlling a capacitive power transfer system according to claim 13, wherein the LCL compensation topology comprises a first inductor (L_{s1}), a second inductor (L_{s2}) and a first capacitor (C_p), said method further comprising the steps of:

20

- configuring the control unit to control the DC power source and/or the inverter to maintain a constant current mode frequency (f_{cc}) equal to a resonant frequency between the first inductor (L_{s1}) and the first capacitor (C_p); and

25

- configuring the control unit to control the DC power source and/or the inverter to maintain a constant voltage mode frequency (f_{cv}).

15. A computer program having instructions which, when executed by a computing device or computing system, cause the computing device or computing system to carry out the method for controlling a capacitive power transfer system according to any one of claims 13-14.

30

35

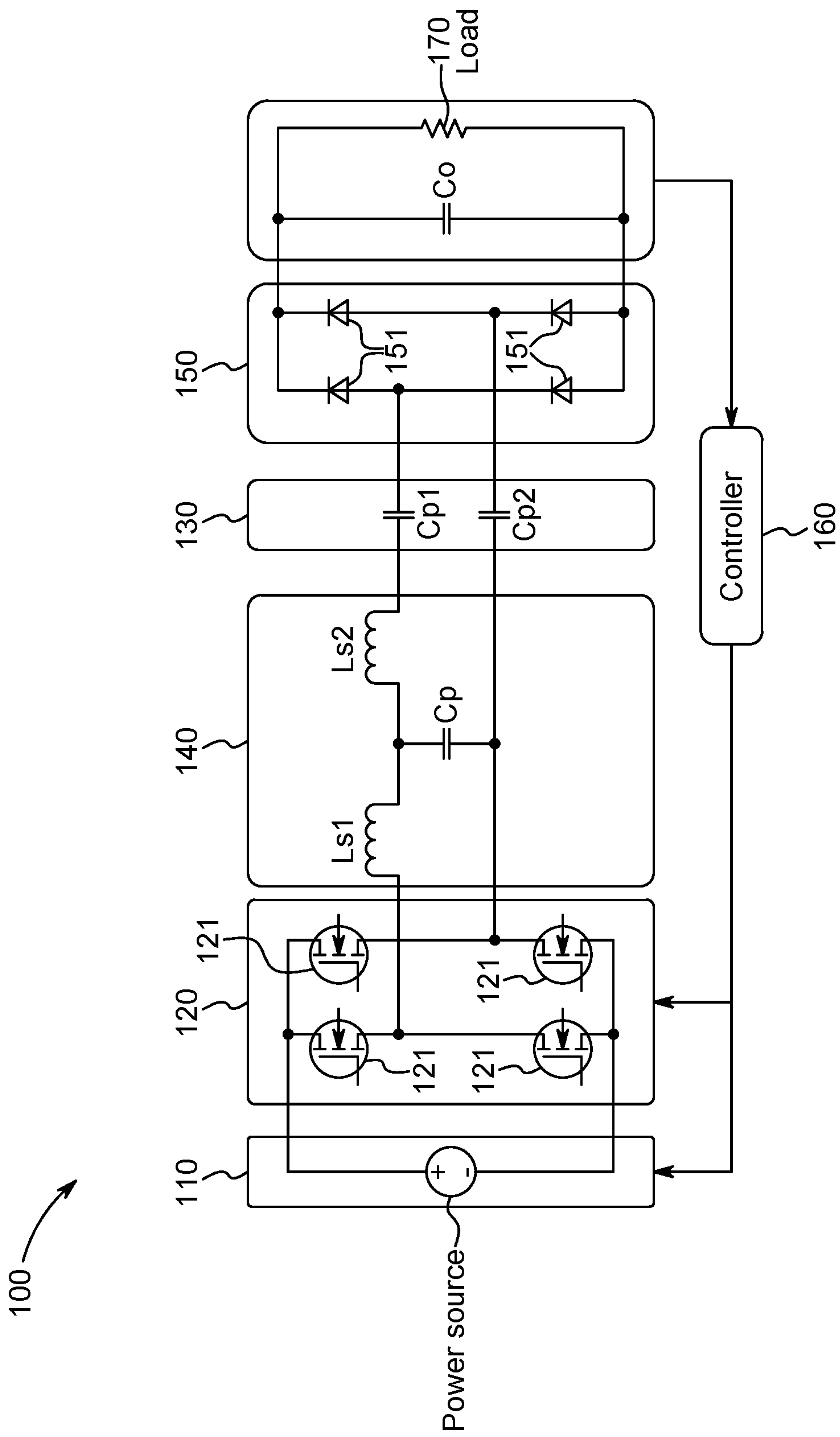


FIG. 1

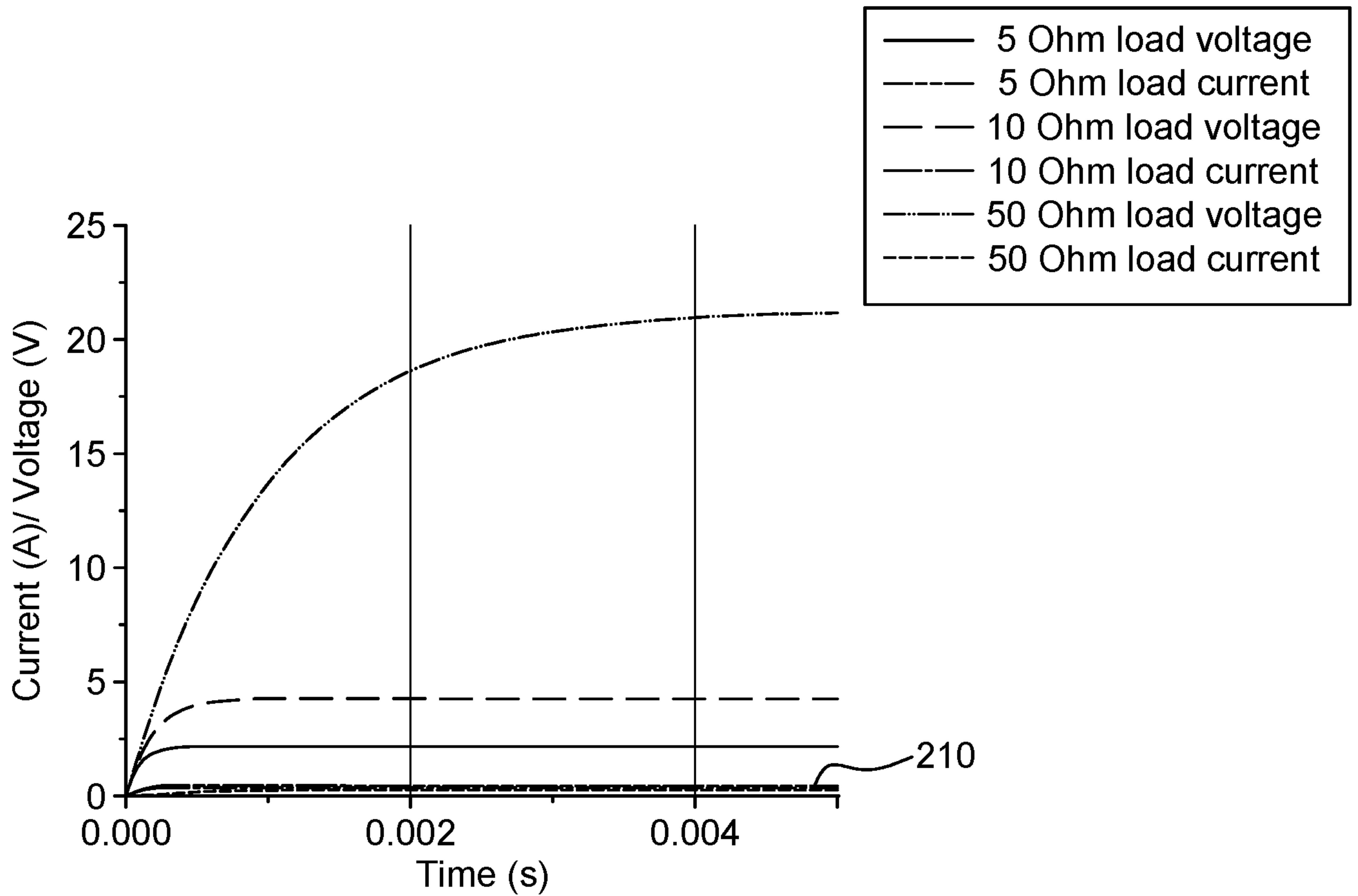


FIG. 2A

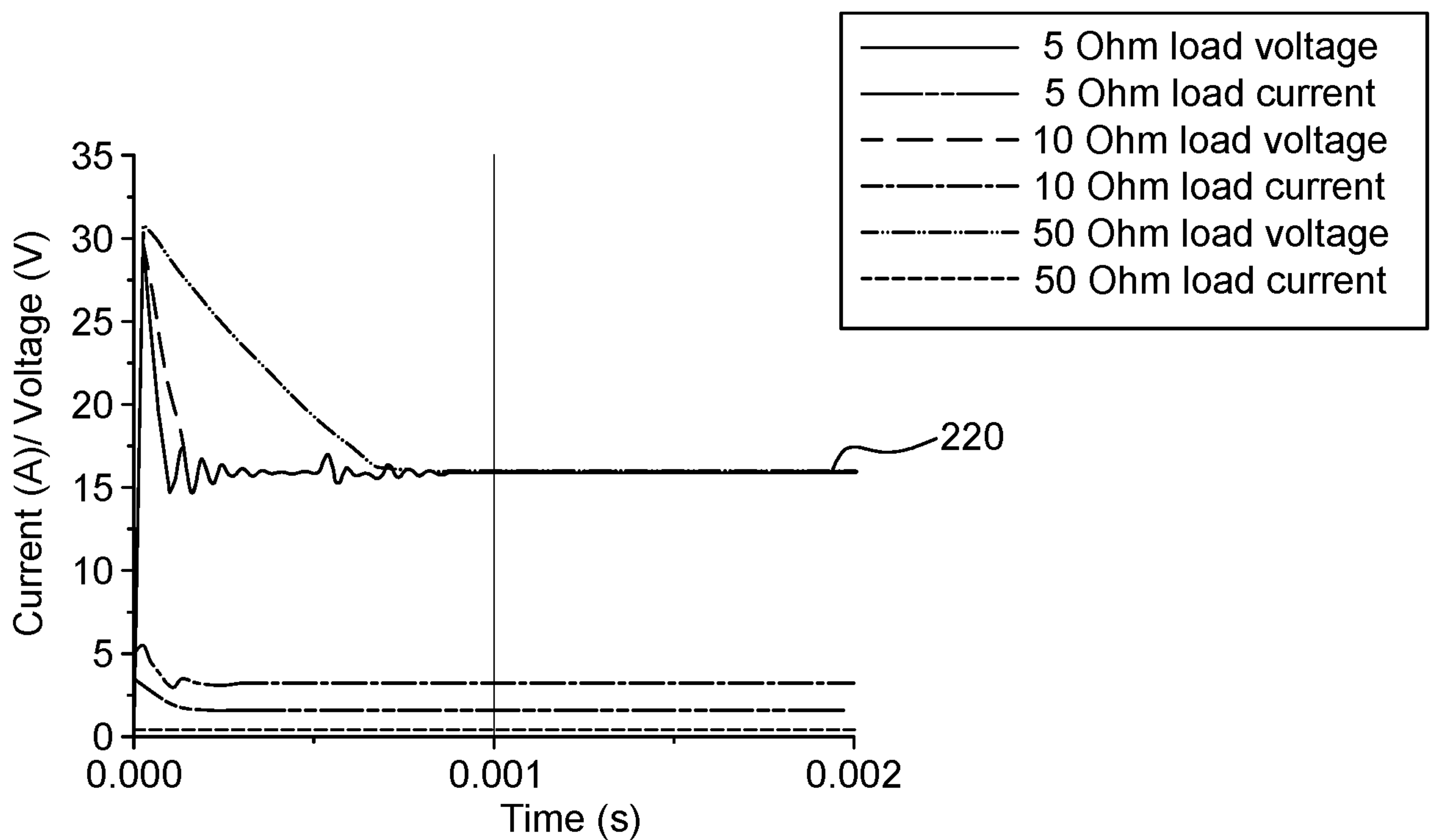


FIG. 2B

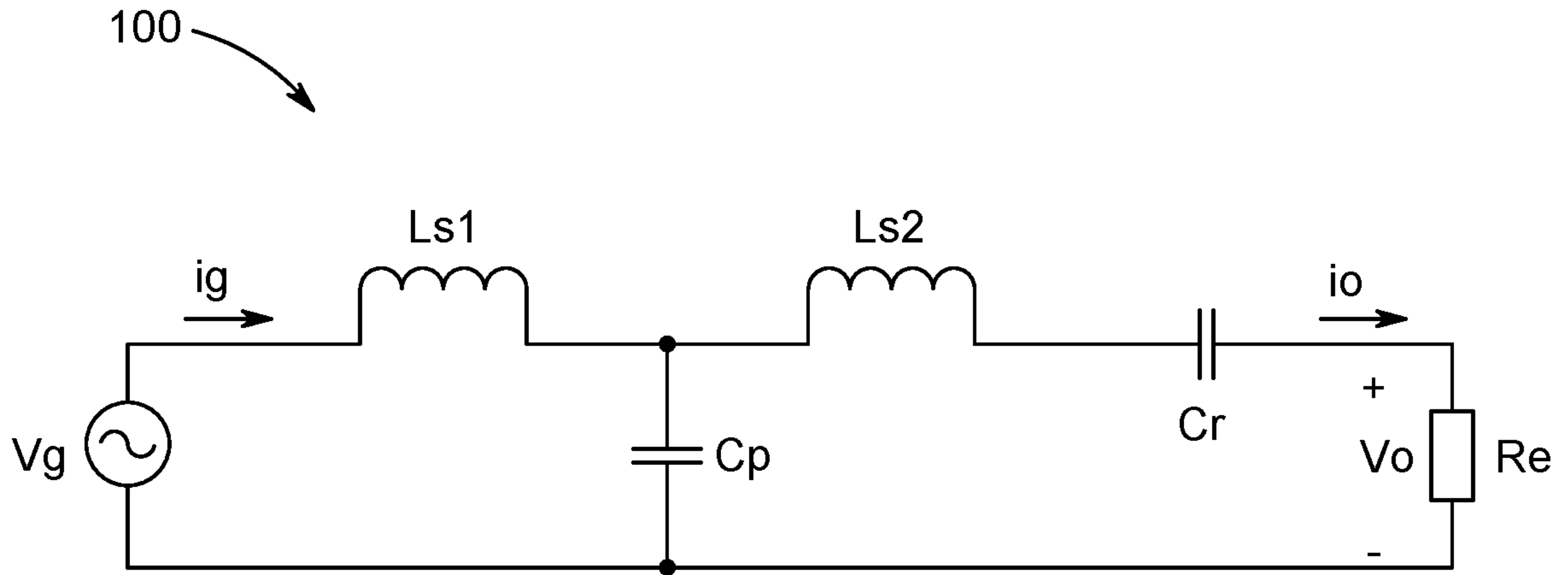


FIG. 3A

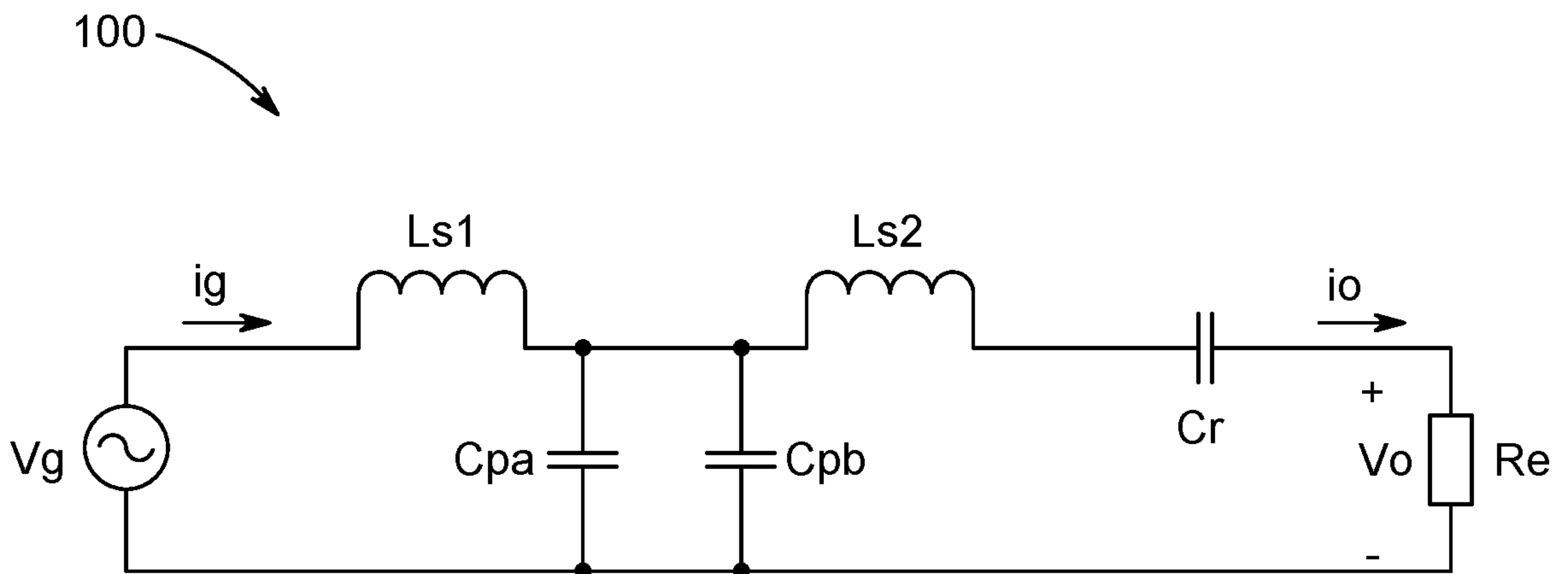


FIG. 3B

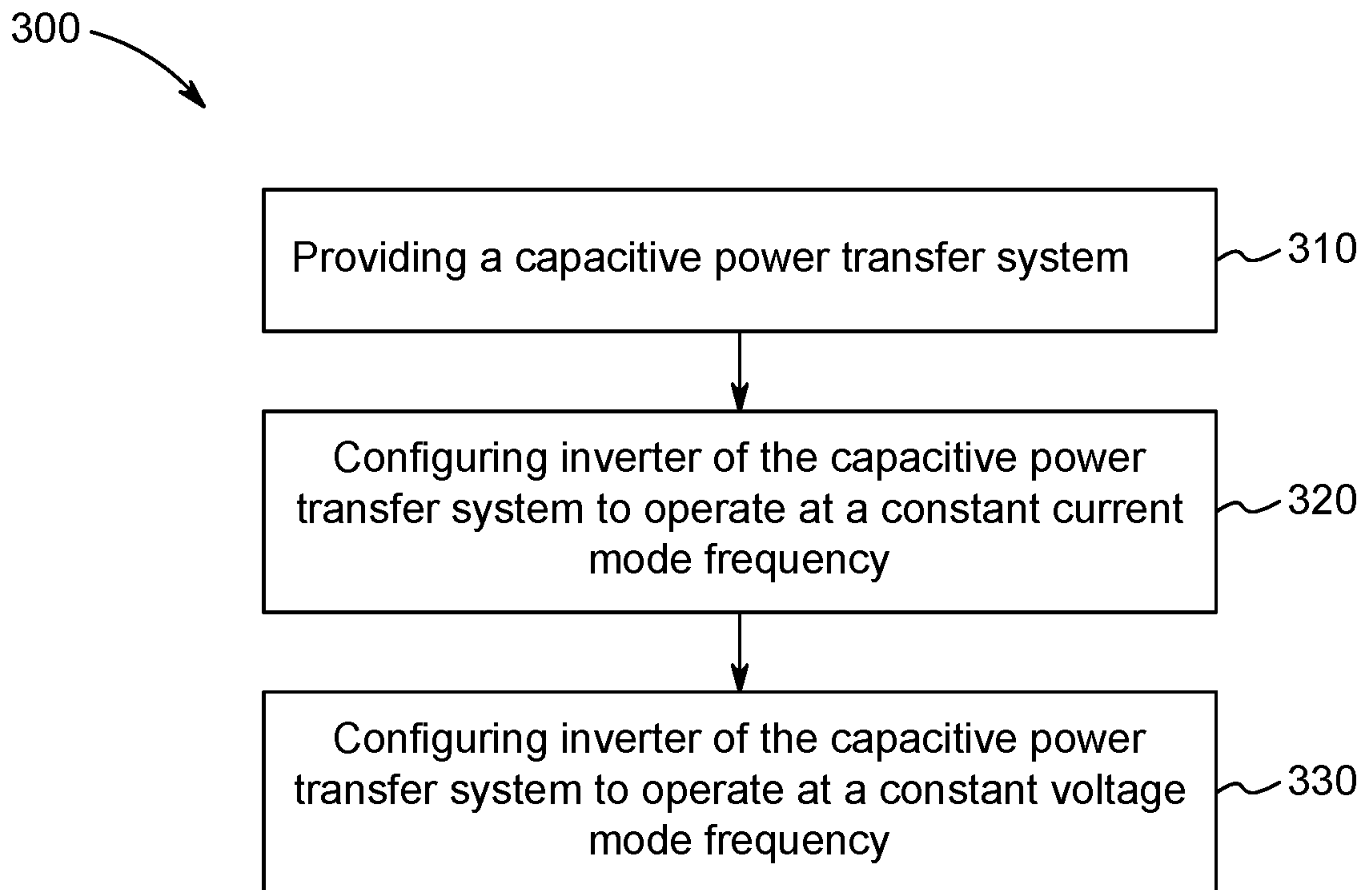


FIG. 4

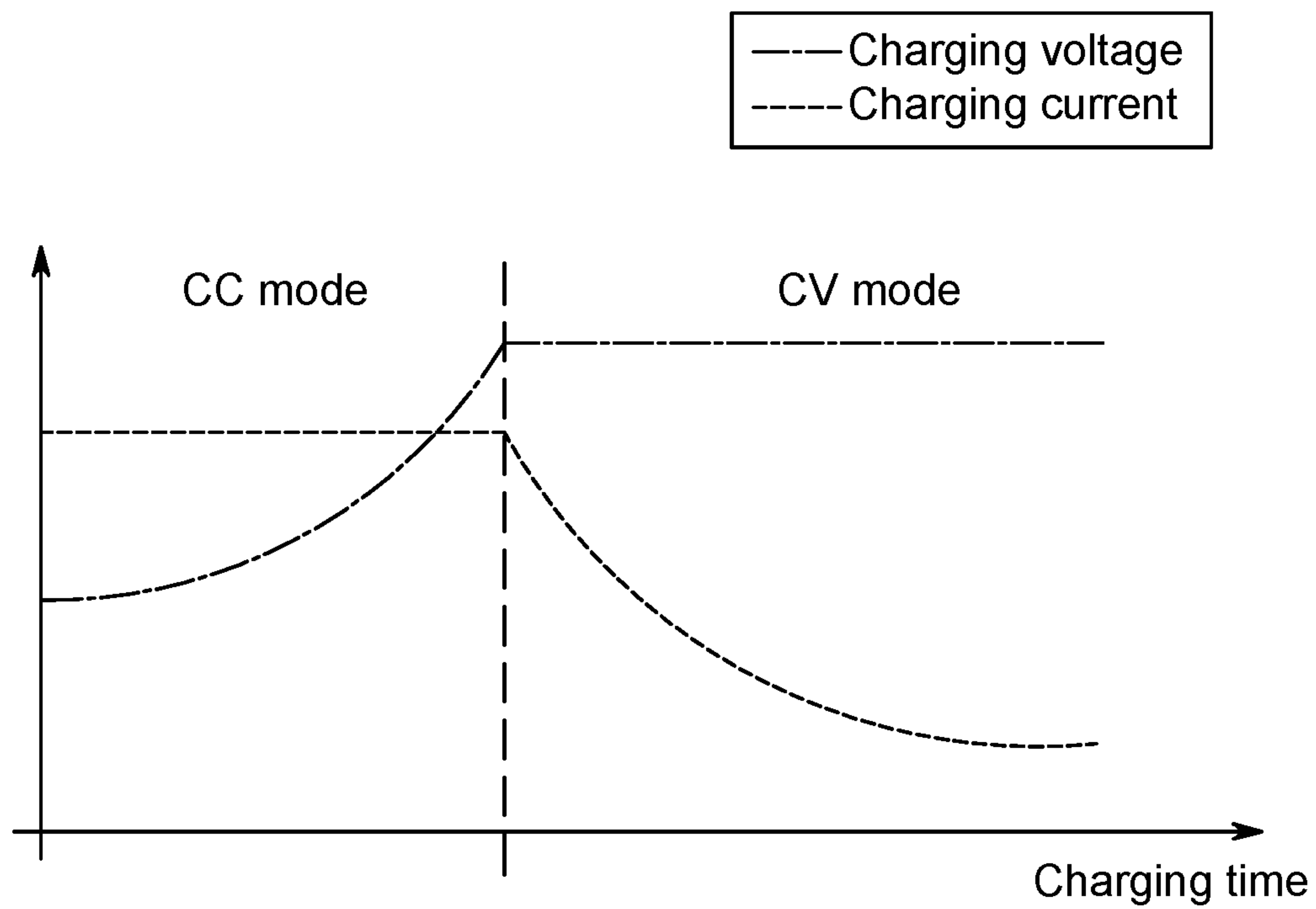


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No PCT/EP2021/050471

A. CLASSIFICATION OF SUBJECT MATTER INV. H02J50/05 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) H02J		
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		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/285467 A1 (TAKAHASHI HIRONOBU [JP]) 31 October 2013 (2013-10-31)	1-15
Y	paragraphs [0042], [0044]; figures 1-2 -----	2,3,14
Y	CN 106 787 253 A (UNIV CHONGQING) 31 May 2017 (2017-05-31) figure 1 -----	2,3,14
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed		"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family
Date of the actual completion of the international search 23 February 2021		Date of mailing of the international search report 03/03/2021
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 Bourdon, Jérémy

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2021/050471

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
US 2013285467	A1	31-10-2013	CN 103403997 A	20-11-2013
			JP 5516824 B2	11-06-2014
			JP W02013125090 A1	30-07-2015
			US 2013285467 A1	31-10-2013
			WO 2013125090 A1	29-08-2013

CN 106787253	A	31-05-2017	NONE	
