

SPECIFICATION

TITLE OF INVENTION:

STATIONARY ELECTROMAGNETIC DEVICE AND BI-DIRECTIONAL DC-DC
5 CONVERTER USING STATIONARY ELECTROMAGNETIC DEVICE

TECHNICAL FIELD

[0001]

The present invention relates to a stationary
10 electromagnetic device, and more particularly, to a technique
for adjusting leakage inductance using a winding structure of a
high-frequency transformer used in switching power supplies,
power converters, and the like.

15 BACKGROUND ART

[0002]

In recent years, the number of power transmission and
distribution devices handling direct-current power, such as
solar power generation systems, systems for charging and
20 discharging emergency batteries during power outages, and
systems for charging electric vehicles, has been increasing.
There has been an increasing demand for a direct current
converter (DC-DC converter) in which an inverter circuit
converts an input direct-current voltage into an alternating-
25 current voltage, a high-frequency transformer transforms the

alternating-current voltage, and a rectifier circuit converts the transformed alternating-current voltage into a direct-current voltage and outputs the direct-current voltage. Depending on the purpose of the DC-DC converter, a function of
5 controlling the operation timing of switching elements constituting the inverter and the rectifier circuit to transmit direct-current power in both directions is required. In addition, since switching loss occurring in the switching element is one of the causes of reduced conversion efficiency
10 of the DC-DC converter, it is necessary to achieve a zero-voltage switching or zero-current switching operation using a resonance phenomenon of an inductor component L and a capacitor component C in the circuit and to reduce the switching loss.

[0003]

15 It is necessary to provide the inductor component L with an appropriate value in series to the high-frequency transformer in order to provide the above-mentioned bidirectional direct-current power control function and the zero-voltage switching or zero-current switching function which are necessary to
20 improve the performance of the DC-DC converter (for example, see Patent Document 1). In addition to a method in which the inductor component L is provided in a reactor device or the like separately from the high-frequency transformer, a method in which the leakage inductance L_s is provided in the high-
25 frequency transformer by devising a winding structure of the

high-frequency transformer is generally used. Compared to the former method, the latter method can reduce the number of parts and the cost.

[0004]

5 In this regard, a technique related to a winding structure of a high-frequency transformer having a desired leakage inductance L_s is disclosed. For example, Patent Document 2 discloses a configuration of a transformer (stationary electromagnetic device) including a primary winding portion that
10 is disposed on one magnetic leg portion of a single-phase core portion, at least one first secondary winding portion that is on the same magnetic leg as a magnetic leg, on which the primary winding portion is disposed, and is magnetically closely coupled to the primary winding portion, and at least one second secondary
15 winding portion that is on the other magnetic leg portion of the core and is magnetically loosely coupled to the primary winding portion. Furthermore, Patent Document 3 discloses a configuration of a high-frequency magnetic leakage transformer in which a primary winding and a secondary winding are disposed
20 around a core with a required gap therebetween and a ferrite powder molded plate with low magnetic permeability is interposed as a path core between the two windings to obtain an appropriate value of a leakage inductance L_s .

25 CITATION LIST

PATENT LITERATURE

[0005]

Patent Document 1: JP 2019-103257 A

Patent Document 2: JP 2013-98189 A

5 Patent Document 3: JP 2004-39847 A

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0006]

10 The stationary electromagnetic device disclosed in Patent Document 2 is a technique in which the first secondary winding is provided on the same magnetic leg as the primary winding and the second secondary winding is provided on a different magnetic leg to separate a magnetically close portion from a magnetically

15 loose portion, thereby controlling the value L_s of the leakage inductance of the stationary electromagnetic device. However, since the primary winding is provided on only one magnetic leg in this configuration, the range of the possible value of L_s is narrow as in the configuration according to the related art. In

20 addition, in the high-frequency magnetic leakage transformer disclosed in Patent Document 3, the range of the possible value of L_s is wider than that in the configuration according to the related art, however, additional material costs are required as compared to the related art, since a magnetic material with

25 low magnetic permeability is combined with the core portion.

[0007]

The present invention has been made in view of the above background, and an object of the present invention is to provide a stationary electromagnetic device in which a wide range of leakage inductance L_s can be set.

Another object of the present invention is to provide a static electromagnetic machine suitable for use in a bidirectional DC-DC converter.

10 SOLUTIONS TO PROBLEM

[0008]

Representative features of the invention disclosed in this application are described as follows.

According to one feature of the present invention, there is provided a stationary electromagnetic device in which first and second primary windings and first and second secondary windings are wound around two magnetic leg portions of a single-phase core obtained by molding a magnetic material in an annular shape, the primary windings are connected in series, and the secondary windings are connected in series. The first primary winding and the first secondary winding are wound around the first magnetic leg portion so as to overlap each other while maintaining a constant gap therebetween, and the second primary winding and the second secondary winding are wound around the second magnetic leg portion side by side in a vertical direction

while maintaining a constant gap therebetween. In the first magnetic leg portion around which the first primary winding and the first secondary winding are wound so as to overlap each other, the first primary winding on a high voltage side is disposed on an outer peripheral side, and the first secondary winding on a low voltage side is disposed on an inner peripheral side. Each of the primary winding and the secondary winding includes a wire that is wound a plurality of times, and these wires are sealed in a cylindrical shape with a first insulating material and a second insulating material.

[0009]

According to another feature of the present invention, the wires constituting the primary winding and the secondary winding wound around the magnetic leg portion have structures in which the wires are aligned parallel to an axial direction of the magnetic leg and are sealed with the insulating materials, and a spacer made of a non-conductor is provided in a gap portion between the structures to maintain a constant gap. In addition, the wires constituting the first primary winding and the first secondary winding that are wound around the first magnetic leg portion so as to overlap each other may be aligned at a constant angle with respect to the axial direction of the magnetic leg. The insulating materials, such as resins, that seal the wires may be configured to have a tapered structure, and a spacer may be provided in a gap portion between the insulating materials

to maintain a constant gap.

[0010]

According to still another feature of the present invention, there is provided a bidirectional DC-DC converter including the above-described stationary electromagnetic device, a first inverter circuit connected to the primary winding of the stationary electromagnetic device, and an inverter circuit connected to the secondary winding. When the first inverter circuit converts an input direct-current voltage to an alternating-current voltage, control is performed such that the second inverter circuit converts an alternating-current voltage converted by the stationary electromagnetic device into a direct-current voltage and outputs the direct-current voltage to a secondary side to perform forward DC-DC conversion from a primary side to the secondary side. When a secondary-side direct-current voltage input to the second inverter circuit is converted into an alternating-current voltage and a direct-current voltage is output to the primary side, control is performed such that the first inverter circuit converts an alternating-current voltage converted by the stationary electromagnetic device into the direct-current voltage to perform reverse DC-DC conversion from the secondary side to the primary side.

ADVANTAGEOUS EFFECTS OF INVENTION

[0011]

According to the configuration of the present invention, for the stationary electromagnetic device (high-frequency transformer) in the DC-DC converter used for various purposes, it is possible to provide a wide range of leakage inductance L_s in the high-frequency transformer, without applying a special structure or method. In addition, since the volume of the high-frequency transformer is reduced compared to the structure according to the related art, the effect of reducing the size and cost is obtained. Further, it is possible to achieve a stationary electromagnetic device having a high-frequency transformer suitable for a bidirectional control function for direct-current power, therefore, it is possible to achieve a stationary electromagnetic device that has excellent overall conversion efficiency and reduces power loss to promote energy saving and a bidirectional DC-DC converter using the stationary electromagnetic device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012]

Fig. 1 is a vertical cross-sectional view illustrating a stationary electromagnetic device 1 according to a first embodiment of the present invention.

Fig. 2 is a top view illustrating the stationary electromagnetic device 1 according to the first embodiment of

the present invention.

Fig. 3 is a vertical cross-sectional view illustrating an internal structure of windings of the stationary electromagnetic device 1 according to the first embodiment of the present invention.

Fig. 4 is a graph illustrating a correlation between the volume and leakage inductance of the stationary electromagnetic device 1 in the first embodiment of the present invention and in a conventional example.

Fig. 5 is a vertical cross-sectional view illustrating an internal structure of windings of a stationary electromagnetic device 1A according to a second embodiment of the present invention.

Fig. 6 is a vertical cross-sectional view illustrating a stationary electromagnetic device 1B according to a modification example in which the structure of the windings illustrated in Fig. 5 is changed.

Fig. 7 is a schematic diagram illustrating a method for assembling the stationary electromagnetic device 1A according to the second embodiment of the present invention.

Fig. 8 is a schematic diagram illustrating a method for assembling a stationary electromagnetic device 1C according to a modification example of the assembly method illustrated in Fig. 7.

Fig. 9 is a vertical cross-sectional view illustrating a

stationary electromagnetic device 1D according to a third embodiment of the present invention.

Fig. 10 is a vertical cross-sectional view illustrating a stationary electromagnetic device 1E according to a fourth
5 embodiment of the present invention.

Fig. 11 is a diagram illustrating an application example of a stationary electromagnetic device 1 according to a fifth embodiment of the present invention and is a circuit diagram illustrating a DC-DC converter obtained by combining inverter
10 circuits 60 and 70.

Fig. 12 is a vertical cross-sectional view illustrating a stationary electromagnetic device 101A according to Conventional Example 1.

Fig. 13 is a vertical cross-sectional view illustrating a
15 stationary electromagnetic device 101B according to Conventional Example 2.

DESCRIPTION OF EMBODIMENTS

[0013]

20 Hereinafter, embodiments of the present invention will be described in detail with reference to the drawings. In addition, in the following drawings, the same portions are denoted by the same reference numerals, and a repeated description thereof will be omitted. Further, in the present specification, front-back,
25 left-right, and up-down directions are described as directions

illustrated in the drawings.

[Embodiment 1]

[0014]

The configuration and effects of a first embodiment of the present invention will be described with reference to Figs. 1 to 4. Before the description of the first embodiment, configurations of stationary electromagnetic devices 101A and 101B according to the related art will be described with reference to Figs. 12 and 13. Fig. 12 is a vertical cross-sectional view illustrating the stationary electromagnetic device according to the related art in a vertical plane. Here, the vertical plane is a plane that passes through central axis lines A1 and B1 of two magnetic leg portions of a first magnetic leg portion 2a and a second magnetic leg portion 2b. In Fig. 12, the stationary electromagnetic device 101A has a single-phase core 2 that is molded in an annular shape, and the two magnetic leg portions 2a and 2b are formed in the single-phase core 2. A primary winding 11 and a secondary winding 21 are wound around the outer periphery of the magnetic leg portion 2a in an overlapping manner. In addition, a primary winding 12 and a secondary winding 22 are wound around the magnetic leg portion 2b so as to overlap each other. In the present specification, a method that winds the primary winding and the secondary winding on the closer (inner) and farther (outer) sides of a magnetic leg portion, such as the magnetic leg portion 2a, such that the

primary winding and the secondary winding entirely or partially overlap each other when viewed in a radial direction from the central axis line of the magnetic leg portion is referred to as "lap winding". In the "lap winding", in general, the primary windings 11 and 12 through which a high-voltage current flows are wound on the outer side further away from the magnetic leg portions 2a and 2b, and the secondary windings 21 and 22 through which a low-voltage current flows are wound on the inner side closer to the magnetic leg portions 2a and 2b. The primary windings 11 and 12 are connected by a connection means 11a, and end portions of the primary windings are connected to electrodes 14a and 14b. Similarly, the secondary windings 21 and 22 are connected by a connection means 21a, and end portions of the secondary windings are connected to electrodes 24a and 24b. A constant gap length d is provided between the primary winding 11 and the secondary winding 21 and between the primary winding 12 and the secondary winding 22 in the radial direction. The gap length d is set to be constant in the directions of the central axis lines A1 and B1 of the magnetic leg portions 2a and 2b. As described above, in the stationary electromagnetic device 101A according to the related art, a desired leakage inductance L_s is provided between the primary winding and the secondary winding by the magnitude of the gap length d .

[0015]

Fig. 13 illustrates a stationary electromagnetic device

101B according to another conventional example. The stationary electromagnetic device 101B has a single-phase core 2 that is molded in an annular shape. A primary winding 11 and a secondary winding 21 are wound side by side around a magnetic leg portion 5 2a of two magnetic leg portions 2a and 2b that are formed in the single-phase core 2 so as to have a gap (gap d) therebetween in the up-down direction, and a primary winding 12 and a secondary winding 22 are wound side by side around the magnetic leg portion 2b so as to have a gap (gap d) therebetween in the up-down 10 direction. In the present specification, a method that winds the primary winding and the secondary winding side by side on one side (here, the lower side) and the other side (here, the upper side) of one magnetic leg portion as viewed in the direction of the central axis lines A1 and B1 such that the 15 primary winding and the secondary winding are formed adjacent to each other in a non-contact state as viewed in the direction of the central axis of the magnetic leg portion as described above is referred to as "parallel winding". The primary windings 11 and 12 wound around the two magnetic leg portions 2a and 2b 20 are connected in series by the connection means 11a, and the secondary windings 21 and 22 are connected in series by the connection means 21a. The first primary winding 11 and the first secondary winding 21 are disposed so as to have a constant gap length d therebetween in the direction of the central axis 25 line of the magnetic leg portion 2a, and the second primary

winding 12 and the second secondary winding 22 are disposed so as to have a constant gap length d therebetween in the direction of the central axis line B1. The gap length d is set to be constant at any position in a circumferential direction. The primary windings 11 and 12 have electrodes 14a and 14b provided in end portions thereof, respectively, and the secondary windings 21 and 22 have electrodes 24a and 24b provided in end portions thereof, respectively.

[0016]

Next, the stationary electromagnetic device 1 according to this embodiment will be described with reference to Fig. 1. Fig. 1 is a vertical cross-sectional view illustrating the stationary electromagnetic device 1 according to the first embodiment in the vertical plane. This cross section (vertical plane) is a plane that passes through a central axis line A1 of a first magnetic leg portion 2a and a central axis line B1 of a second magnetic leg portion 2b. The stationary electromagnetic device 1 has a single-phase core 2 molded in an annular shape. The single-phase core 2 is manufactured by laminating a large number of layers of thin plate-shaped magnetic materials such as thin amorphous or nanocrystalline materials. The use of the laminated core makes it possible to reduce eddy current loss. The upper and lower division surfaces of the single-phase core 2 are not illustrated in Fig. 1. However, the single-phase core 2 may be configured as an integrated core that does not have the

division surfaces in the annular portion illustrated in Fig. 1, or may be configured as a divided type that will be described with reference to Figs. 7 and 8. In addition, the single-phase core 2 may be made of sintered (ceramic) ferrite manufactured by mixing, sintering, and molding an insulating magnetic material, such as ferrite, as a powder raw material.

[0017]

A first primary winding 11 and a first secondary winding 21 are wound around the first magnetic leg portion 2a formed in the single-phase core 2 so as to overlap each other (lap winding), and a second primary winding 12 and a second secondary winding 22 are wound around the second magnetic leg portion 2b so as to be adjacent to each other in the direction of the central axis line B1 (parallel winding). The primary windings 11 and 12 wound around the two magnetic leg portions 2a and 2b are connected in series by a connection means 11a, and electrodes 14a and 14b are provided at the other ends of each winding. Similarly, the secondary windings 21 and 22 wound around the two magnetic leg portions 2a and 2b are connected in series by a connection means 21a, and electrodes 24a and 24b are provided at the other ends (ends away from the connection means 21a) of the secondary windings 21 and 22, respectively. In the schematic view illustrated Fig. 1, the connection means 11a and the connection means 21a appear to be wired in the core 2, but in practice are wired outside the core 2. In this embodiment, the

number of turns of the first primary winding 11 can be the same as or different from the number of turns of the second primary winding 12. In addition, the number of turns of the first secondary winding 21 can be the same as or different from the number of turns of the second secondary winding 22. The connection means 11a and the connection means 21a may draw the end portions of the primary winding and the secondary winding and connect them without disconnection, or may disconnect the end portions and then reconnect the end portions. Alternatively, wiring lines for connection may be prepared. Alternatively, the end portions may be electrically connected by other methods.

[0018]

On the side of the first magnetic leg portion 2a, the first primary winding 11 and the first secondary winding 21 are disposed so as to have a constant gap d therebetween in the radial direction with respect to the central axis line A1. A constant gap is also formed between an inner peripheral surface of the first secondary winding 21 and an outer peripheral surface of the magnetic leg portion 2a. In addition, a positional relationship is established such that a constant gap is formed between the inner peripheral surface of the first secondary winding 21 and the outer peripheral surface of the first magnetic leg portion 2a. On the side of the second magnetic leg portion 2b, the primary winding 12 and the secondary winding 22 are disposed apart from each other so as to have a constant gap

therebetween in an axial direction with respect to the central axis line B1 (lap winding). That is, in the "lap winding" state according to this embodiment, a positional relationship is established such that regions in which the primary winding 12 and the secondary winding 22 are located do not overlap each other in the direction of the central axis B1 of the second magnetic leg portion 2b. On the side of the second magnetic leg portion 2b, the second secondary winding 22 and the second primary winding 12 are disposed so as to have a constant gap d therebetween in the direction of the central axis line B1. The gap length d is set to be constant at any positions on an upper surface of the primary winding 12 and a lower surface of the secondary winding 22. In addition, a constant gap is also formed between an inner peripheral surface of the second secondary winding 22 and an outer peripheral surface of the magnetic leg portion 2b and between an inner peripheral surface of the second primary winding 12 and the outer peripheral surface of the magnetic leg portion 2b.

[0019]

In general, a transformer for an AC power supply is configured such that leakage inductance L_s is as small as possible. Therefore, it is preferable that the gap d between the primary winding 11 and the secondary winding 21 and the gap between the secondary winding 21 and the first magnetic leg portion 2a are as small as possible. The reason is that, in a

transformer for AC or the stationary electromagnetic device 1 according to this embodiment, one-way voltage conversion in which alternating-current power is output from the winding on the secondary side due to a voltage converted by electromagnetic induction from the winding on the primary side to the winding on the secondary side is performed. In contrast, in the stationary electromagnetic device 1 according to this embodiment, it is necessary to perform alternating-current voltage conversion in a reverse direction from the secondary windings 21 and 22 to the primary windings 11 and 12, in addition to alternating-current voltage conversion from the primary windings 11 and 12 to the secondary windings 21 and 22. Therefore, setting is performed to optimize total bidirectional voltage conversion efficiency rather than to make the leakage inductance L_s as small as possible. That is, the gap d between the primary winding 11 or 12 and the secondary winding 21 or 22 is adjusted such that the leakage inductance L_s falls within a desired magnitude (range).

[0020]

In the embodiment illustrated in Fig. 1, the length of the gap d in the lap winding on the side of the first magnetic leg portion 2a and the length of the gap d in the parallel winding on the side of the second magnetic leg portion 2b are set to be equal to each other. However, the gap length on the side of the first magnetic leg portion 2a may be d_1 , the gap length on the

side of the second magnetic leg portion 2b may be d_2 , and d_1 and d_2 may be set to different values such that a desired leakage inductance L_s is provided between the windings in each of the magnetic leg portions 2a and 2b. The stationary electromagnetic device 1 is configured to have a width W , a depth D (see Fig. 2 which will be described below for letter D), and a height H . The magnitudes of W , H , and D are any values, however, for example, in a case where an alternating-current voltage of 6.6 kV is converted into a secondary direct-current voltage of 380 V per stationary electromagnetic device 1 using, for example, seven stationary electromagnetic devices 1, the size (W , D , and H) of the stationary electromagnetic device 1 is approximately 20 cm to 30 cm. However, the stationary electromagnetic device 1 according to this embodiment is not limited to the size or the weight and may be a small stationary electromagnetic device in which each of W , D , and H is less than 20 cm or may be a large stationary electromagnetic device in which each of W , D , and H is equal to or greater than 30 cm, for example, is approximately 1 m. The present invention can be applied to stationary electromagnetic devices 1 having single-phase cores 2 with various sizes.

[0021]

Fig. 2 is a top view illustrating the stationary electromagnetic device 1 illustrated in Fig. 1. Since the primary winding 12 and the secondary winding 22 on the side of

the second magnetic leg portion 2b have the same inner and outer shapes, only the secondary winding 22 is visible when viewed from above in the example illustrated in Fig. 2. Here, the stationary electromagnetic device is a so-called "shell type" in which coils are wound around the magnetic leg portions 2a and 2b of the single-phase core (core) 2. The single-phase core 2 is formed by laminating a large number of thin plate-shaped magnetic materials of the same type. Therefore, the outer shape of the first magnetic leg portion 2a and the second magnetic leg portion 2b is a substantially rectangular cross-sectional shape when viewed from above. The primary winding 11 and the secondary winding 21 which are wound coaxially around the first magnetic leg portion 2a have a cylindrical shape, but do not have a completely circular cross section. The cross-sectional shape of the outer and inner peripheral surfaces of the primary winding 11 and the secondary winding 21 of the single-phase core 2 is a shape (substantially rectangular shape) close to a rectangular shape along the outer shape of the magnetic leg portions 2a and 2b. Similarly, the primary winding 12 and the secondary winding 22 that are wound coaxially around the second magnetic leg portion 2b also have a cylindrical shape, and the cross-sectional shape of each of the outer and inner peripheral surfaces thereof is a substantially rectangular shape.

[0022]

Fig. 3 is a vertical cross-sectional view illustrating an

example of a structure of a winding portion according to this embodiment. Fig. 3(A) illustrates a partial cross-section of the first primary winding 11 and the first secondary winding 21 wound around the first magnetic leg portion 2a so as to overlap each other, and Fig. 3(B) illustrates a partial cross-section of the second primary winding 12 and the second secondary winding 22 wound side by side around the second magnetic leg portion 2b. An outer peripheral side and an inner peripheral side represented by arrows in Fig. 3 indicate positions based on the central axis line A1 in the first magnetic leg portion 2a and indicate positions based on the central axis line B1 in the second magnetic leg portion 2b. The first primary winding 11 is wound such that a thin wire 15 is aligned parallel to the central axis line A1 (see Fig. 1), and the first secondary winding 21 is wound such that a thick wire 25 is aligned parallel to the central axis line A1. Fig. 3 illustrates a state in which the wire 15 is wound twice and a state in which the wire 25 is wound once. However, the number of times the wires 15 and 25 are wound around the first magnetic leg portion 2a is a design matter and may be set appropriately. The wires 15 and 25 may be Litz wires configured by twisting a plurality of thin wires which are made of copper, aluminum, or the like and whose surfaces are coated with an insulating material or may be formed in a shape in which a thin plate material, such as copper or aluminum, is wound around a core (magnetic leg portion 2a). The

wound wires 15 and 25 are sealed with insulating materials 16 and 26, such as resins, respectively.

[0023]

When the stationary electromagnetic device 1 is
5 manufactured, assembly is performed such that a spacer 7 is provided in a gap portion between the sealed windings 11 and 21. Similarly, on the side of the second magnetic leg portion 2b, assembly is performed such that a spacer 8 is interposed between the second primary winding 12 in which the wire 15 is wound and
10 the second secondary winding 22 in which the wire 25 is wound. The spacers 7 and 8 are made of an insulating material that does not conduct electricity and can be manufactured by integrally molding, for example, a synthetic resin in a ring shape. The dimensions of the spacers 7 and 8 can be precisely controlled
15 in this way to provide a desired leakage inductance L_s between the windings. In the present specification, the gap between the first insulating material 16 and the second insulating material 26 and the gap between the first insulating material 17 and a second insulating material 27 are described as the gap d .
20 However, from an electrical point of view, the gap d is determined not by the insulating material portion but by a gap between an end surface of the wire 15 and an end surface of the wire 25. Therefore, the value of the gap d is determined considering the position of the wire and the position of the
25 outer surface of the insulating material.

[0024]

Next, a correlation between the volume and the leakage inductance L_s of the stationary electromagnetic device according to this embodiment will be described with reference to Fig. 4.

5 Fig. 4 is a graph illustrating the state of a relative change in the volume and the leakage inductance L_s when the gap length d between the primary winding and the secondary winding is changed for the stationary electromagnetic devices with the same specifications. A dashed line 45 is a line indicating the state
10 of the change in the leakage inductance L_s in the stationary electromagnetic device 101A according to a first conventional example illustrated in Fig. 12, and a dashed line 46 is a line indicating the state of the change in the leakage inductance L_s in the stationary electromagnetic device 101B according to a
15 second conventional example illustrated in Fig. 13. A solid line 40 is a straight line indicating the relationship between the volume ($= W \times D \times H$) and the leakage inductance L_s of the stationary electromagnetic device 1 according to this embodiment.

[0025]

20 A point represented by "d" on each of the lines 40, 45, and 46 is a point where the gap length between the primary winding and the secondary winding is the minimum value required to maintain a dielectric strength voltage, and a point represented by "2d" is a point where the gap length is twice the
25 minimum value d . In addition, as illustrated in Figs. 1 and 2,

the volume of the stationary electromagnetic device is a value calculated by the product of the width W , height H , and depth D of the stationary electromagnetic device 1. Further, an effective value V of a voltage generated between the electrodes 14a and 14b of the primary winding when the secondary winding of the stationary electromagnetic device 1 is short-circuited and a sinusoidal current with a frequency f and an effective value I flows through the primary winding is calculated using three-dimensional electromagnetic analysis, and the leakage inductance L_s of the stationary electromagnetic device 1 is a result calculated by the following equation:

$$L_s = V / (2\pi f I) \quad \dots \text{(Equation 1)}.$$

[0026]

Since the primary winding and the secondary winding constituting the stationary electromagnetic device 101A (see Fig. 12) according to the first conventional example are wound so as to overlap each other, magnetic coupling is strong, and the leakage inductance L_s is the smallest value as represented by the dashed line 45. In this winding structure, as the gap length d increases, the magnetic coupling is reduced. Therefore, L_s increases, but the width W of the stationary electromagnetic device increases at the same time, as a result, the volume of the stationary electromagnetic device increases. In contrast, since the primary winding and the secondary winding constituting the stationary electromagnetic device 101B (see Fig. 13)

according to the second conventional example are wound side by side, the magnetic coupling is weak, and the leakage inductance L_s is the largest value as represented by the dashed line 46. In this winding structure, as the gap length d increases, the magnetic coupling is further reduced, and thus L_s increases. On the other hand, the gap length d is not capable of being reduced any further in order to maintain the dielectric strength voltage between the primary winding and the secondary winding, and L_s is not capable of being reduced any further. As can be seen from the stationary electromagnetic device 101A having the characteristics represented by the dashed line 45 and the stationary electromagnetic device 101B having the characteristics represented by the dashed line 46, the leakage inductance L_s differs greatly depending on which of the structures of the stationary electromagnetic devices 101A and 101B is adopted, and the adjustment range of each of the volume and the leakage inductance L_s by the change in the gap length d is limited.

[0027]

In this embodiment, the structure illustrated in Fig. 12 in which the primary winding 11 and the secondary winding 21 are wound around the first magnetic leg portion 2a of the stationary electromagnetic device so as to overlap each other and the structure illustrated in Fig. 12 in which the primary winding 12 and the secondary winding 22 are wound side by side around

the second magnetic leg portion 2b are mixed. The value of the leakage inductance L_s in this structure has the intermediate characteristics between the characteristics of the two conventional examples as represented by the solid line 40.

5 Furthermore, in this embodiment, the value of the leakage inductance L_s can be adjusted by changing each of the ratio between the numbers of turns of the first and second primary windings 11 and 12 having two structures and the ratio between the numbers of turns of the first and second secondary windings
10 21 and 22. The solid line 40 indicates a case where the numbers of turns of the two windings are equal to each other. A solid line 40a illustrated in Fig. 4 indicates the correlation between the volume and L_s in a case where the ratio between the numbers of turns in the magnetic leg portion 2a around which the primary
15 winding and the secondary winding are wound so as to overlap each other and the magnetic leg portion 2b around which the primary winding and the secondary winding are wound side by side is 1 : 2. A solid line 40b indicates the correlation in a case where the ratio between the numbers of turns is 2 : 1. It is
20 possible to design the stationary electromagnetic device 1 in which the adjustable range of the leakage inductance L_s is expanded by changing the ratio between the numbers of turns in two winding structures having different magnetic coupling strengths and which has any volume range and leakage inductance
25 L_s in a region 41 hatched in Fig. 4. Therefore, in the

stationary electromagnetic device 1 according to this embodiment,
it is possible to achieve the leakage inductance L_s within a
wide range including the region that is not capable of being
designed in the characteristics 45 and 46 of the two conventional
5 examples, without making the volume of the stationary
electromagnetic device 1 larger than necessary.

[Embodiment 2]

[0028]

Next, a second embodiment of the present invention will be
10 described with reference to Figs. 5 and 6. Fig. 5 is a vertical
cross-sectional view illustrating an internal structure of
windings of a stationary electromagnetic device 1A according to
the second embodiment of the present invention. Fig. 5(A)
illustrates the first primary winding 11 and the first secondary
15 winding 21 that are wound around the first magnetic leg portion
2a. The wires 15 and 25 constituting the first primary winding
11 and the first secondary winding 21 that are wound so as to
overlap each other on the side of the first magnetic leg portion
2a are aligned at a constant angle θ with respect to the axial
20 direction of the first magnetic leg portion 2a, are sealed, and
are fixed through a spacer 7a made of a resin or the like. The
angle θ is, for example, about 0° to 20° . At this time, an
inner peripheral surface of the spacer 7a of the primary winding
11 has a tapered structure in which the inner diameter is small
25 on the upper side and increases toward the lower side.

[0029]

An outer peripheral surface of an insulating material 26a of the secondary winding 21 is formed in a conical surface shape in which the outer diameter is small on the upper side and increases toward the lower side. Then, the spacers 7a are provided in a gap portion between the inner peripheral surface of an insulating material 16a of the primary winding 11 and the outer peripheral surface of the insulating material 26a of the secondary winding 21. Here, three ring-shaped spacers 7a are used, and the dimensions of the spacers 7a and the gap d are adjusted such that the gap length between the primary winding 11 and the secondary winding 21 is a predetermined value to provide a desired leakage inductance L_s between the windings.

[0030]

Fig. 5(B) illustrates the second primary winding 12 and the second secondary winding 22 wound side by side around the second magnetic leg portion 2b. The structure of the second magnetic leg portion 2b around which the windings are wound side by side is the same as the structure illustrated in Fig. 3(B). On the side of the second magnetic leg portion 2b, the wires 15 and 25 constituting the second primary winding 12 and the second secondary winding 22 wound so as to overlap each other are aligned parallel to the central axis line B1 of the second magnetic leg portion 2b, and the primary winding 12 and the second secondary winding 22 are disposed side by side in the

direction of the central axis line B1 of the magnetic leg portion 2b. The second primary winding 12 and the second secondary winding 22 are disposed side by side with a gap therebetween in the direction of the central axis line B1 by two ring-shaped
5 spacers 8 having different diameters.

[0031]

Fig. 6 is a vertical cross-sectional view illustrating a stationary electromagnetic device 1B according to a modification example in which the winding structure of the stationary
10 electromagnetic device 1B illustrated in Fig. 5 is changed. In the stationary electromagnetic device 1B illustrated in Fig. 5, each of the wire 15 and the wire 25 is aligned at a slight angle θ with respect to the central axis line A1 of the first magnetic leg portion 2a in the up-down direction. In contrast, in the
15 stationary electromagnetic device 1B illustrated in Fig. 6, each of the wire 15 and the wire 25 is aligned in a direction parallel to the central axis line A1 (see Fig. 1) of the first magnetic leg portion 2a. The shape of an inner peripheral surface of an insulating material 16b of the primary winding 11 and the shape
20 of an outer peripheral surface of an insulating material 26b of the secondary winding 21 are conical shapes as in Fig. 5(A) by partially changing the thickness in the radial direction. Three spacers 7a having different diameters are interposed between the insulating material 16b and the insulating material 26b to form
25 a predetermined gap d therebetween. The structure of the second

magnetic leg portion 2b around which the windings are wound parallel to each other as illustrated in Fig. 6(B) is the same as the structures of the primary winding 12 and the secondary winding 22 illustrated in Fig. 3(B) and Fig. 5(B). The second
5 primary winding 12 and the second secondary winding 22 are disposed side by side with a gap d therebetween in the direction of the central axis line B1 by two ring-shaped spacers 8 having different diameters.

[0032]

10 Fig. 7 is a schematic diagram illustrating a method for assembling the stationary electromagnetic device 1A according to the second embodiment. In this example, the single-phase core 2 is divided at a center position in the up-down direction. This shape has the advantage that, since the upper and lower
15 parts of the single-phase core 2 are symmetrical in shape, the single-phase core 2 can be formed by disposing the same parts on the upper and lower sides. First, the lower single-phase core 2 is placed on a workbench or the like, and the first secondary winding 21 is inserted into the first magnetic leg
20 portion 2a of the single-phase core 2. The secondary winding 21 is held by a jig or the like (not illustrated) such that a portion of a lower surface thereof is a predetermined distance away from an upper surface of a lower connection portion 2d that connects the lower end of the first magnetic leg portion 2a and
25 the lower end of the second magnetic leg portion 2b of the

single-phase core 2. Then, three spacers 7 with different sizes are placed outside the secondary winding 21. The spacer 7 with the largest diameter is held by the outer peripheral surface of the secondary winding 21 in the vicinity of the lower side, and the spacer 7 with the medium diameter is held by the outer peripheral surface of the secondary winding 21 in the vicinity of the center. The spacer 7 with the smallest diameter is held by the outer peripheral surface of the secondary winding 21 in the vicinity of the upper end portion. After the three spacers 7 are positioned in this way, the first primary winding 11 is inserted in the direction from the top to the bottom. At this time, a downward movement is restricted by the three spacers 7 due to the inner tapered shape of the primary winding 11. This state corresponds to the positional relationship among the primary winding 11, the spacers 7, and the secondary winding 21 illustrated in Fig. 6. As described above, the first primary winding 11 and the first secondary winding 21 are configured such that a constant angle θ is formed between facing portions of the inner peripheral surface of the first primary winding 11 and the outer peripheral surface of the first secondary winding 21. Even in a case where there is a variation in the finished dimensions, when the first primary winding 11 is inserted from above, the gap length d can be kept constant by the insulating material 7 interposed between the first primary winding 11 and the first secondary winding 21 due to its own weight. Therefore,

it is possible to shorten the time required to adjust the leakage inductance L_s of the stationary electromagnetic device 1A.

[0033]

Then, the second primary winding 12 is inserted into the
5 second magnetic leg portion 2b of the single-phase core 2. The
primary winding 12 is held by a jig or the like such that a
portion of a lower surface thereof is a predetermined distance
away from the upper surface of the lower connection portion 2d
that connects the lower end of the first magnetic leg portion
10 2a and the lower end of the second magnetic leg portion 2b of
the single-phase core 2. Then, two ring-shaped spacers 8 with
different diameters are placed on the primary winding 12. Then,
the second secondary winding 22 is placed on these spacers 8.
Then, the upper single-phase core 2 is inserted in the direction
15 from the top to the bottom as illustrated in Figure to join the
magnetic leg portions 2a and 2b of the upper single-phase core
2 and the lower single-phase core 2. In this way, the stationary
electric device 1A according to the second embodiment is
assembled. However, the stationary electromagnetic device 1
20 illustrated in Fig. 1 can also be assembled in the same procedure
as the stationary electromagnetic device 1B illustrated in Fig.
8.

[0034]

Fig. 8 is a schematic diagram illustrating a method for
25 assembling a stationary electromagnetic device 1C which is a

modification example of the assembly method illustrated in Fig.

7. In the method illustrated in Fig. 7, the division surface of the upper single-phase core 2 and the lower single-phase core 2 is located between the second primary winding 12 and the second

5 secondary winding 22 that are wound side by side. Therefore,

when the upper single-phase core 2 is moved in the direction from the top to the bottom to be joined to the lower single-phase core 2, the upper single-phase core 2 needs to pass through

the second secondary winding 22 placed above the second primary

10 winding 12 with the spacers 8 interposed therebetween. At this

time, unless the upper single-phase core 2 is held by some means (for example, a jig used during manufacturing) so as not to

deviate from the second secondary winding 22 in the lateral direction (the horizontal direction perpendicular to the central

15 axis line B1), there is a concern that the second secondary

winding 22 will deviate in the horizontal direction. As a result,

it is impossible to insert the upper single-phase core 2 between

the first secondary winding 21 and the second secondary winding

22, which causes deterioration of assemblability. Therefore,

20 in the stationary electromagnetic device 1C illustrated in Fig.

8, an upper core 3 and a lower core 4 are asymmetrical in shape,

and the division surface is located at a position that is at

least above the upper surface of the second secondary winding

22.

25 [0035]

In the example illustrated in Fig. 8, the division surface is set at a position that is located above the upper surfaces of both the first secondary winding 21 and the second secondary winding 22 after assembly, which makes it possible to improve the assemblability of the primary windings 11 and 12 and the secondary windings 21 and 22, particularly, the assemblability of the secondary windings 21 and 22. In addition, it is easy to draw out wires from the primary windings (11 and 12) that are connected in series and to perform wiring around the cores 3 and 4, and it is easy to draw out wires from the secondary windings (21 and 22) that are connected in series and to perform wiring around the cores 3 and 4. Therefore, it is possible to easily perform an operation of attaching the windings 11, 12, 21, and 22 to the cores 3 and 4. However, a method of dividing the single-phase core 2 is not limited only to the examples illustrated in Figs. 7 and 8. For example, the lower core 4 illustrated in Fig. 8 has a U-shape, but may be formed in a J-shape, and the upper core 3 may be formed in an inverted J-shape. In this case, when the division surface on the first magnetic leg portion side is the same as the division surface on the first magnetic leg portion side in Fig. 6 and the division surface on the second magnetic leg portion side is the same as the division surface on the second magnetic leg portion side in Fig. 8, the assemblability of the second magnetic leg portion is not hindered. In addition, the upper core 3 and the lower

core 4 can be a common part.

[Embodiment 3]

[0036]

Fig. 9 is a vertical cross-sectional view illustrating a stationary electromagnetic device 1D according to a third embodiment of the present invention. In the stationary electromagnetic device 1D, the first primary winding 11 and the first secondary winding 21 are wound side by side around one side of the single-phase core 2 molded in an annular shape, that is, around the first magnetic leg portion 2a in a longitudinal direction of the magnetic leg portion 2a. In addition, the second primary winding 12 and the second secondary winding 22 are wound around a portion of the second magnetic leg portion 2b on the other side so as to overlap each other. Furthermore, a third primary winding 13 is wound around a portion of the second magnetic leg portion 2b below the second secondary winding 22 side by side in the longitudinal direction of the magnetic leg portion 2b. The primary windings (11, 12, and 13) wound around the two magnetic leg portions are connected in series by the connection means 11a and 12a. Here, the connection means 11a on a high-voltage side can be formed of a wire. On the side of the first magnetic leg portion 2a, the primary winding 11 is disposed on the upper side, and the primary winding 12 on the side of the second magnetic leg portion 2b around which the windings are wound so as to overlap each other is

disposed on the outer peripheral side. Therefore, the primary windings 11 and 12 can be connected by the connection means 11a at the shortest distance between the first magnetic leg portion 2a and the second magnetic leg portion 2b. In addition, the primary windings 12 and 13 can also be connected by a connection means 12a at the shortest distance outside the magnetic leg portion 2b.

[0037]

A constant gap length d_1 is provided between the primary winding 11 and the secondary winding 21 which are wound side by side, a constant gap length d_2 is provided between the primary winding 12 and the secondary winding 22 which are wound so as to overlap each other, and a constant gap length d_3 is provided between the primary winding 13 and the secondary winding 22 which are wound side by side. The lengths of the gaps d_1 to d_3 can be adjusted to provide a desired leakage inductance L_s between the windings. In addition, in this embodiment, in order to reliably maintain the gap length between the windings, the spacers 7 and 8 made of an insulating material may be provided between the windings as in Embodiments 1 and 2, which is not illustrated in Fig. 9.

[0038]

In the third embodiment, the magnetic coupling between the primary winding 12 and the secondary winding 22 is strong. This portion around which the windings are wound so as to overlap

each other is a portion of the second magnetic leg portion 2b, and the magnetic coupling of the remaining portion is weak. Therefore, the leakage inductance L_s is larger than those in the first and second embodiments. Furthermore, in the configuration of this embodiment, the value of the leakage inductance L_s can be controlled by changing the ratio between the number of turns of the windings wound around the first magnetic leg portion 2a and the second magnetic leg portion 2b. At this time, it is possible to prevent the range of the leakage inductance L_s that can be provided in the stationary electromagnetic device 1D, that is, the region 41 illustrated in Fig. 4 can be shifted can in the upward direction.

[Embodiment 4]

[0039]

A fourth embodiment of the present invention will be described with reference to Fig. 10. Fig. 10 is a vertical cross-sectional view illustrating a stationary electromagnetic device 1E according to the fourth embodiment of the present invention. In the stationary electromagnetic device 1E, the first primary winding 11 and the first secondary winding 21 are wound around the first magnetic leg portion 2a formed in the single-phase core 2 molded in an annular shape so as to overlap each other, and the second primary winding 12 and the second secondary winding 22 are wound side by side around the second magnetic leg portion 2b. In addition, the third primary winding

13 is wound outside the second secondary winding 22. The primary windings 11 and 12 and the primary windings 12 and 13 wound around the two magnetic leg portions are connected in series by connection means 11a and 13a, respectively. Constant gap lengths d_1 to d_3 are provided between the primary winding 11 and the secondary winding 21, and a set value of d_1 makes it easy to provide a desired leakage inductance L_s between the windings. Further, in the fourth embodiment, in order to stably maintain the gap lengths d_1 to d_3 between the windings, the spacers 7 and 8 made of an insulating material may be provided between the windings as in Embodiments 1 and 2, which is not illustrated in Fig. 10.

[0040]

In the fourth embodiment, in the first magnetic leg portion 2a, the primary winding 11 and the secondary winding 21 are wound so as to overlap each other, and the magnetic coupling between the windings is strong. On the side of the second magnetic leg portion 2b, in an upper portion as viewed in the direction of the central axis line B1, the primary winding 13 is wound on the outer peripheral side of the secondary winding 22 so as to overlap the secondary winding 22, and the primary winding 12 is disposed in the remaining lower portion such that the secondary winding 22 and the primary winding 13 are wound side by side. At this time, the magnetic coupling between the second secondary winding 22 and the third primary winding 13 is

strong, and the magnetic coupling between the second secondary winding 22 and the second primary winding 12 is weak. Therefore, the leakage inductance L_s is smaller than those in the first and second embodiments. In addition, in the configuration of this embodiment, the value of the leakage inductance L_s can be controlled by changing the ratio between the numbers of turns of the windings wound around the first magnetic leg portion 2a and the second magnetic leg portion 2b. At this time, it is possible to prevent the range of the leakage inductance L_s that can be provided in the stationary electromagnetic device 1E, that is, the region 41 illustrated in Fig. 4 can be shifted in the downward direction.

[Embodiment 5]

[0041]

Next, a fifth embodiment of the present invention will be described with reference to Fig. 11. Fig. 11 is a simple circuit diagram illustrating a bidirectional DC-DC converter 50 that transforms a direct-current voltage. The bidirectional DC-DC converter 50 is configured by combining the stationary electromagnetic device 1 according to the first embodiment, an inverter circuit 60 that is connected to the primary side (14a and 14b) of the stationary electromagnetic device 1, and an inverter circuit 70 that is disposed on the secondary side of the stationary electromagnetic device 1. The stationary electromagnetic device 1 has the same configuration as that

illustrated in Figs. 1 to 3 and is only an example. Any of the stationary electromagnetic devices 1A to 1E described in Embodiments 2 to 4 may be used as the stationary electromagnetic device illustrated in Fig. 11. The first inverter circuit 60 is connected to the electrodes 14a and 14b of the primary winding of the stationary electromagnetic device 1, and the second inverter circuit 70 is connected to electrodes 24a and 24b of the secondary winding of the stationary electromagnetic device 1. Since the inverter circuits 60 and 70 can be well-known circuits, only a brief description thereof will be made here.

[0042]

The first inverter circuit 60 is configured to include a plurality of (here, four) switching elements 61 to 64 and one or more capacitors 65. A direct-current voltage V_{dc1} input to the DC-DC converter 50 is converted into an alternating-current voltage with any frequency by the switching elements 61 to 64 disposed in a bridge shape and is then input to the primary windings 11 and 12 of the stationary electromagnetic device 1. In the inverter circuit 60, a control unit (not illustrated) controls the turn-on and turn-off of a gate voltage such that an alternating current with a predetermined frequency is supplied between the primary windings 11 and 12, which is not illustrated in Fig. 11. For example, field effect transistors (FETs) or insulated gate bipolar transistors (IGBTs) can be used as the switching elements 61 to 64.

[0043]

The stationary electromagnetic device 1 converts the voltage according to the ratio between the numbers of turns of the primary windings 11 and 12 and the secondary windings 21 and 22, and the converted alternating current is output to the electrodes 24a and 24b. The alternating current output to the electrodes 24a and 24b is converted back into a direct current by the second inverter circuit 70, and a direct-current voltage V_{dc2} is output. The second inverter circuit 70 can have the same circuit configuration as the first inverter circuit 60, and the control unit (not illustrated) controls the turn-on and turn-off of the gate voltages of four switching elements 71 to 74 connected in a bridge shape such that a predetermined direct-current voltage is output. One or more capacitors 75 are provided between the positive and negative electrodes on the output sides of the switching elements 71 to 74.

[0044]

In the bidirectional DC-DC converter 50, the input from the secondary winding side is output to the primary winding side, which makes it possible to return regenerative power from an induction device on the secondary winding side to the supply side of the primary winding side. Therefore, it is possible to provide the inverter circuit 70 capable of adjusting the voltage, without providing a rectifier circuit, such as a diode bridge circuit, on the secondary winding side. The bidirectional DC-

DC converter 50 in this stationary electromagnetic device 1, the optimal value of the leakage inductance L_s can be set considering not only forward voltage conversion (voltage conversion from the primary winding to the secondary winding) but also reverse voltage conversion (voltage conversion from the secondary winding to the primary winding). Therefore, it is possible to reduce conversion loss in a case where surplus energy of a storage battery or the like provided on the secondary side is returned to the primary side. According to the fifth embodiment, it is possible to achieve the bidirectional DC-DC converter 50 that can improve the total reuse efficiency of energy to contribute to energy saving and the stationary electromagnetic device 1 suitable for use in the bidirectional DC-DC converter 50.

[0045]

The present invention has been described above on the basis of a plurality of embodiments. However, the present invention is not limited to the above-described embodiments, and various modifications can be made without departing from the gist of the present invention.

REFERENCE SIGNS LIST

[0046]

1, 1A to 1F Stationary electromagnetic device
2 (single-phase) Core

- 2a, 2b Magnetic leg portion
- 2d Lower connection portion (of magnetic leg portion)
- 3, 4 Core
- 7, 8 Spacer
- 5 11, 12, 13 Primary winding
- 11a, 12b, 13a Connection means (for primary windings)
- 14a, 14b Electrode (of primary winding)
- 15 Wire (of primary winding)
- 16, 16a, 16b, 17, 18 Insulator (of primary winding)
- 10 21, 22 Secondary winding
- 21a, 22a Connection means (for secondary windings)
- 24a, 24b Electrode (of secondary winding)
- 25 Wire (of secondary winding)
- 26, 26a, 26b, 27, 28 Insulator (of secondary winding)
- 15 40, 40a, 40b Volume and leakage inductance of stationary
electromagnetic device according to first embodiment of present
invention
- 41 Designable range of stationary electromagnetic device
according to first embodiment of present invention,
- 20 45 Correlation between volume and leakage inductance of
stationary electromagnetic device 101A according to first
conventional example
- 46 Correlation between volume and leakage inductance of
stationary electromagnetic device 101B according to second
25 conventional example

50	DC-DC converter
60, 70	Inverter circuit
d	Gap length between primary winding and secondary winding
Ls	Leakage inductance (of stationary electromagnetic device)
5 W	Width (of stationary electromagnetic device)
H	Height (of stationary electromagnetic device)
D	Depth (of stationary electromagnetic device)

CLAIMS

[Claim 1]

A stationary electromagnetic device in which first and second primary windings and first and second secondary windings
5 are wound around first and second magnetic leg portions of a single-phase core obtained by molding a magnetic material in an annular shape, respectively, the first primary winding and the second primary winding are connected in series, and the first secondary winding and the second secondary winding are connected
10 in series,

wherein the first primary winding and the first secondary winding are wound around the first magnetic leg portion so as to overlap each other while maintaining a constant gap therebetween, and

15 the second primary winding and the second secondary winding are wound side by side around the second magnetic leg portion while maintaining a constant gap therebetween in a direction of a central axis line of the second magnetic leg portion.

20 [Claim 2]

The stationary electromagnetic device according to claim 1,

wherein the number of turns of the first primary winding is the same as or different from the number of turns of the
25 second primary winding, and

the number of turns of the first secondary winding is the same as or different from the second secondary winding.

[Claim 3]

5 The stationary electromagnetic device according to claim 2,

 wherein, in the first magnetic leg portion, the first primary winding includes a wire wound a plurality of times, and the wire is sealed in a cylindrical shape with an insulating
10 material,

 the first secondary winding includes a wire wound a plurality of times and is sealed in a cylindrical shape with an insulating material, and

 the primary winding and the secondary winding are aligned
15 coaxially with respect to a central line of the first magnetic leg portion while a first spacer is provided in a gap portion between the two insulating materials to maintain a constant gap.

[Claim 4]

20 The stationary electromagnetic device according to claim 3,

 wherein, in the second magnetic leg portion, the first primary winding of the primary winding includes a wire wound a plurality of times and is sealed with an insulating material,

25 the first primary winding of the secondary winding includes

a wire wound a plurality of times and is sealed with an insulating material, and

the primary winding and the secondary winding are disposed side by side in the direction of the central axis line of the second magnetic leg portion while a second spacer is provided in a gap portion between the two insulating materials to maintain a constant gap.

[Claim 5]

10 The stationary electromagnetic device according to claim 4,

wherein, in the first magnetic leg portion, the wires constituting the first primary winding and the first secondary winding are sealed with the insulating materials so as to be aligned at a constant angle with respect to the direction of the central line of the first magnetic leg portion,

an inner peripheral surface of the sealed first primary winding is formed at an angle θ with respect to the direction of the central line of the first magnetic leg portion,

20 an outer peripheral surface of the sealed first secondary winding is formed at an angle θ with respect to the direction of the central line of the first magnetic leg portion so as to be parallel to the inner peripheral surface, and

the first spacer is interposed between the inner peripheral surface of the first primary winding and the outer peripheral

25

surface of the first secondary winding to maintain a constant gap between the first primary winding and the first secondary winding.

5 [Claim 6]

The stationary electromagnetic device according to claim 4,

wherein the single-phase core is configured by laminating thin plate-shaped magnetic materials and is configured in a shape in which the single-phase core is divided in a plane
10 orthogonal to the direction of the central line of the first magnetic leg portion and in a plane orthogonal to the direction of the central line of the second magnetic leg portion.

15 [Claim 7]

A stationary electromagnetic device comprising:

a single-phase core obtained by molding a magnetic material in an annular shape and having two magnetic leg portions,

wherein a primary winding is divided into a first primary
20 winding and a second primary winding wound around both the two magnetic leg portions,

a secondary winding is divided into a first secondary winding and a second secondary winding wound around both the two magnetic legs,

25 in one of the two magnetic leg portions, the primary

winding and the secondary winding are wound so as to overlap each other in a state in which a constant gap between the primary winding and the secondary winding is maintained in a radial direction, and

5 in the other of the two magnetic leg portions, the primary winding and the secondary winding are wound side by side with a constant gap therebetween in a direction of a central line of the magnetic leg portion.

10 [Claim 8]

The stationary electromagnetic device according to claim 7,

wherein, in the one magnetic leg portions around which the primary winding and the secondary winding are wound so as to
15 overlap each other, the primary winding on a high voltage side is disposed an outer peripheral side, and the secondary winding on a low voltage side is disposed on an inner peripheral side,

the first primary winding of the primary winding includes a wire wound a plurality of times and is sealed in a cylindrical
20 shape with a first insulating material,

the first secondary winding of the secondary winding includes a wire wound a plurality of times and is sealed in a cylindrical shape with a second insulating material, and

a spacer is interposed between the first and second
25 insulating materials to maintain a constant gap between the

first primary winding and the second secondary winding.

[Claim 9]

The stationary electromagnetic device according to claim
5 7,

wherein, in the one magnetic leg portion around which the
primary winding and the secondary winding are wound so as to
overlap each other, the primary winding on a high voltage side
is disposed on an outer peripheral side, and the primary winding
10 on a low voltage side is disposed on an inner peripheral side.

[Claim 10]

The stationary electromagnetic device according to claim
9,

15 wherein, in the other magnetic leg portion, a portion of
the primary winding is wound on an outer peripheral side of the
secondary winding wound side by side so as to overlap the
secondary winding in a state in which a constant gap is
maintained therebetween in the radial interval.

20

[Claim 11]

The stationary electromagnetic device according to claim
10,

wherein the first primary winding and the first secondary
25 winding are wound around one of the two magnetic leg portions

so as to overlap each other while maintaining a constant gap therebetween, and the second primary winding and the second secondary winding are wound side by side around the other magnetic leg portion while maintaining a constant gap therebetween,

in the other magnetic leg portion, a third primary winding is wound on an outer peripheral side of the second secondary winding so as to overlap the second secondary winding, and

the first to third primary windings are connected in series, and the first and second secondary windings are connected in series.

[Claim 12]

The stationary electromagnetic device according to claim 1,

wherein the first primary winding, the second primary winding, the first secondary winding, and the second secondary winding are configured by winding a Litz wire configured by twisting a plurality of thin wires made of copper, aluminum, or the like having an insulating material applied to a surface thereof around a core, or is configured by winding a thin plate material made of copper or aluminum around a core.

[Claim 13]

A bidirectional DC-DC converter using a stationary

electromagnetic device, comprising:

the stationary electromagnetic device configured by winding a first primary winding and a first secondary winding around a first magnetic leg portion of a single-phase core
5 obtained by molding a magnetic material in an annular shape so as to overlap each other while maintaining a constant gap between the first primary winding and the first secondary winding, winding a second primary winding and a second secondary winding side by side around a second magnetic leg portion of the single-
10 phase core while maintaining a constant gap between the second primary winding and the second secondary winding in a direction of a central axial line of the second magnetic leg portion, connecting the first primary winding and the second primary winding in series, and connecting the first secondary winding
15 and the second secondary winding in series;

a first inverter circuit connected to the primary winding and having a plurality of switching elements and one or more capacitors; and

a second inverter circuit connected to the secondary
20 winding and having a plurality of switching elements and one or more capacitors,

wherein, when the first inverter circuit converts an input direct-current voltage into an alternating-current voltage, control is performed such that the second inverter circuit
25 converts an alternating-current voltage converted by the

stationary electromagnetic device into a direct-current voltage to perform DC-DC conversion from a primary side to a secondary side, and

when the second inverter circuit converts an input direct-current voltage into an alternating-current voltage, control is performed such that the first inverter circuit converts an alternating-current voltage converted by the stationary electromagnetic device into a direct-current voltage to perform reverse DC-DC conversion from the secondary side to the primary side.

[Claim 14]

The bidirectional DC-DC converter using a stationary electromagnetic device according to claim 13,

wherein the number of turns of the first primary winding is the same as or different from the number of turns of the second primary winding, and

the number of turns of the first secondary winding is the same as or different from the number of turns of the second secondary winding.

[Claim 15]

The bidirectional DC-DC converter using a stationary electromagnetic device according to claim 14,

wherein, in the first magnetic leg portion, the first

primary winding includes a wire wound a plurality of times, and the wire is sealed in a cylindrical shape with an insulating material,

the first secondary winding includes a wire wound a plurality of times and is sealed in a cylindrical shape with an insulating material, and

the primary winding and the secondary winding are aligned coaxially with respect to a central line of the first magnetic leg portion while a first spacer is provided in a gap portion between the two insulating materials to maintain a constant gap.