3-3-2016

Power Transfer System

Hua Bai

Xuan Joe Zhou

US 20160065079A1

(19) United States

(12) Patent Application Publication

Bai et al.

(10) Pub. No.: US 2016/0065079 A1

(43) Pub. Date: Mar. 3, 2016

(54) **POWER TRANSFER SYSTEM**

(71) Applicant: **KETTERING UNIVERSITY**, Flint, MI (US)

(72) Inventors: **Hua Bai**, Flint, MI (US); **Xuan Zhou**, Novi, MI (US)

(21) Appl. No.: **14/843,307**

(22) Filed: **Sep. 2, 2015**

Related U.S. Application Data

(60) Provisional application No. 62/045,055, filed on Sep. 3, 2014.

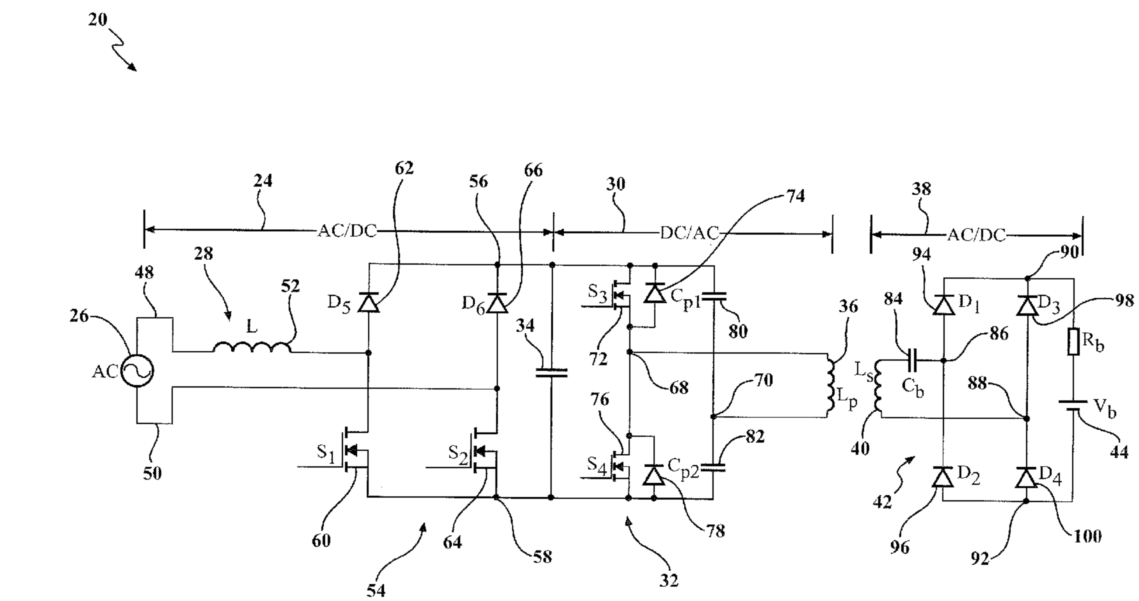
Publication Classification

(51) **Int. Cl.**
H02M 3/335 (2006.01)

(52) **U.S. Cl.**
CPC *H02M 3/33507* (2013.01)

(57) **ABSTRACT**

A power transfer system and method are provided for transferring power from an AC supply outputting an AC voltage. The system includes a controller and a primary rectifier coupled to the controller and to the AC supply for converting the AC voltage to a DC bus voltage. An inverter is coupled with the primary rectifier and the controller for converting the DC bus voltage to a primary AC voltage. A primary coil is connected to the inverter. A secondary coil is in communication with the primary coil for producing an induced AC voltage. A secondary rectifier is connected to the secondary coil for rectifying the induced AC voltage to a secondary DC voltage. At least one sensor is connected to the secondary rectifier for outputting a signal proportional to the secondary DC voltage and the controller is configured to vary the DC bus voltage based on the signal from the sensor.



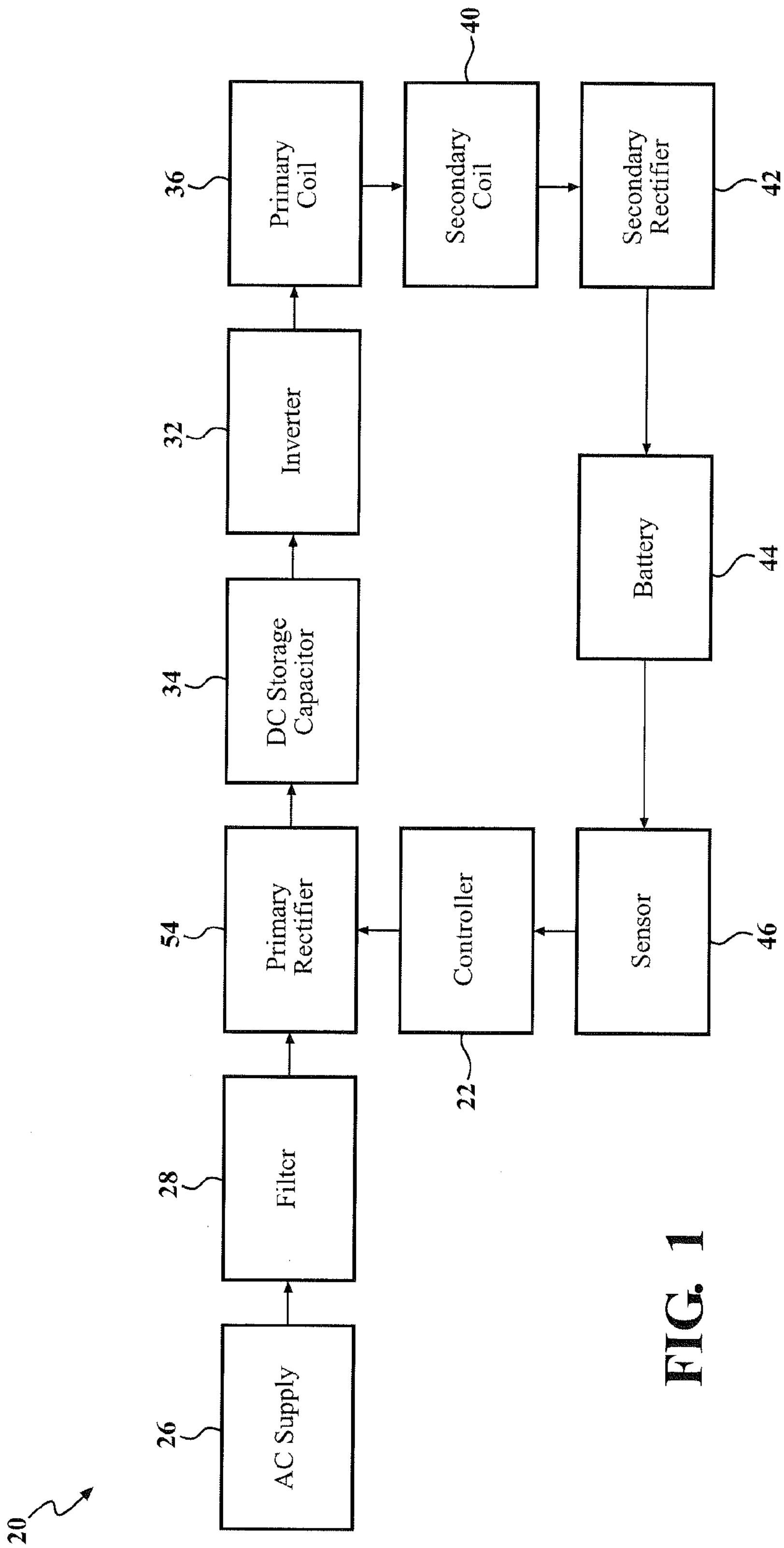
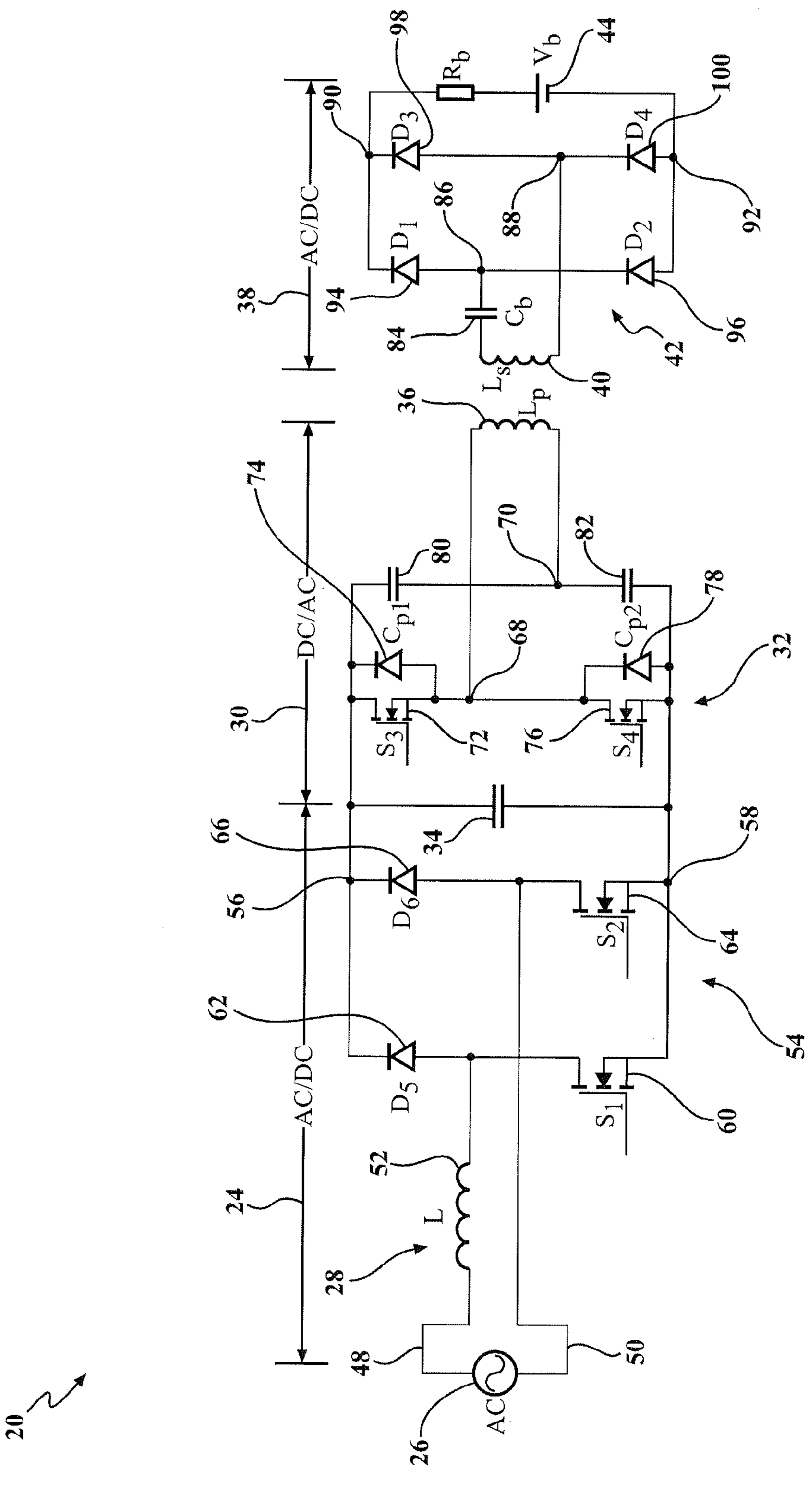

20
26
AC Supply
28
Filter
54
Primary Rectifier
34
DC Storage Capacitor
32
Inverter
36
Primary Coil
40
Secondary Coil
42
Secondary Rectifier
44
Battery
46
Sensor
22
Controller

FIG. 1



20
AC
26
48
50
24
AC/DC
28
L
52
D5
62
S1
60
54
D6
56
66
S2
64
58
34
30
DC/AC
S3
72
S4
76
32
Cp1
74
80
68
70
82
Cp2
78
36
Lp
Ls
40
38
AC/DC
Cb
84
86
D1
94
D2
96
42
88
D3
90
98
D4
92
100
Rb
Vb
44

FIG. 2

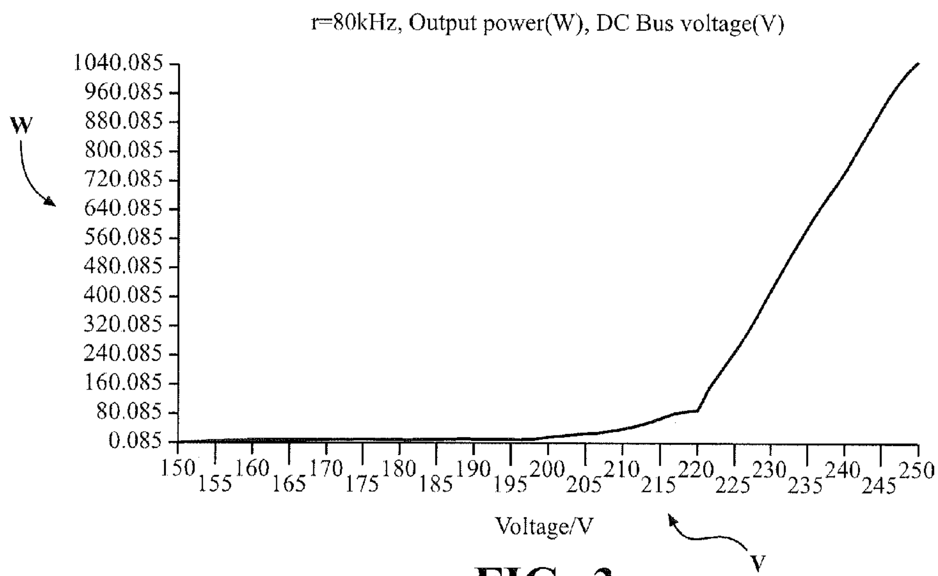

r=80kHz, Output power(W), DC Bus voltage(V)
W
1040.085
960.085
880.085
800.085
720.085
640.085
560.085
480.085
400.085
320.085
240.085
160.085
80.085
0.085
150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250
Voltage/V
V

FIG. 3

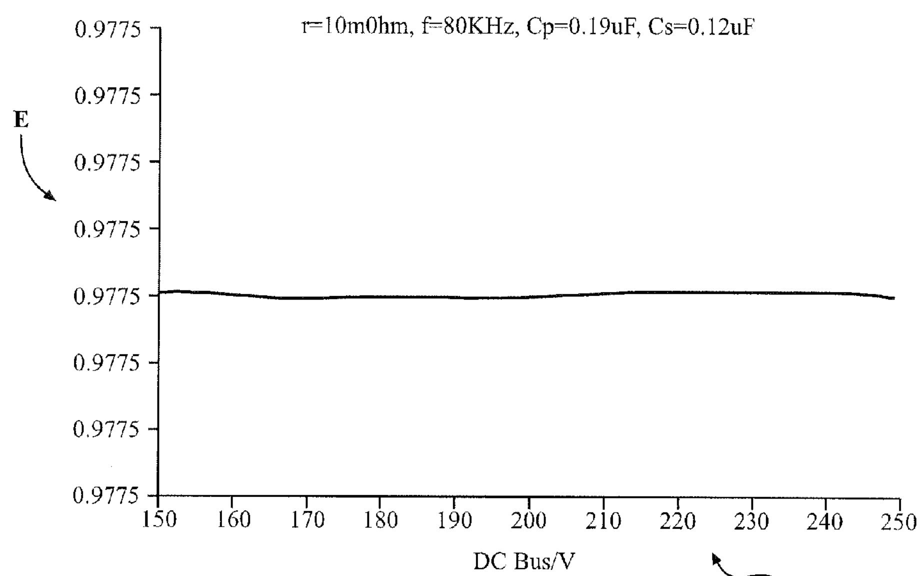

r=10m0hm, f=80KHz, Cp=0.19uF, Cs=0.12uF
E
0.9775
0.9775
0.9775
0.9775
0.9775
0.9775
0.9775
0.9775
150 160 170 180 190 200 210 220 230 240 250
DC Bus/V
V

FIG. 4

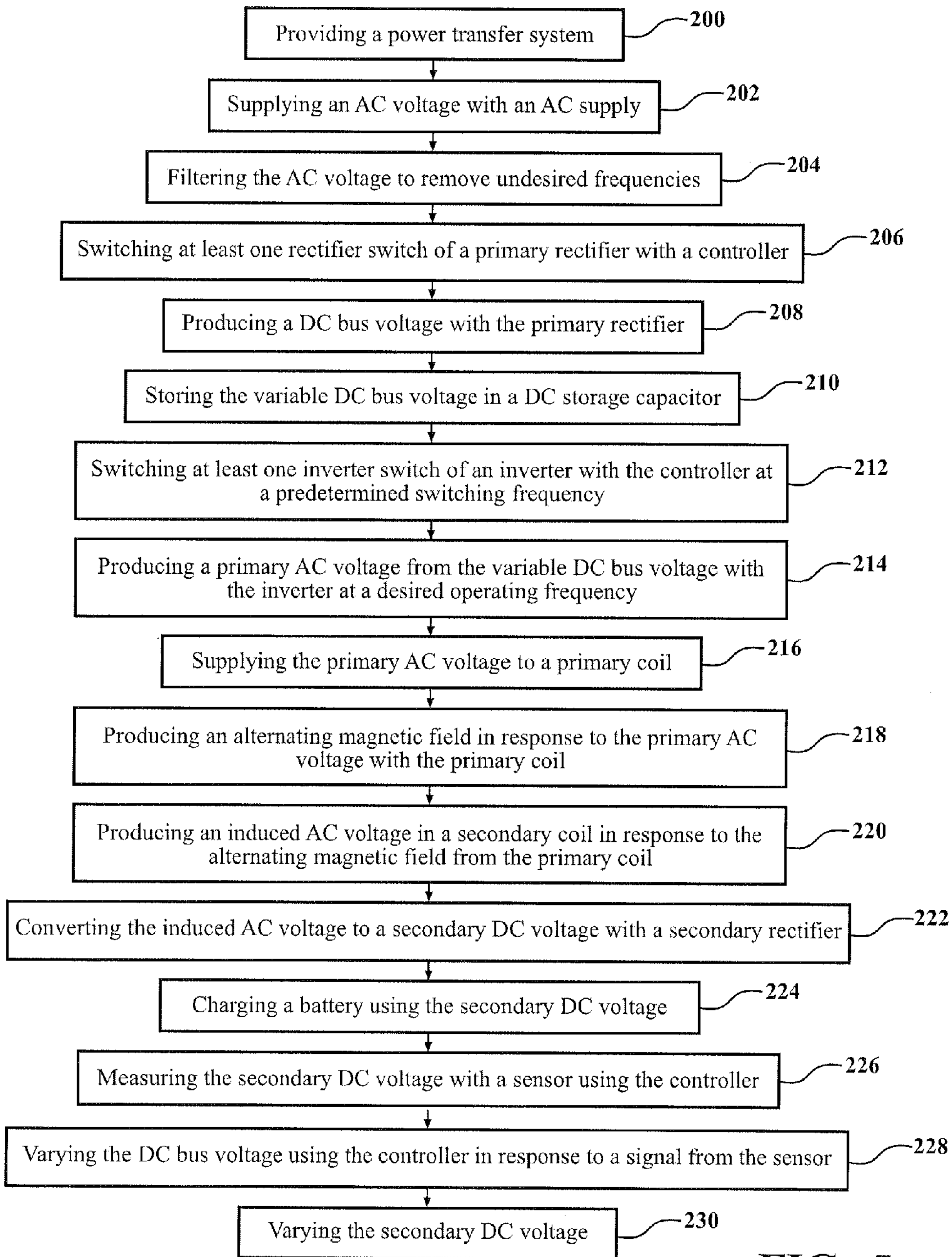

Providing a power transfer system
200
Supplying an AC voltage with an AC supply
202
Filtering the AC voltage to remove undesired frequencies
204
Switching at least one rectifier switch of a primary rectifier with a controller
206
Producing a DC bus voltage with the primary rectifier
208
Storing the variable DC bus voltage in a DC storage capacitor
210
Switching at least one inverter switch of an inverter with the controller at a predetermined switching frequency
212
Producing a primary AC voltage from the variable DC bus voltage with the inverter at a desired operating frequency
214
Supplying the primary AC voltage to a primary coil
216
Producing an alternating magnetic field in response to the primary AC voltage with the primary coil
218
Producing an induced AC voltage in a secondary coil in response to the alternating magnetic field from the primary coil
220
Converting the induced AC voltage to a secondary DC voltage with a secondary rectifier
222
Charging a battery using the secondary DC voltage
224
Measuring the secondary DC voltage with a sensor using the controller
226
Varying the DC bus voltage using the controller in response to a signal from the sensor
228
Varying the secondary DC voltage
230

FIG. 5

POWER TRANSFER SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of and priority to U.S. Provisional Application Ser. No. 62/045,055 filed Sep. 3, 2014, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present disclosure relates generally to a power transfer system and in particular, a power transfer system for electric vehicles and other related power transfer applications.

[0004] 2. Related Art

[0005] Electronic devices such as laptops, cell phones, smart phones, smart devices, smart watches, tablets, MP3 players, digital media players generally require batteries and in some cases employ wireless power transfer (WPT) systems in order to charge the batteries of the devices. Charging systems for electric and/or hybrid vehicles may also utilize WPT systems. Given the increasing demand for hybrid and electric vehicles as well as increased use of electronic devices, automotive companies and electronic device manufacturers are each motivated to design and manufacture improved high power WPT systems for vehicles and non-vehicle electronic devices respectively.

[0006] Many WPT systems utilize a topology involving the resonance or transfer of energy between two coils forming a transformer, with one coil acting as a power transmitter (i.e. primary coil) and the other acting as the receiver (i.e. secondary coil). The two coils may for example have a large air gap (e.g. greater than 10 centimeters). At least one capacitor can also be used in parallel and/or series with each of the two coils to enhance the electromagnetic field link between the two coils and allow highly effective power transfer. An alternating current (AC) voltage is generally supplied to the primary coil which induces an alternating voltage in the secondary coil. The induced voltage in the secondary coil is used to charge the battery of the vehicle or electronic device.

[0007] Power transfer systems may use an inverter that includes electronic switches (e.g. transistors) that are periodically switched on and off to produce the necessary AC voltage which is supplied to the primary coil. In order to adjust the amount of induced voltage in the secondary coil, the switching frequency of the inverter may be adjusted. However, various problems arise when the switching frequency is adjusted in this manner. Adjusting the switching frequency can lead to big changes in the induced voltage in the secondary coil (i.e. charging voltage). Additionally, as switching frequency increases, the system's overall efficiency decreases due to high switching loss. Existing engineering standards such as SAE J-2954 may also require wireless chargers to operate at specific frequencies. As such, there is an increasing need for power transfer systems which address the problems of known systems.

SUMMARY AND ADVANTAGES OF THE INVENTION

[0008] This section provides a general summary of the present disclosure and is not intended to be interpreted as a comprehensive disclosure of its full scope or all of its features, aspects, and objectives. Accordingly, the aspects of the present disclosure provide a power transfer system for transferring power to a battery of an electric device and a method of transferring power utilizing the power transfer system.

[0009] It is an aspect of the present disclosure to provide a power transfer system for transferring power from an AC supply outputting an AC voltage and including a controller. A primary rectifier defines a first primary node and a second primary node and is connected to the AC supply for converting the AC voltage to a DC bus voltage. An inverter is coupled with the primary rectifier and the controller for converting the DC bus voltage to a primary AC voltage. A primary coil is connected to the inverter for producing an alternating magnetic field in response to receiving the primary AC voltage. A secondary coil is in communication with the primary coil for producing an induced AC voltage in response to the alternating magnetic field from the primary coil. A secondary rectifier is connected to the secondary coil for rectifying the induced AC voltage from the secondary coil to a secondary DC voltage. The primary rectifier includes a first rectifier switch connected between the second primary node and the AC supply and coupled to the controller. A first rectifier diode is connected between the first primary node and the AC supply. The primary rectifier also includes a second rectifier switch connected between the second primary node and the AC supply and coupled to the controller. A second rectifier diode is connected between the first primary node and the AC supply. The controller is configured to control the first rectifier switch and the second rectifier switch for varying the DC bus voltage to produce a desired secondary DC voltage.

[0010] It is another aspect of the present disclosure to provide a power transfer system for transferring power from an AC supply outputting an AC voltage and including a controller. A filter is connected to the AC supply for filtering out undesirable frequencies from the AC voltage and outputting a filtered AC voltage. A primary rectifier that is an active rectifier is connected to the filter and to the controller for converting the filtered AC voltage to a variable DC bus voltage. A DC storage capacitor is connected to the primary rectifier for retaining the DC bus voltage. An inverter which is of the half bridge type is coupled with the primary rectifier and the controller for converting the DC bus voltage to a primary AC voltage. A primary coil is connected to the inverter for producing an alternating magnetic field in response to receiving the primary AC voltage. A secondary coil is in communication with the primary coil for producing an induced AC voltage in response to the alternating magnetic field from the primary coil. A secondary rectifier of the full bridge type is connected to the secondary coil for rectifying the induced AC voltage from the secondary coil to a secondary DC voltage. At least one sensor is coupled with the secondary rectifier and is in communication with the controller for monitoring the secondary DC voltage and outputting a proportional signal. The controller is configured to control the primary rectifier for varying the DC bus voltage in response to the signal from the sensor and to control the inverter to produce a desired secondary DC voltage.

[0011] It is another aspect of the present disclosure to provide a method of power transfer including the step of supplying an AC voltage with an AC supply. The method continues with switching at least one rectifier switch of a primary rectifier with a controller and producing a DC bus voltage with the primary rectifier. Next, switching at least one inverter switch of an inverter with the controller at a predetermined switching frequency and producing a primary AC voltage from the variable DC bus voltage with the inverter at a desired operating frequency. Then the method includes the steps of supplying the primary AC voltage to a primary coil and producing an alternating magnetic field in response to the primary AC voltage with the primary coil. The method continues by producing an induced AC voltage in a secondary coil in response to the alternating magnetic field from the primary coil. The method proceeds with converting the induced AC voltage to a secondary DC voltage with a secondary rectifier. The method concludes with varying the DC bus voltage using the controller and varying the secondary DC voltage.

[0012] The aspects of the present disclosure may provide various advantages. For example, the power transfer system does not utilize an alternation of the switching frequency of the inverter. Consequently, the induced voltage in the secondary coil (i.e. charging voltage) may be accurately controlled. Additionally, because of a constant switching frequency, the power transfer system's overall efficiency may be maintained with minimal switching loss. As a result, the power transfer system may operate at a specific frequency required by existing engineering standards such as Society of Automotive Engineers (SAE) J-2954.

[0013] These and other aspects and areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purpose of illustration only and are not intended to limit the scope of the present disclosure

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The drawings described herein are for illustrative purposes only of selected embodiments and not all implementations, and are not intended to limit the present disclosure to only that actually shown. With this in mind, various features and advantages of example embodiments of the present disclosure will become apparent from the following written description when considered in combination with the appended drawings, in which:

[0015] FIG. **1** is a block diagram of a power transfer system in accordance with the present disclosure;

[0016] FIG. **2** is a circuit diagram of a circuit of a power transfer system in accordance with the present disclosure;

[0017] FIG. **3** is a graphical illustration of power transfer power of a power transfer system as a function of DC bus voltage in accordance with the present disclosure;

[0018] FIG. **4** is a graphical illustration of efficiency of a power transfer system as a function of DC bus voltage in accordance with the present disclosure; and

[0019] FIG. **5** is a flowchart of a method for a power transfer system in accordance with the present disclosure.

DETAILED DESCRIPTION OF THE ENABLING EMBODIMENTS

[0020] Detailed examples of the present disclosure are provided herein; however, it is to be understood that the disclosed examples are merely exemplary and may be embodied in various and alternative forms. It is not intended that these examples illustrate and describe all possible forms of the disclosure. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the disclosure.

[0021] The aspects of a power transfer system disclosed herein may provide a controller configured to vary a direct current (DC) bus voltage produced from an alternating current (AC) supply to adjust the power of the system based on the system's needs at the time. Specifically, based on a battery voltage and/or current of the system detected by at least one sensor.

[0022] As those of ordinary skill in the art will understand, various features of the present disclosure as illustrated and described with reference to any of the Figures may be combined with features illustrated in one or more other Figures to produce examples of the present disclosure that are not explicitly illustrated or described. The combinations of features illustrated provide representative examples for typical applications. However, various combinations and modifications of the features consistent with the teachings of the present disclosure may be desired for particular applications or implementations.

[0023] FIG. **1** illustrates a block diagram of a power transfer system **20** in accordance with the present disclosure. FIG. **2** illustrates a corresponding circuit diagram of the power transfer system **20** in accordance with the present disclosure. The power transfer system **20** includes a controller **22** may be known as a three stage system which can be broken down into three parts: 1) a primary AC/DC portion **24** which may include an AC supply **26**, a filter **28**, and a primary rectifier **54**, 2) a primary DC/AC portion **30** which may include an inverter **32**, a DC storage capacitor **34**, and a primary coil **36**, and 3) a secondary AC/DC portion **38** which may include a secondary coil **40**, a secondary rectifier **42**, a battery **44**, and at least one sensor **46**.

[0024] The AC supply **26**, also known as an alternating current input, has a positive supply node **48** and a negative supply node **50** for providing an AC voltage across the positive supply node **48** and the negative supply node **50**. The AC voltage may be produced by a power supply or by a control device having a power system. The filter **28** is connected to the AC supply **26** for filtering out or removing unwanted and undesirable frequencies from the AC voltage supplied by the AC supply **26**. In one aspect of the power transfer system **20**, the filter **28** is of the passive type and includes a filter inductor **52** connected between the positive supply node **48** and the primary rectifier **54**. In another aspect of the power transfer system **20**, the filter **28** is a passive filter utilizing an inductor-capacitor circuit configuration (not shown). It should be understood that the filter **28** may be another type of filter such as, but not limited a high pass filter, a low pass filter, a band pass filter, or no filter at all. Each type of filter **28** may remove a respective range of frequencies.

[0025] The primary rectifier **54** (i.e. primary AC-to-DC converter) defines a first primary node **56** and a second primary node **58** and is connected to the filter **28** for converting the AC voltage to a DC bus voltage. The primary rectifier **54** includes a first rectifier switch **60** connected between the second primary node **58** and the filter inductor **52** of the filter **28** and is coupled to the controller **22**. According to an aspect, the first rectifier switch **60** is a metal-oxide-semiconductor field-effect transistor (MOSFET). However, it should be appreciated that the first rectifier switch **60** may be another type of switch such as, but not limited to another type of field-effect transistor (FET), or a bipolar junction transistor (BJT). In the event that no filter **28** is utilized, the first rectifier switch **60** may instead be connected between the second primary node **58** and the positive supply node **48**. A first rectifier diode **62** is connected between the first primary node **56** and the filter inductor **52** of the filter **28**. The primary rectifier **54** also includes a second rectifier switch **64** (e.g. FET, MOSFET, or BJT) connected between the second primary node **58** and the negative supply node **50** of the AC supply **26** and coupled to the controller **22**. A second rectifier diode **66** is also connected between the first primary node **56** and the negative supply node **50** of the AC supply **26**.

[0026] The DC storage capacitor **34** is connected to the primary rectifier **54** between the first primary node **56** and the second primary node **58** for storing the DC bus voltage from the primary rectifier **54** in an electrostatic field and retaining the DC bus voltage across the first primary node **56** and the second primary node **58**. The DC storage capacitor **34** may be made of any type of material known in the art (e.g. ceramic or electrolytic).

[0027] The inverter **32** (i.e. DC-to-AC converter) is of the half bridge type and has a positive primary coil node **68** and a negative primary coil node **70** and is connected to the DC storage capacitor **34** for converting the DC bus voltage to a primary AC voltage. The inverter **32** includes a first inverter switch **72** (e.g. FET, MOSFET, or BJT) connected between the first primary node **56** and the positive primary coil node **68** and is connected to the controller **22**. Additionally, the inverter **32** includes a first flyback diode **74** connected between the first primary node **56** and the positive primary coil node **68** in parallel with the first inverter switch **72** for preventing voltage spikes across the first inverter switch **72**. The inverter **32** also includes a second inverter switch **76** (e.g. FET, MOSFET, or BJT) connected between the second primary node **58** the positive primary coil node **68** and connected to the controller **22**. As with the first inverter switch **72**, the inverter **32** also includes a second flyback diode **78** connected between the second primary node **58** and the positive primary coil node **68** in parallel with the second inverter switch **76** for preventing voltage spikes across the second inverter switch **76**.

[0028] The primary coil **36** of the power transfer system **20** is connected between the positive primary coil node **68** and the negative primary coil node **70** of the inverter **32** for producing an alternating magnetic field in response to receiving the primary AC voltage from the inverter **32**. The secondary coil **40** of the power transfer system **20** is in communication with the primary coil **36** for producing an AC induced voltage in response to the alternating magnetic field from the primary coil **36**. In other words, the primary coil **36** may be considered a transmitter and the secondary coil **40** may be considered a receiver. It should be appreciated by one skilled in the art that the primary coil **36** may transfer energy between the primary coil **36** and the secondary coil **40** through electromagnetic induction. Additionally, the primary coil **36** and the secondary coil **40** may be used to realize electrical isolation.

[0029] The secondary rectifier **42** (i.e. secondary AC-to-DC converter) has a positive secondary coil node **86** and a negative secondary coil node **88** and defines a first secondary node **90** and a second secondary node **92**. According to an aspect of the disclosure, the secondary rectifier **42** is of the full bridge or full wave type of rectifier. The secondary rectifier **42** includes a first bridge diode **94** coupled to the secondary coil **40** at the positive secondary coil node **86** and connected to the first secondary node **90**. A second bridge diode **96** is connected to the second secondary node **92** and coupled to the secondary coil **40** at the positive secondary coil node **86**. A third bridge diode **98** is connected between the negative secondary coil node **88** and the first secondary node **90**. Finally, a fourth bridge diode **100** is connected between the third bridge diode **98** at the negative secondary coil node **88** and the second secondary node **92**. The bridge diodes **94**, **96**, **98**, **100** connected in this configuration provide for a rectification of the induced AC voltage from the secondary coil **40** to a secondary DC voltage.

[0030] The power transfer system **20** further includes a first primary coil tuning capacitor **80** connected between the first primary node **56** and the negative primary coil node **70**. Similarly, a second primary coil tuning capacitor **82** is connected between the second primary node **58** and the negative primary coil node **70**. A secondary coil tuning capacitor **84** is connected between the secondary coil **40** and the positive secondary coil node **86**. Generally, coil tuning capacitors **80**, **82**, **84** are added to a power transfer system **20** in order to "tune" the primary coil **36** and the secondary coil **40** to provide resonance between the coils **36**, **40** and increased efficiency of the power transfer system **20**. According to an aspect of the disclosure, the first primary coil tuning capacitor **80** and the second primary coil tuning capacitor **82** may each have a capacitance of 0.19 microfarads (μF). According to another aspect, the secondary tuning capacitor **84** may have a capacitance of 0.12 microfarads (μF). However, it should be understood that the capacitance of the coil tuning capacitors **80**, **82**, **84** may be selected depending, for example, on the characteristics of the coils **36**, **40**. It should also be appreciated that the power transfer system **20** may include any number of coil tuning capacitors **80**, **82**, **84** (including zero), in series or in parallel with the primary coil **36** and/or secondary coil **40**. If, for example, no secondary coil tuning capacitor **84** is utilized, the first bridge diode **94** would instead be connected between the secondary coil **40** at the positive secondary coil node **86** and the first secondary node **90**. Similarly, the second bridge diode **96** would instead be connected between the secondary coil **40** at the positive secondary coil node **86** and the second secondary node **92**.

[0031] The battery **44** is connected between the first secondary node **90** and the second secondary node **92** for storing the secondary DC voltage from the secondary rectifier **42**. The battery **44** may have an internal resistance represented by R_b (FIG. **2**). According to an aspect of the disclosure, the at least one sensor **46** (FIG. **1**) is connected to the battery **44** and is coupled with the controller **22** for monitoring the secondary DC voltage at the battery **44** and outputs a signal proportional to a magnitude of the secondary DC voltage. The battery **44** may be responsible for powering an electric device. In an aspect of the present disclosure, the electric device may be any type of electrical device such as, but not limited to an electric vehicle, a computer, a laptop, a smart phone, a cell phone, a smart watch, smart glasses, a smart device, a tablet, a MP3 player, a digital media player. The battery **44** may receive and store the energy transferred from the primary coil **36** to the secondary coil **40** and through the secondary rectifier **42** to be used for the electric device.

[0032] According to an aspect of the disclosure, the at least one sensor **46** (FIG. **1**) may communicate with the controller **22** wirelessly. For example, the controller **22**, primary rectifier **54**, DC storage capacitor **34**, inverter **32**, and primary coil **36** may be part of a "charger" and the secondary coil **40**, secondary rectifier **42**, battery **44**, and at least one sensor **46** may part of the device or vehicle portion of the power transfer system **20** that may be remote from the "charger". In such an arrangement, the signal of the sensor **46** is preferably communicated wirelessly, since the device or vehicle may be not wired to the "charger". However, it should be appreciated that the at least one sensor **46** can be coupled with the controller **22** in any manner including being coupled via a wire. Additionally, it should be understood that there may also be other sensors **46** coupled to other parts of the power transfer system **20** such as, but not limited to the primary rectifier **54** and/or the primary coil **36**.

[0033] The controller **22** may be configured to receive the signal from the at least one sensor **46**, such as measurements relating to the voltage and/or the current at the battery **44**. Referring back to FIG. **1**, the controller **22** may be in communication with the first rectifier switch **60** and second rectifier switch **64** of the primary rectifier **54** and as such, may control the first rectifier switch **60** and second rectifier switch **64** of the primary rectifier **54** based on the signal from the at least one sensor **46**.

[0034] In operation, the controller **22** is configured to control the first rectifier switch **60** and the second rectifier switch **64** of the primary rectifier **54** to produce a desired secondary DC voltage in response to the signal from the sensor **46**. The output of the primary rectifier **54** is a variable DC bus voltage that is varied to achieve the secondary DC voltage necessary to charge the battery **44**. In other words, by controlling the first rectifier switch **60** and second rectifier switch **64** of the primary rectifier **54**, the DC bus voltage may be adjusted and in turn, the secondary DC voltage at the battery **44** is varied as a result based on the input received from the at least one sensor **46**. By sampling the voltage and/or current, the controller **22** may determine higher or lower power is needed to charge the electric device. Consequently, the controller **22** may increase or decrease the duty cycle in operating the first rectifier switch **60** and second rectifier switch **64** of the primary rectifier **54**. Increasing or decreasing the duty cycle of the first rectifier switch **60** and second rectifier switch **64** of the primary rectifier **54** produces a variable DC bus voltage. For instance, if the at least one sensor **46** detects a low secondary DC voltage, the DC bus voltage may be increased to produce an increased secondary DC voltage (i.e. a higher charging power).

[0035] As described in the prior art, power transfer systems **20** typically produce a varying output power by varying the operating frequency which may cause issues with or have an adverse effect on system efficiency. In contrast, the power transfer system **20** shown in FIGS. **1** and **2** utilizes the controller **22** to vary the DC bus voltage of the circuitry based the sensor **46** signal. In order to achieve this, the controller **22** is configured to control the first inverter switch **72** and the second inverter switch **76** of the inverter **32** at a predetermined switching frequency to create the primary AC voltage of the inverter **32** at a desired operating frequency. For example, the desired operating frequency may be chosen from a specific range (e.g. 70-100 kHz) or a specific operating frequency such as 80 kHz as required by wireless charging specifications such as J-2954 promulgated by the Society of Automotive Engineers (SAE). In any event, the switching frequency of the inverter **32** is intended to remain constant as the DC bus voltage is varied.

[0036] FIG. **3** is a graphical illustration of the output power of a power transfer system **20** as a function of the DC bus voltage in accordance with the present disclosure. In particular, FIG. **3** shows the relationship between the DC bus voltage (in Volts), indicated as V and the output power (in Watts), indicated as W while the switching frequency of the inverter **32** of the power transfer system **20** is maintained to produce a desired operating frequency of 80 kHz. As discussed above, as the DC bus voltage increases or varies based on signal of the sensor **46**, the output power or power transfer power of the power transfer system **20** increases as illustrated.

[0037] FIG. **4** is a graphical illustration of the efficiency of the power transfer system **20** as a function of the DC bus voltage in accordance with the present disclosure. In particular, FIG. **4** illustrates the efficiency, indicated as E, of the power transfer system **20** as a function of the DC bus voltage, indicated as V, based on the operation of the power transfer system **20** as discussed above in FIGS. **1-3**. As shown, the power transfer system **20** operates with a constant efficiency of 97.75% as the DC bus voltage varies or increases and as the output power of the system increases. Meanwhile, the frequency of the power transfer system **20** may be maintained at 80 kHz.

[0038] FIG. **5** is a flowchart of a method for operating a power transfer system **20** in accordance with the present disclosure. The method may include **200** providing a power transfer system **20** as described above. The method may include the step of **202** supplying an AC voltage with an AC supply **26**. As disclosed, the AC supply **26** may be a power supply or a device controller **22** having a power supply. The method may also include the step of **204** filtering the AC voltage to remove undesired frequencies. It should be understood that the method may be alternatively carried out without filtering. The method proceeds with the steps of **206** switching at least one rectifier switch of a primary rectifier **54** (i.e. AC/DC converter) with a controller **22** and **208** producing a DC bus voltage with the primary rectifier **54**. The method may also include **210** storing the variable DC bus voltage in a DC storage capacitor **34**. It should be appreciated that this step could be omitted. The method continues with the steps of **212** switching at least one inverter **32** switch of an inverter **32** with the controller **22** at a predetermined switching frequency and **214** producing a primary AC voltage from the variable DC bus voltage with the inverter **32** at a desired operating frequency. Next, **216** supplying the primary AC voltage to a primary coil **36** and **218** producing an alternating magnetic field in response to the primary AC voltage with the primary coil **36**. The next step is **220** producing an induced AC voltage in a secondary coil **40** in response to the alternating magnetic field from the primary coil **36**. The method continues by **222** converting the induced AC voltage to a secondary DC voltage with a secondary rectifier **42** (i.e. AC/DC converter) and **224** charging a battery **44** using the secondary DC voltage. The method may also include **226** measuring the secondary DC voltage with a sensor **46** using the controller **22**. It should be understood that the sensor **46** may instead be configured to measure current rather than voltage or the power transfer system **20** may also include multiple sensors **46**. The method concludes by **228** varying the DC bus voltage using the controller **22** in response to a signal from the sensor **46** and **230** varying the secondary DC voltage. In other words, the controller **22** may be in electrical communication with the at least one sensor **46** (e.g. wirelessly) and may vary the DC bus voltage to adjust the power output of the power transfer system **20** to charge the battery **44** of the electric device (e.g. electric vehicle or electronic device) based on the secondary DC voltage at the battery **44** detected by the sensor **46**.

[0039] It should also be appreciated that the power transfer system **20** described herein is not limited to wireless charging. But may also be used for other applications such as, but not limited to inductive heating, as an isolated DC/DC converter, as a conventional battery charger, or any power electronics converters where the DC bus voltage is variable. In the case of the conventional battery charger, it should be understood that the primary coil **36** in communication with the secondary coil **40** comprises a transformer. Therefore, the power transfer system **20** could alternatively be used in a conventional battery charging or power transfer application in which the electric device (e.g. electric vehicle, electronic device, etc.) is being charged via a wired connection. Any gap or spacing between the primary coil **36** and secondary coil **40** in such an application would provide desirable isolation, for example.

[0040] While examples of the disclosure have been illustrated and described, it is not intended that these examples illustrate and describe all possible forms of the disclosure. Rather, the words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the disclosure. Additionally, the features and various implementing embodiments may be combined to form further examples of the disclosure.

[0041] The foregoing description is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

[0042] Those skilled in the art will recognize that the inventive concept disclosed in association with an example power transfer system **20** can likewise be implemented into many other electrical systems. Example embodiments are provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0043] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," "including," and "having," are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0044] When an element or layer is referred to as being "on," "engaged to," "connected to," or "coupled to" another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on," "directly engaged to," "directly connected to," or "directly coupled to" another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," etc.). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0045] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[0046] Spatially relative terms, such as "inner," "outer," "beneath," "below," "lower," "above," "upper," and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated degrees or at other orientations) and the spatially relative descriptions used herein interpreted accordingly.

What is claimed is:

1. A power transfer system for transferring power from an AC supply outputting an AC voltage comprising;

a controller,

a primary rectifier defining a first primary node and a second primary node and connected to the AC supply for converting the AC voltage to a DC bus voltage,

an inverter coupled with said primary rectifier and said controller for converting the DC bus voltage to a primary AC voltage,

a primary coil connected to said inverter for producing an alternating magnetic field in response to receiving the primary AC voltage,

a secondary coil in communication with said primary coil for producing an induced AC voltage in response to the alternating magnetic field from said primary coil,

a secondary rectifier connected to said secondary coil for rectifying the induced AC voltage from said secondary coil to a secondary DC voltage,

said primary rectifier including a first rectifier switch connected between said second primary node and the AC supply and coupled to said controller and a first rectifier diode connected between said first primary node and the AC supply, said primary rectifier including a second rectifier switch connected between said second primary node and the AC supply and coupled to said controller and a second rectifier diode connected between said first primary node and the AC supply,

said controller configured to control said first rectifier switch and said second rectifier switch for varying the DC bus voltage to produce a desired secondary DC voltage.

2. A power transfer system as set forth in claim **1** wherein said inverter includes a first inverter switch connected between said first primary node and said primary coil and connected to said controller and a first flyback diode connected between said first primary node and said primary coil in parallel with said first inverter switch for preventing voltage spikes across said first inverter switch and a second inverter switch connected between said second primary node and said primary coil and connected to said controller and a second flyback diode connected between said second primary node and said primary coil in parallel with said second inverter switch for preventing voltage spikes across said second inverter switch.

3. A power transfer system as set forth in claim **2** further including a battery connected to said secondary rectifier for storing the secondary DC voltage from said secondary rectifier.

4. A power transfer system as set forth in claim **3** further including at least one sensor connected with said battery and coupled with said controller for monitoring the secondary DC voltage at said battery and outputting a signal proportional to the secondary DC voltage and wherein said controller is configured to control said first rectifier switch and said second rectifier switch for varying the DC bus voltage in response to the signal from said sensor to produce the desired secondary DC voltage.

5. A power transfer system as set forth in claim **2** wherein said controller is configured to control said first inverter switch and said second inverter switch of said inverter at a predetermined switching frequency to create the primary AC voltage of said inverter at a desired operating frequency.

6. A power transfer system as set forth in claim **5** wherein said desired operating frequency is between 70 and 100 kHz.

7. A power transfer system as set forth in claim **1** wherein said secondary rectifier has a positive secondary coil node and a negative secondary coil node and defines a first secondary node and a second secondary node and includes a first bridge diode coupled to said secondary coil at said positive secondary coil node and connected to said first secondary node and a second bridge diode connected to said second secondary node and coupled to said secondary coil at said positive secondary coil node and a third bridge diode connected between said negative secondary coil node and said first secondary node and a fourth bridge diode connected between said third bridge diode at said negative secondary coil node and said second secondary node.

8. A power transfer system as set forth in claim **7** further including a first primary coil tuning capacitor connected between said first primary node and said negative primary coil node and a second primary coil tuning capacitor connected between said second primary node and said negative primary coil node and a secondary coil tuning capacitor connected between said secondary coil and said positive secondary coil node for tuning resonance between said primary coil and said secondary coil.

9. A power transfer system as set forth in claim **1** further including a DC storage capacitor connected to said primary rectifier between said first primary node and said second primary node for storing the DC bus voltage from the primary rectifier in an electrostatic field across said first primary node and said second primary node.

10. A power transfer system for transferring power from an AC supply outputting an AC voltage comprising;

a controller,

a filter connected to the AC supply for filtering out undesirable frequencies from the AC voltage and outputting a filtered AC voltage,

a primary rectifier being an active rectifier and connected to said filter and said controller for converting the filtered AC voltage to a variable DC bus voltage,

a DC storage capacitor connected to said primary rectifier for retaining the DC bus voltage,

an inverter being of the half bridge type and coupled with said primary rectifier and said controller for converting the DC bus voltage to a primary AC voltage,

a primary coil connected to said inverter for producing an alternating magnetic field in response to receiving the primary AC voltage,

a secondary coil in communication with said primary coil for producing an induced AC voltage in response to the alternating magnetic field from said primary coil,

a secondary rectifier of the full bridge type coupled to said secondary coil for rectifying the induced AC voltage from said secondary coil to a secondary DC voltage,

at least one sensor coupled with said secondary rectifier and in communication with said controller for monitoring the secondary DC voltage and outputting a proportional signal, and

said controller configured to control said primary rectifier for varying the DC bus voltage in response to the signal from said sensor and to control said inverter to produce a desired secondary DC voltage.

11. A power transfer system as set forth in claim **10** wherein the AC supply has a positive supply node and a negative supply node and said primary rectifier defines a first primary node and a second primary node and said primary rectifier includes a first rectifier switch connected between the second primary node and the positive supply node of the AC supply and coupled to said controller and a first rectifier diode connected between said first primary node and the positive supply node of the AC supply and a second rectifier switch connected between said second primary node and the negative supply node of the AC supply and coupled to said controller and a second rectifier diode connected between said first primary node and the negative supply node of the AC supply.

12. A power transfer system as set forth in claim **11** wherein said inverter includes a first inverter switch connected between said first primary node and said primary coil and connected to said controller and a first flyback diode connected between said first primary node and said primary coil in parallel with said first inverter switch for preventing voltage spikes across said first inverter switch and a second inverter switch connected between said second primary node and said primary coil and connected to said controller and a second flyback diode connected between said second primary node and said primary coil in parallel with said second inverter switch for preventing voltage spikes across said second inverter switch.

13. A power transfer system as set forth in claim **10** wherein said secondary rectifier has a positive secondary coil node and a negative secondary coil node and defines a first secondary node and a second secondary node and includes a first bridge diode connected between said secondary coil at said positive secondary coil node and said first secondary node and a second bridge diode connected between said second secondary node and said secondary capacitor at said positive secondary coil node and a third bridge diode connected between said negative secondary coil node and said first secondary node and a fourth bridge diode connected between said third bridge diode at said negative secondary coil node and said second secondary node and wherein said controller is configured to control said first inverter switch and said second inverter switch of said inverter at a predetermined switching frequency to create the primary AC voltage of said inverter.

14. A power transfer system as set forth in claim **13** further including a first primary coil tuning capacitor connected between said first primary node and said negative primary coil node and a second primary coil tuning capacitor connected between said second primary node and said negative primary coil node and a secondary coil tuning capacitor connected between said secondary coil and said positive secondary coil node for tuning resonance between said primary coil and said secondary coil.

15. A power transfer system as set forth in claim **10** further including a battery connected to said secondary rectifier for storing the secondary DC voltage from said secondary rectifier.

16. A method of power transfer comprising the steps of:
supplying an AC voltage with an AC supply,
switching at least one rectifier switch of a primary rectifier with a controller,
producing a DC bus voltage with the primary rectifier,
switching at least one inverter switch of an inverter with the controller at a predetermined switching frequency,
producing a primary AC voltage from the variable DC bus voltage with the inverter at a desired operating frequency,
supplying the primary AC voltage to a primary coil,
producing an alternating magnetic field in response to the primary AC voltage with the primary coil,
producing an induced AC voltage in a secondary coil in response to the alternating magnetic field from the primary coil,
converting the induced AC voltage to a secondary DC voltage with a secondary rectifier,
varying the DC bus voltage using the controller, and
varying the secondary DC voltage.

17. A method of power transfer as set for in claim **16** further including the step of measuring the secondary DC voltage with a sensor using the controller and wherein the step of varying the DC bus voltage using the controller is defined as varying the DC bus voltage using the controller in response to a signal from the sensor.

18. A method of power transfer as set for in claim **16** further including the step of filtering the AC voltage to remove undesired frequencies.

19. A method of power transfer as set for in claim **16** further including the step of charging a battery using the secondary DC voltage.

20. A method of power transfer as set forth in claim **16** further including the step of storing the variable DC bus voltage in a DC storage capacitor.

* * * * *