

Power transfer system

The invention relates to a power transfer system comprising a transfer pick-up circuit for inductively picking up
5 power from a cable carrying an alternating supply current.

US8,093,758 describes a power transfer system for inductively coupled power transfer (ICPT). It describes a circuit having a primary conductive path supplied with
10 alternating current from a power supply comprising a resonant converter. It also describes inductively coupling a secondary circuit to the first circuit using a transformer. The secondary circuit comprises a winding and a capacitor whereby the capacitor is connected in parallel to the winding. The winding
15 forms an inductive element. A load is parallel to the inductive element and the capacitor. A controlled shorting switch is used to decouple the pick-up and thereby regulate the impedance to the primary conductive path. Without the short, the secondary circuit would resonate. The controlled shorting switch is
20 parallel to the inductive capacitor and the inductive element. Because the controlled shorting switch causes large conduction losses and to allow for frequency variations of the current in the primary path, US8,093,758 describes the use of a variable inductor or a variable capacitor in parallel to the inductive
25 element and the capacitor. The power transfer system comprises sensing means to sense a condition of the load and control means to selectively tune or de-tune the secondary circuit in response to load conditions sensed by the sensing means by varying the effective capacitance or inductance of the secondary circuit to
30 control the transfer of power to the secondary circuit dependent on the sensed load condition. The control means comprises two switches with appropriate drivers to control the current flowing through an inductor or capacitor that thereby becomes variable. The sensing means sense the phase of a voltage in the resonant
35 circuit. The control means is adapted to drive switching means

to connect the variable inductor or to disconnect the variable capacitor to the secondary circuit a predetermined time period after a voltage zero crossing. Thereby the control means varies the variable inductance or variable capacitor such that the
5 resonant frequency is detuned away from resonance (the track frequency) when the load is small and does not need high power to be transferred through the secondary circuit. The secondary circuit is tuned toward the track frequency as the load increases and high power transfer is required to satisfy the
10 demand from the increased load.

A disadvantage of the power transfer system as described in US8,093,758 is that a relatively expensive controller is needed and that the output voltage to the load must be sensed. Moreover, the switches cause noise in the pick-up circuit and
15 therefore on the primary path when switching. This noise may disturb the function of other pick-ups coupled to the cable or may require that the power supply is robust against this noise in that the alternating current is not effected and remains as intended.

20 It is an object of the present invention to ameliorate one or more of these problems or to at least provide an alternative power transfer system.

The object is reached by a power transfer system according to an embodiment of the invention, comprising a
25 transfer pick-up circuit for inductively picking up power from a cable carrying an alternating supply current, comprising

- a first circuit comprising the secondary winding of a transformer for providing an inductive coupling to the cable and a first capacitive module connected in parallel to the
30 transformer;

characterized by

the transfer pick-up circuit comprising

- a second circuit connected in parallel to the first circuit and comprising a second inductive module and means to
35 transfer power to a load, the means being in series with the

second inductive module.

The secondary winding, the first capacitive module, the second inductive module, the means and where present the load together form a transfer pick-up circuit. The transfer pick-up
5 circuit is a resonant circuit, i.e. a circuit that can resonate depending on the frequency of the alternating supply current.

The second inductive module, the first capacitive module and the secondary winding of the transformer together form a low pass filter for noise in the direction of the cable. Thus noise
10 from the load or the means is filtered. Therefore a source of the alternating supply current on the cable does not have to be very robust and other inductively coupled power transfer pick-up circuits coupled to the cable can function optimally.

Preferably the alternating supply current alternates at
15 a cable frequency and the first circuit has a first resonance in a first frequency range around a first resonance frequency below the cable frequency and the power transfer system is arranged such that when in use the second circuit forms an infinitely high impedance, the transformer is not saturated at the cable
20 frequency.

The secondary winding can be modelled as an ideal transformer winding and a magnetizing inductance parallel to the ideal transformer winding. The ideal transformer winding has zero impedance, i.e. the inductance, resistance and capacitance
25 of the ideal transformer are zero.

In the transfer pick-up circuit, the second circuit is parallel to the first circuit. By placing the second circuit parallel to the first circuit, the impedance of the second circuit is parallel to the impedance of the first circuit.
30 Therefore, when the impedance of the second circuit is high compared to the impedance of the first circuit, the behaviour of the first circuit becomes dominant. Moreover, if the second circuit forms an infinitely high impedance during use, the second circuit effectively plays no role.

35 In practise, resonance peaks of circuits do not have an

infinitely small width but have a resonance in a frequency range. In this embodiment, the first frequency range is around a first resonance frequency, where the resonance reaches a maximum. The first resonance frequency is below the cable
5 frequency, which means that at the cable frequency the resonance is not at its maximum.

In addition, transformers have a limited maximum power transfer above which they saturate. Therefore, at least over a saturation frequency range the transfer pick-up circuit will
10 cause the transformer to saturate. Therefore, when in practise the second circuit forms an infinite load at the cable frequency, the transfer pick-up circuit will pick-up less energy from the cable than when the transformer would saturate. In other words, there is a decoupling of the transfer pick-up
15 circuit from the cable.

This decoupling can be advantageous in several situations. As the second circuit comprises means to transfer power to a load, the impedance of the second circuit depends on the impedance of the load (and therefore also on the presence of
20 a load). Moreover, the resistance of the second circuit rises with a rising resistance of the load. When the second circuit is only closed by the presence of the load (i.e. when it is open without a load being present), the resistance of the second circuit reaches a maximum when there is no load connected.
25 Switching off the load may have the same effect. In combination with the decoupling at high impedance of the second circuit, this means that there is decoupling at high impedance of the load and especially when there is no load connected. This for instance means that there is a relatively low power loss when
30 there is no load present or when the load is switched off and indeed in such situations it is desired that power loss is minimal.

To achieve this decoupling, a controller is not required. Because no controller is required, the power transfer
35 pick-up is relatively cheap and reliable. Instead, the

difference in coupling is achieved by the different resonant properties of the transfer pick-up circuit depending on the impedance of the load itself.

The inventors realized that because the magnetic inductance of the transformer is separate from the magnetic inductance of the inductive module, they could advantageously have more freedom to increase the difference between the first resonance frequency and the cable frequency without deteriorating the ability to transfer power to a load in comparison to the situation wherein the load would be parallel to the first circuit without being in series with the second inductive module.

In a preferred embodiment the second circuit comprises a second capacitive module arranged in series with the second inductive module and parallel to the means, wherein the second capacitive module and the second inductive module are arranged for having a second resonance in a second frequency range around a second resonance frequency when in practise the load impedance is infinitely high and wherein the second resonance is arranged such that the impedance of the transfer pick-up circuit is lower than the impedance of the first circuit at the cable frequency when in practise the load is infinitely high.

By having a capacitive module in the second circuit, even with an infinitely high impedance of the load, the second circuit plays a role in the transfer pick-up circuit. Moreover, the second circuit has a second resonance. Because the second circuit has the second capacity module in series with the second inductive module, the impedance of the second circuit is low at the resonance with a minimum at the second resonance frequency. As the second circuit is parallel to the first circuit, a low impedance of the second circuit causes the impedance of the transfer pick-up circuit to be low.

Because in this embodiment the transfer pick-up circuit has a lower impedance than the first circuit, the power picked up

from the cable is further reduced at the cable frequency when in use the load forms an infinitely high impedance.

When the impedance of the load is lowered, at the cable frequency the load becomes more dominant with respect to the second capacitive module, effectively diminishing the series resonance. This makes power transfer to the load possible. In the case where the load impedance approaches zero, the second capacitive module is completely bypassed and the behaviour of the circuit with or without a second capacitive module becomes equal.

Preferably, at the cable frequency the impedance of the second circuit is lower than the impedance of the first circuit when in practice the load impedance is infinitely high.

Because the impedance of the second circuit is lower than the impedance of the first circuit, the impedance of the transfer pick-up circuit is significantly reduced.

In the preferred embodiment, preferably the means comprise a rectifier arranged to supply the load from the output side of a rectifier and a capacitive reservoir module connected to the output side of the rectifier arranged to be in parallel to the load.

Because the means are parallel to the second capacitive module and are arranged to supply the load from an output side of the rectifier, an increasing load resistance still leads to an increased resistance of the second circuit.

Because the capacitive reservoir module is in parallel to the load and behind the rectifier, there is a reservoir of energy for the load so ripple that may be present on the output side of the rectifier in the voltage and current is smoothed out.

Preferably the means comprise a third inductive module arranged to be in series with the load and the capacitive reservoir module.

The capacitive reservoir module loads when the alternating voltage on the output side of the rectifier reaches

a threshold value. Therefore it loads at the tops of an alternating voltage on the output side of the rectifier. This loading characteristic may disturb the resonance of the resonant transfer pick-up circuit. The advantage of the inductance of the third inductive module is that the resonant circuit is loaded relatively evenly and that the secondary resonant circuit is less disturbed.

Preferably, a source for providing the alternating supply current wherein the source is arranged to vary the cable frequency.

Because the source can vary the cable frequency, the impedance of the power transfer pick-up on the cable can be varied to accommodate for the number of inductively coupled power transfer pick-ups coupled to the cable. Also, switching between frequencies can be used as a signal for an inductively coupled power transfer pick-up coupled to the cable.

Embodiments of the invention will now be described by way of example only, with reference to the accompanying schematic drawings in which corresponding symbols indicate corresponding parts.

Figures

- Figure 1 depicts an inductively coupled power transfer system according to the invention
- Figure 2a depicts an electrical circuit representation of the inductively coupled power transfer system of figure 1
- Figure 2b depicts an electrical circuit representation of the inductively coupled power transfer system of figure 1
- Figure 3 depicts the power picked up from the cable at different frequencies when the load is at a nominal value in the transfer pick-up circuit of figure 2b

- Figure 4 depicts the maximum primary transformer voltage at different frequencies when the load is at a nominal value in the transfer pick-up circuit of figure 2b
- Figure 5 depicts the power picked up from the cable at different frequencies with a very high impedance as load to the transfer pick-up circuit of figure 2b
- Figure 6 depicts the maximum primary transformer voltage at different frequencies with a very high impedance as load to the transfer pick-up circuit of figure 2b
- 10 - Figure 7 depicts an electrical circuit representation of the inductively coupled power transfer system of figure 1
 - Figure 8 depicts the power picked up from the cable at different frequencies when the load is at a nominal value in the transfer pick-up circuit of figure 7
- 15 - Figure 9 depicts the maximum primary transformer voltage at different frequencies when the load is at a nominal value in the transfer pick-up circuit of figure 7
 - Figure 10 depicts the power picked up from the cable at different frequencies with a very high impedance as load to the transfer pick-up circuit of figure 7
- 20 - Figure 11 depicts the maximum voltage over the primary transformer voltage at different frequencies with a very high impedance as load to the transfer pick-up circuit of figure 7
- Figure 12 depicts an alternative detail of the inductively coupled power transfer system of figure 1

Description

Example without capacitive module in transfer circuit

30 In an example according to an embodiment of the invention, a power supply (1) is arranged to supply an alternating current to a cable (2) with a current source. This is shown in figure 1. A power transfer pick-up (3) comprising a ferrite element (4) is placed in proximity to the cable (figure 2a and figure 2b). The power transfer pick-up further comprises a secondary winding

35

(17) around the ferrite element (4). The ferrite element (4) forms the core of a transformer and is at least partially within the secondary winding. The power transfer pick-up (3) is placed such that there is an inductive coupling between the cable (2) and the power transfer pick-up (3).

Figure 2a shows an electrical circuit diagram of the power transfer pick-up (3). The power transfer pick-up (3) further comprises a first capacitive module (7). The first capacitive module (7) is connected in parallel to the secondary winding (17) and the combination of the first capacitive module and the secondary winding forms a first circuit (8).

For the purpose of explaining the invention using electrical circuit drawings, the secondary winding can be modelled as the secondary part (5) of an ideal transformer and a first inductive module (6) parallel to the secondary part (5) of the ideal transformer. The first inductive module (6) represents the magnetizing inductance of the transformer. Figure 2b shows the electrical circuit diagram of the power transfer pick-up using this model. The power transfer pick-up further comprises a second circuit (9) connected in parallel to the first circuit (8). The second circuit (9) comprises a second inductive module (10).

In figure 2a and figure 2b the circuit diagram is shown with a load connected to the second circuit (9) via connection means (16) which are in series with the second inductive module (10). The connection means (16) are formed by a pair of receptacles for a plug.

The load is a switchable light bulb. The light bulb is switched on and off at demand, which means that the load varies. The light bulb is resistive. When the light bulb is off, the resistance of the light bulb is infinitely high. When the light bulb is on, the resistance has a nominal value. The load is connected to the means by a plug. This facilitates a fast and easy exchange of the light bulb.

The first circuit and the second circuit together form a transfer pick-up circuit that is resonant. For the purpose of explaining the invention and the choice of values for the components in the transfer pick-up circuit, several different situations will be described.

The first capacitive module (7) has a capacitance C_p with a value of about 64 nF. The second inductive module (10) is a coil with an inductance L_s of 820 uH. The first inductive module (6) has a value L_p of 1944 uH, i.e. the secondary winding of the transformer has an inductance of 1944 uH.

These values have been chosen to arrange that the resonance frequency ($f_{transfer\ pick-up}$) of the transfer pick-up circuit is close to a cable frequency of 26 kHz when the load is a short (i.e. has zero impedance). The values are therefore chosen using

$$f_{transfer\ pick-up} = \frac{1}{2\pi \sqrt{\frac{L_p L_s}{L_p + L_s} C_p}}$$

As the skilled man will realise, not all values are readily available for the capacitors, coils and transformers, so that the resonance frequency ($f_{transfer\ pick-up}$) may deviate a little from the exact cable frequency. In this example, a capacitor with a capacitance value of 64 nF is not readily available (i.e. capacitors with this value are not produced by default). Therefore the first capacitive module (7) comprises two capacitors connected in parallel with values 56 nF and 8.2 nF which are default values. Additionally there typically are large production tolerances on capacitors, coils and transformers. For instance, the value of capacitors may vary with 50%, 10%, 5% or 1% and the inductance of a coil may vary with 20% or 10% because of production tolerances. Moreover, resonances occur in a frequency range around a frequency where the resonance is at a maximum.

In this case the combined resonance frequency according to the nominal values of the components has a value of about 26.197 kHz, i.e. it is less than one percent off from the cable frequency.

5

The alternating current is supplied by a current source of the power supply (1). The power transferred to the load (load power) is shown in figure 3 for a range of frequencies. Figure 3 shows that load power is at or close to maximum for the chosen values.

10

The above values were chosen for the situation where the load has a value such as intended during use, i.e. has a nominal value. In this case this is about 61 Ω .

The values for L_p , L_s and C_p are however chosen by neglecting the nominal load. This is useful to design a circuit wherein the impedance of the load is not (exactly) known yet. When designing the transfer pick-up the impedance values for the light bulb can be used to arrange that the maximum of the peak (which is at the resonance frequency of the transfer pick-up circuit) is as close as possible to the cable frequency by changing the values of C_p , or L_p or L_s . This is done by solving the equation for the complex impedance of the transfer pick-up circuit to have a zero imaginary part for a certain load impedance (Z_{load}) according to

15

20

$$\Im\{Z_{transfer\ pick-up}\} = \Im\left\{\frac{1}{\frac{1}{j\omega L_p} + j\omega C_p + \frac{1}{j\omega L_s + Z_{load}}}\right\} = 0$$

25

wherein Z is used to indicate impedance and $\Im$ is used to indicate imaginary parts.

Figure 4 shows the maximum primary transformer voltage (in the figure referred to as V_{peak}) as a function of the cable frequency for the same situation as figure 3. The maximum primary transformer voltage is the maximum voltage drop experienced by the cable at the power transfer pick-up. The

30

voltage drop varies over time as the current is an alternating current. As the alternating current is supplied by a current source, the voltage drop experienced by the cable corresponds to the power picked up from the cable.

5

In case the load has an infinitely high impedance, the power picked up by the power transfer circuit peaks at a different frequency of the alternating current in the cable. In figure 5 a situation wherein the load has a very high impedance is shown. The behaviour of the power picked up from the cable when the load has a very high impedance approximates the behaviour when the load has an infinite impedance. Figure 6 shows the maximum primary transformer voltage for this situation.

10

The primary transformer voltage is limited to 5.0 V by the core (4) of the transformer. As the core (4) is made from ferrite, it saturates at a flux density of about 0.3 to 0.5 Tesla. The flux density is determined by

15

$$B_{max} = \frac{U_{max}}{2\pi f N A_e}$$

20

wherein U_{max} is the peak voltage over the transformer, A_e is the effective cross section of the core, N is the number of windings and f is the frequency.

25

If the load has an infinitely high impedance, the second circuit also has an infinitely high impedance and effectively the second circuit is not relevant for the behaviour of the resonant transfer pick-up circuit. The resonance of the transfer pick-up circuit is determined by the first circuit, which has a resonance with a maximum at a frequency around 15 kHz. To distinguish with other resonance frequencies in the power transfer circuit, this resonance frequency will further be referred to as the first resonance frequency.

30

The relation between the first resonance frequency (f_{first}), the magnetizing inductance of the first inductive module and the capacitance of the first capacitive module is given by

$$f_{first} = \frac{1}{2\pi\sqrt{L_p C_p}}.$$

This formula is also used to select the values for the magnetizing inductance of the first inductive module and the capacitance of the first capacitive module.

At this first resonance frequency, the core (4) is saturated. Because the core is saturated, the power picked up by the power transfer pick-up is limited and the maximum primary transformer voltage is limited.

As is clear from the frequencies given above, as well as from comparison of figures 3 and 5 or figures 4 and 6, the resonance frequency of the transfer pick-up circuit (the circuit which combines the first circuit (8) and the second circuit (9)) comprising a load with nominal impedance is closer to the cable frequency than the first resonance frequency.

Example with capacitive module in transfer circuit

In an example according to a preferred embodiment of the invention, the power transfer circuit is as described above, but the second circuit additionally comprises a second capacitive module (11) parallel to the means (16) for transferring power to the load. The second capacitive module (11) is also in series with the second inductive module (10). The second capacitive module (11) has a value C_s for the capacitance. When there is no load connected to the means (16), and taken separately from the rest of the transfer pick-up circuit, the second circuit has a resonance with a maximum (i.e. a minimum impedance) at a second resonance frequency (f_{second}) determined by

$$f_{second} = \frac{1}{2\pi\sqrt{L_s C_s}}$$

In this example, the nominal value C_s is 44 nF, leading to a value for the second resonance frequency of the second circuit (f_{second}) of about 26,496 kHz. Although this deviates less than 2% from the cable frequency, readily available components can be used. The second capacitive module (11) comprises two capacitors connected in parallel with values 22 nF and 22 nF, which are readily available components. The skilled man will appreciate that in other examples of the invention it may be possible to use a single readily available capacitor in the second capacitive module.

Figure 8 shows the power transferred to the load for this embodiment for different cable frequencies for the situation wherein the load has nominal impedance. As in the earlier example this nominal load impedance is about 61 Ω .

This figure 8 should be compared with figure 3 for comparing the situation with and without the second capacitive module. From comparison it will be clear to the skilled person that the behaviour of the transfer pick-up circuit with the second capacitive module (11) is comparable to the behaviour of the transfer pick-up circuit without the second capacitive module (11).

In addition, figure 9 shows the maximum primary transformer voltage for this value of the capacity of the second capacitive module (11). Figure 9 should be compared with figure 4, for comparing the situation with and without the second capacitive module. From comparison it will be clear to the skilled person that the behaviour of the transfer pick-up circuit with the second capacitive module (11) is comparable to the behaviour of the transfer pick-up circuit without the second capacitive module (11). The advantage of the presence of the second capacitive module (11) is shown in figure 10 and 11.

Figure 11 shows the behaviour of the transfer pick-up circuit when the load is very high. The behaviour approximates the situation wherein the load is not present (i.e. has an

infinite impedance). In this case, what is shown is the behaviour in the form of the maximum primary transformer voltage as a function of the cable frequency. Here, as in the situation without the secondary capacitive module (11), the maximum
5 primary transformer voltage clips when the core (4) saturates in a frequency range, but not at the cable frequency. As discussed above, the second circuit has a second resonance frequency at the cable frequency (i.e. it deviates as much as to allow for the use of components with default values as available on the
10 market). As the second circuit is a series circuit, the second circuit forms a short (parallel to the first circuit) at the second resonance frequency. The cable frequency is not exactly the second resonance frequency, but at the cable frequency, the impedance of the second circuit is still low. The advantage of
15 the second capacitive module is that at the cable frequency of 26 kHz, the transfer pick-up circuit forms a lower impedance to the cable than the first circuit would. In this example even the maximum primary transformer voltage is negligible because the impedance of the second circuit is very low and much lower than
20 the impedance of the first circuit. This corresponds to the power picked up from the cable being negligible at the cable frequency of 26 kHz in figure 10. This means that because of the presence of the second capacitive module (11) and with the values of the first inductive module, the second inductive
25 module, the first capacitive module and the second capacitive module at this cable frequency, if there is no load connected to the power transfer pick up (or if the load is switched off) there is no power picked up from the cable (2) and the power transfer pick-up (3) will not influence the inductively coupled
30 power transfer system to which it is coupled.

Like figure 11, figure 10 shows the behaviour of the transfer pick-up circuit when the load is very high as an approximation of the behaviour when the load not present in the form of the power transferred to the load as a function of the

cable frequency. The transfer pick-up circuit now has third resonance frequency, which is above the cable frequency.

Example with rectifier

5 In a further embodiment (figure 12) the first capacitive module (7) comprises two capacitors (71,72) connected in parallel to each other, wherein one capacitor (71) has a value of 33 nF and the other capacitor (72) has a value of 100 nF.

10 In the embodiment the secondary capacitive module (11) also comprises two capacitors (111,112) connected in parallel to each other. One capacitor (111) has a value of 4.7 nF and the other capacitor has a value of 56 nF.

The magnetizing inductance (C_p) of the secondary winding has a value of 847 μ H and the inductance of the second
15 inductance module has a value of 1000 μ H.

With these values the transfer pick-up circuit is arranged to pick-up power from the cable when the cable frequency switches between 20 kHz and 21 kHz. This means that the cable frequency is in a cable frequency range of 20 kHz to 21 kHz with
20 21 kHz being the upper frequency limit. The intended impedance of the load, in this example a LED-light is 220 Ω . The resonance frequency of the transfer pick-up circuit is within the cable frequency range. When a load with the intended impedance is connected, the resonance frequency is also within the cable
25 frequency range.

The power transfer pick-up further comprises a rectifier circuit (13). The rectifier is arranged to provide a unidirectional (but still varying) voltage at its output side.

On the output side there is a capacitor (14) of 47 μ F. The
30 load (12) is connected parallel to the capacitor. Both the capacitor (14) and the load (12) are connected to the rectifier (13) in series with an inductor (15) of 820 μ H.

While specific embodiments of the invention have been described, it will be appreciated by the person skilled in the art that the invention may be practised otherwise than as described, but still according to the teachings of the invention. For instance, the power transfer system can comprise more than one power transfer pick-up and supply power to a combination of loads of different nature such as switched mode power supplies, resistors and LED-lamps. The loads can also be sensors. The sensors can also communicate via the power transfer pick-up to other components connected to the cable (2). Additionally the second inductive module may comprise one or more coils. Furthermore, the rectifier may be a half-wave rectifier. Also, the second resonance frequency may deviate from the cable frequency such that when the load has an infinite impedance, the impedance of the second circuit is smaller than the impedance of the first circuit by at least a factor of 10, 20, 50 or 100.

Claims

1. Power transfer system comprising a transfer pick-up circuit for inductively picking up power from a cable carrying an alternating supply current, comprising

- a first circuit comprising the secondary winding of a transformer for providing an inductive coupling to the cable and a first capacitive module connected in parallel to the transformer;

characterized by

the transfer pick-up circuit comprising

- a second circuit connected in parallel to the first circuit and comprising a second inductive module and means to transfer power to the load, the means being in series with the second inductive module.

2. Power transfer system according to claim 1, wherein

- the alternating supply current alternates at a cable frequency; and wherein

the first circuit has a first resonance in a first frequency range around a first resonance frequency below the cable frequency and the power transfer system is arranged such that when in use the second circuit forms an infinitely high impedance, the transformer is not saturated at the cable frequency.

3. Power transfer system according to claim 2, wherein

- the second circuit comprises a second capacitive module arranged in series with the second inductive module and parallel to the means and wherein

- the second capacitive module and the second inductive module are arranged for having a second resonance in a second frequency range around a second resonance frequency when in practise the load impedance is infinitely high and wherein the second resonance is arranged such that the impedance of the

transfer pick-up circuit is lower than the impedance of the first circuit at the cable frequency when in practise the load is infinitely high.

5 4. Power transfer system according to claim 3, wherein at the cable frequency the impedance of the second circuit is lower than the impedance of the first circuit when in practice the load impedance is infinitely high.

10 5. Power transfer system according to claim 3 or 4, wherein the means comprise a rectifier arranged to supply the load from the output side of a rectifier and a capacitive reservoir module connected to the output side of the rectifier arranged to be in parallel to the load.

15

 6. Power transfer system according to claim 5, wherein the means comprise a third inductive module arranged to be in series with the load and the capacitive reservoir module.

20 7. Power transfer system according to any of the preceding claims comprising a source for providing the alternating supply current wherein the source is arranged to vary the cable frequency.