Optimal Control of the installed power in domestic induction cooking hobs with re-configurable structure topology

This invention concerns the optimal control of a flexible and reconfigurable topology wherein a control strategy of the power semiconductor switches allows separated powering of two coils with regulated power up to their rated values. Furthermore, it allows the utilisation of all the installed power and using it for driving any of the coils. This performance provides ultra-fast heating ability with a power capacity higher than the rated power of the coil without increasing the rating characteristics of the system. In addition, it allows the matching of the installed power to the demands in order to lower the temperature of the electronic power devices, leading to an improving in the system reliability and integrability.

FIG 1
Description

OBJECT OF THE INVENTION

The object of the present invention is the optimal control and the management of the power provided by a flexible and reconfigurable topology based on the three-phase bridge with non-symmetric legs. This flexible and reconfigurable topology constitutes a module which is able to drive two loads, which in this preferred embodiment, are the two heating plates of an induction cooking hob (Figure 1). The goals achieved with the optimal control proposed are:

a) The proposed control drives both coils independently with regulated power up to their power ratings.
b) The proposed control allows the utilisation of all the installed power and using it for driving anyone of the coils providing ultra-fast heating ability. This performance provides a power capacity higher than the rated power of the coil without increasing the rating characteristics of the system.
c) The proposed control matches the installed power to the demands in order to lower the temperature of the electronic power devices, improving in the system reliability and integrability, and lowering the heat sinking demands.

FIELD OF THE INVENTION

This invention relates to induction heating and more specifically to the optimal control of the installed power in induction cooking apparatus with re-configurable structure topology, which provides ultra-fast heating ability and optimised semiconductor switches power losses.

BACKGROUND OF THE INVENTION

The principle of induction cooking are the eddy current and hysteretic losses in the surface of a metallic object therein. It has several advantages over heating by conventional techniques such as convection or conduction. Induction heating is usually faster than convection or conduction heating because lower thermal mass is associated with induction heating systems. In addition, the induction heating focuses the heat within the heated object yielding higher energy transfer efficiency in contrast to convection or conduction heating wherein the heat is produced outside the heated object.

The domestic induction heating hobs are driven by an alternate current of medium frequency (25-65 kHz) applied to an induction coil which heats by induction a pot or a pan placed on the coil. This current is generated by a power converter based on a solid-state power devices. In what follows a new concept of the control strategy for the power converter used for induction heating hobs is presented. This control strategy lower the power losses in the electronic power switches of the converter and provides ultra-fast heating ability.

The owner of this patent also owns the Patent of Invention n° 539.790 wherein an electronic system drives by a high frequency pulsed current a thermal plate as those used in an electric hob. This system uses a full-bridge inverter with MOS transistors which drives a flat coil housed inside a thermal plate by a serial of high frequency power pulses heating ferromagnetic pots or pans.

The transistorised full-bridge described in the aforementioned Patent is activated by a control circuit which achieves the regulation and the self adaptation of the firing time for each leg of the transistorised full-bridge, scheduled in relation with the inductive-energy time recovering of the flat coil, and stopping the powering of the coil when there is non-ferromagnetic load. In that way, when a ferromagnetic pot or pan is placed on the thermal plate, a thermal with self-firing ability is achieved.

Although the induction heating method is fast, the rising time necessary to reach the stationary thermal state can be shortened if the spare power drive capacity of an idle bridge which normally drives the induction heating plate are used to boost the bridge which drives the active induction plate. Another application of the idle bridge is to help in the reduction of the overall conduction losses of the power semiconductor switches of the active bridge.

To achieve these goals it is necessary a bridge inverter topology with a variable structure able to perform these tasks. The owner of this patent also owners the Patent of Invention which describes the foregoing topology with variable structure. The control of this topology with variable structure is the core of this invention.

DESCRIPTION OF THE INVENTION

This invention provides several control strategies for driving the electronic power switches which feed the induction coils of an induction cooking hob. These strategies aim to perform a regulated power in the pot or pan placed on the coil and lowering the power losses in the electronic power switches. In this way, the working temperature of the electronic power devices is lowered, thus, either the heat sinking demands are reduced or the devices can work in an environment with higher room temperature.

The topology where these control strategies are designed for is the three-phase bridge with non-symmetric legs including one or two switches with a single-pole two-positions each. This topology is obtained by modifying another one which is well-known as the tree-phase bridge. The later is frequently used as DC-AC converter to drive three-phase loads, but in this case, it has been modified by adding one or two switches with a single-pole two-positions each. In this way, a flexible and reconfigurable structure topology is obtained depending
on the position of the switches. A bridge is not symmetric if all their legs are not identical concerning the controllability of the power switches, the working zone of the voltage/current quadrant or the handled power. The modification introduced in the bridge consists in rating individually two of the legs with a power handling capacity fitted to the respective coil rating. These coils constitute two independent heating plates of an induction cooking hob. The third leg, named as common leg, is rated with a power handling capacity equal to the added ratings of the other two legs.

The control strategy implemented allows separated driving of each of the two coils with regulated power up to their rated values.

In the case wherein a single coil demands for power, all the installed power can be used for driving this coil, and thus, performing ultra-fast heating ability with a power capacity higher than the rated power of the coil without increasing the rating characteristics of the system.

The control strategy proposed determines the switch states as a function of the power demands yielding four cases: 1) Both coils off, 2) The first coil demands ultra-fast heating, 3) The second coil demands ultra-fast heating, and 4) Both coils demand power equal to or less than their rated power.

The ultra-fast heating ability consists in driving a single coil with a regulated power higher than its rated power and feeding it with constant frequency. To provide it, the control strategy proposed states a current-controlled voltage-polarity switching.

When driving a single coil with a power equal to or less than its rated power two control strategies are stated depending on the demanded power level. These strategies are either current-controlled voltage-cancellation or duty ratio control. The later is also named energy control.

It is set a power level so called boundary power. This is the maximum power that can be delivered to a load by using the energy control strategy, taking into account the limitations imposed by the Electromagnetic Compatibility Standard concerning the voltage fluctuations and flicker in low voltage supply systems.

The current-controlled voltage-cancellation is used for power demands within the boundary power and the rated power. The energy control is used for power demands below the boundary power.

When the current-controlled voltage-cancellation strategy imposes large voltage-cancellation and the power demand is higher than the boundary power, an alternative control method is proposed. This method maintains constant the voltage-cancellation time and varies the time without voltage-cancellation. This alternative method works with variable frequency and allows the snubbers networks maintaining their functionality. Consequently, the power losses in the electronic power devices can be maintained low.

The proposed control strategy allows driving the two coils with power equal to or less than their respective rated values. If the demanded power is in both coils higher than the boundary power, it is applied the current-controlled voltage-cancellation strategy. The activation time of the electronic power devices is co-ordinated for the sake of optimising their power losses. This co-ordination applies a bipolar voltage to one of the coil at the start of a half-period and to the other coil at the end of a half-period. With this co-ordination it is avoided the simultaneous coil-current overlapping through the electronic power devices, thus minimising the root mean square (RMS) current circulating through the common leg. Consequently, the working temperature of the power electronic devices belonging to the common leg is lowered, improving the reliability and integrability of the system.

The foregoing control strategy allows simultaneously driving of both coils with power levels equal to or lower than their rated values. When the power demand in any coil is lower than the boundary power, the control strategy applied to that coil is the energy control, and for the other coil, is applied the current-controlled voltage-cancellation. For power demands lower than the boundary power in both coils, the energy control applied yields lower switching losses in the electronic power devices when compared to the current-controlled voltage-cancellation strategy.

When both coils demand power equal to or lower than their rated power, the proposed control strategy states a common working frequency for both coils, consequently, there are not intermodulation or sub harmonic frequencies, thus, audible noise is avoided.

Other advantage provided by the foregoing control strategy is that they are able to be implemented in integrated programmable logic devices, thus, allowing maximum integrability, flexibility, programmability and reliability of the control system.

BRIEF DESCRIPTION OF THE DESIGNS

The features of the invention believed to be novel are set forth with particularity in the appended claims. The invention itself, however, together with further objects and advantages thereof, may be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

Figure 1.- Shows the re-configurable and multi-bridge topology with two switches and with power boost in both coils B1 and B2. In this Figure it is named:

- S1 to S6 as the electronic power semiconductor switches.
- B1 and B2 are the load coils.
- The leg formed by S3 and S4 are the so called common leg of the three-phase bridge.
- The leg formed by S1 and S2 are dimensioned for the rated power of B2.
- The leg formed by S5 and S6 are dimensioned for
activated, all the installed power is available for coil B1. If only the switch R2 is activated, all the installed power is available for coil B2. When both switches are activated, the common pole of each switch is electrically connected to its normally-closed (nc) output pole, paralleling together fast heating of coil B2.

Controlled voltage-polarity switching applied to ultra-

The switches positions shown in Figure 1 corresponds both to non-activated state. In this situation the common pole of each switch is electrically connected to its normally-closed (nc) output pole, paralleling together both legs S1-S2 and S5-S6. If only the switch R1 is activated, all the installed power is available for coil B1. If only the switch R2 is activated, all the installed power is available for coil B2. When both switches are activated, each coil uses its own installed rated power.

- Table 1 shows the power available for each coil B1 and B2 versus the activation state represented as "1" or no-activated state represented as "0", of both switches R1 and R2.
- Figure 2 is used for explanation of the current-controlled voltage-polarity switching applied to ultra-fast heating of coil B2.
- Figures 2a, 2b, 2c, and 2d show the control signals for driving the electronic power switches S3, S4, S2-S6 and S1-S5, respectively. The electronic power devices S2-S6 and S1-S5 are activated as two switch pairs. The activation of S3 and S2-S6 determines a current through the coil B2 which comes out of the centre tap of leg S3-S4, as shown in Figure 1, and flows into the coil.
- Figure 2e shows the shape of the pulsed bipolar voltage applied to coil B2.
- Figure 2f depicts the current shape iB2 flowing through the coil B2 when the voltage shape of Figure 2e is applied. The peak current level reached is limited to the reference value iP2. The voltage applied is inverted when the current iB2 of coil B2 reaches the level iP2. That is the reason because it is so called current-controlled voltage-polarity switching.
- The power level applied as ultra-fast heating is controlled by the current amplitude iP2 used for the current-controlled voltage-polarity switching. This power level can be set to values within the rating of B2 and the whole installed power corresponding to adding the ratings of B1 and B2.
- The half periods T are both equal and are determined by the power level indirectly derived from iP2.
- Figure 3 is used for explaining the control applied when any of the coils is powered alone. The situation shown in this figure corresponds to the case in which only the coil B2 is powered.
- Figure 3a shows the control signal for driving the electronic power switch S3. This signal has a 50% of duty ratio and constant half-period T.
- Figure 3b shows the control signal which drives the electronic power switch S4. This control signal is the logically complement of foregoing control signal.
- The control signal of Figure 3c drives both S2 and S6 because all the installed power is applied to B2.
- In the same way S1 and S5 are driven by the control signal in figure 3d. The activation time of S2, S6, S1 and S5 is t2, being t2 less than the half period T. The time t2 determines the width of the bipolar pulsed voltage wave applied to B2, as shown in Figure 3d.
- The time t2 ends when the current iB2 through the coil reaches the reference level iP2 shown in figure 3f. If this level is variable, the voltage wave shape applied to B2 is also variable, thus the power delivered by B2 is variable. When the level of iP2 determines that t2 enlarges up to T then B2 delivers the maximum power which is equal to its rated power. By a continuous or discrete control of iP2, a continuous or discrete control of the delivered power by B2 is obtained.
- To implement it, a time-base of half period Tb is adopted.
- From this half period, times t1 and t2 are derived with Tb = tb1 + tb2.
- During t1 the coil is powered with the boundary power level. During t2 the coil is not powered. In this way, a continuous average power can be obtained by controlling the tb1/Tb ratio.
- Figure 5 is used for explaining the co-ordination of coils controls applied when both coils are powered within the boundary power level and their rated power.
- Figures 5a, 5b, 5c, 5d, 5e, and 5f show the control signals for the electronic power switches S3, S4, S6, S2, S5, and S1, respectively.
- The state of the electronic power switches S6, S5 determine the bipolar wave shape in figure 5g, which drives the coil B1.
- The state of the electronic power switches S2, S1 determine the bipolar wave shape in figure 5h, which drives the coil B2.
- Figure 5i shows the currents iB1 and iB2 flowing through the coils B1 and B2, respectively.
- On both coils are applied a current-controlled voltage-cancellation as described in the third control strategy described below. However, as both coils are powered simultaneously, the activation time of the electronic power devices are co-ordinated for the sake of optimising their power losses.
- From a time-base with half period T1 common for both coils, the activation times t1 and t2 are arranged to be separated as much as possible within
T1. With this arrangement a bipolar voltage as in Figure 5g is applied to coil B1 during t1 placed at the start of the half period T1. In the same way, the bipolar voltage as in Figure 5h is applied to coil B2 during t2 placed at the end of the half period T1. This situation provides current wave shapes iB1 and iB2 flowing through each coil which do not completely overlap in time each other, thus its addition yields lower root mean square current as compared when they fully overlap. Consequently, the power losses in the electronic power devices belonging to the common leg S3-S4 are lowered to minimum, the working temperature of the devices is lowered and the reliability and integrability of the system is enhanced.

- The power level of the coil B1 is determined with the peak value iP1 of the current depicted in figure 5i. In the same way, iP2 limits the current value in the coil B2 and determines its delivered power.

DESCRIPTION OF A PREFERRED EMBODIMENT

This invention provides a control method for the power delivered by the flexible topology in Figure 1. The control strategy is based on the power demand information requested for each load coil B1 and B2 which are used as heating plates of an induction cooking hob.

The positions of the switches R1 and R2 determines the power handling ability of each coil B1 and B2.

The position depicted in Figure corresponds to both switches in non-activated state. If only R1 is activated, all the installed power is available for coil B1. If only R2 is activated, all the installed power is available for coil B2. If both switches are activated, each coil draws its own rated power.

Table 1 shows the power availability for each coil B1 and B2 versus the activated or non-activated state of the switches R1 and R2. The activated state is represented as "1" and the non-activated state represented as "0".

In what follows four control strategies providing in the one hand, the external functionality of attending the demanded power and in the other hand, the internal functionality of producing the minimum power losses in the electronic power devices.

The first control strategy for the flexible topology depicted in Figure 1 consists in determining the positions of switches R1 and R2, thus, their respective activated or non-activated state versus the maximum power availability demanded. All possibilities are constrained to four cases stated in each of the four columns in Table 1.

The second control strategy is used for performing the ultra-fast heating and consist in applying to a single coil a regulated power higher than rated. To get it, it is applied a current-controlled voltage-polarity switching. This control is explained in Figure 2.

Assuming that coil B2 is used for implementing the ultra-fast heating, the first strategy in Table 1 determines that the switch R2 must be activated and the switch R1 must be non activated. The second strategy shown in Figure 2 applies periodically a pulsed bipolar voltage to coil B2. Figure 2e shows the wave shape of the pulsed bipolar voltage applied to B2. Figures 2a, 2b, 2c, and 2d show schematically the control signals for the electronic power devices S3, S4, S2-S6 and S1-S5, respectively. The devices S2-S4 and S1-S5 are activated as two switch pairs. The activation of S3 and S2-S6 determines the current setting up through the coil B2 which comes out of the centre tap of leg S3-S4, as shown in Figure 1, and flows into the coil. As Figure 2f shows, this applied voltage periodically inverts when the current peak iP2 through coil B2 reaches the maximum iP2. That is the reason because this control is named as current-controlled voltage-polarity switching.

The power level applied as ultra-fast heating is controlled by the amplitude value of the current iP2 used for implementing the current-controlled voltage-polarity switching. This power level can be stated controllable with values within the rated power of B2 and the installed power obtained by adding the rated power of B1 and B2. The half periods T are both equal and are determined by the working frequency specified. Once the frequency is selected, it is maintained constant. The situation shown in Figure 1 corresponds to a fast-heating of B2 with a power corresponding to the power boost stated. The period T and the selected power boost in the load coil B2 indirectly determines iP2.

The third control strategy is used for powering any of the coils alone with regulated power equal to or less than its rated power. Taking the demanded power level as reference, it will be applied two control strategies. These strategies are either current-controlled voltage-cancellation or duty ratio control. The later is also named energy control. The energy control is later explained using Figure 4.

The current-controlled voltage-cancellation is used for power demands within the boundary power and the rated power. The energy control is used for power demands below the boundary power.

Assuming as an example that this strategy is applied to coil B2. Figure 3 shows the current-controlled voltage-cancellation applied to coil B2. The power electronic device S3 is activated with the control signal in Figure 3a which has a 50% duty ratio and a half period T1. The device S4 belonging to the same leg is activated with the complementary of the foregoing signal as shown in Figure 3b. As it is only a coil involved, all the installed power is applied to it by activating both S2 and S6 with the control signal in Figure 3c. In the same way, S1 and S5 are both activated with the control signal in Figure 3d.

The activation time of S2, S6, S1 and S5 is t2 and is lower than the half period T1. The time t2 ends when the current through the coil B2 reaches the reference level iP2 shown in Figure 3f. If this level varies, it is obtained a variable voltage wave shape applied to B2, and...
thus, a variable power.

Alternatively, the same objective can be achieved by increasing the reference level $iP2$, maintaining $T1$-t2 constant and increasing simultaneously both T1 and t1. In other words, by lowering the frequency and increasing simultaneously the reference $iP2$ to rise the power delivered. The opposite action will be taken for lowering the power delivered. This method is proposed when the current-controlled voltage-cancellation strategy imposes large voltage-cancellation and the power demand is higher than the boundary power. This method maintains constant the voltage-cancellation time and varies the time without voltage-cancellation. This alternative method works with variable frequency and allows the snubbers networks maintaining their functionality. Consequently, the power losses in the electronic power devices can be optimised and maintained low.

Assuming that the working frequency is maintained constant, with the current peak level $iP2$ of coil B2 is derived the time t2 by which the voltage applied to coil is cancelled. Thus, it is a current-controlled voltage-cancellation.

When $iP2$ is such that t2 equals to T1 the maximum power is applied to B2 and this is stated as its rated power. By the continuous or discrete control of $iP2$ it can be obtained a continuous or discrete control of the power delivered by B2.

Although a continuous power control can be obtained following the foregoing procedure, from the device loses point of view, this procedure can be improved with low power demands. Thus, this procedure is not used for power demands below the boundary power. For power demands below the boundary power it is used the duty ratio control method also named as energy control. This control is explained using Figure 4.

The energy control uses the aforementioned current-control voltage cancellation but setting $iP2$ to that value corresponding to the boundary power.

To implement it, it is adopted a time base with period $Tb$ lower than the thermal time constant of the heating system constituted by any of the coils B1, B2, and the heated pot or pan. From this period, times t1 and t2 are derived with $Tb=tb1+tb2$ as shown in Figure 4. If during $Tb$ is delivered energy, the system is delivering the boundary power (BP) as power level. If it is only delivering energy within $tb1$ and the system is not activated within $tb2$, the average power (AP) level delivered is:

$$AP_B1= BP_B1(tb1/Tb)$$

In this way, it is obtained a continuous regulation of the average power delivered by setting the $tb1/Tb$ ratio.

The boundary power is selected lower than the maximum allowed by the Electromagnetic Compatibility Standard concerning the voltage fluctuations and flicker in low voltage supply systems, when the energy control strategy is applied. This Standard limits the switched power versus the switching ratio. In our case, the boundary power level depends on the selected value for $1/Tb$.

The fourth control strategy is applied when both coils B1 and B2 are simultaneously powered with power levels equal or lower than their rated power. If the power demands of both coils are higher than the boundary power, it will be applied the powering guidelines depicted in Figure 5. Figures 5a, 5b, 5c, 5d and 5f show the control signal for the electronic power devices S3, S4, S6, S2, S5 and S1, respectively. The device states of S6 and S5 determine the bipolar wave shape in Figure 5g used for powering the coil B1. The device states of S2 and S1 determine the bipolar wave shape in Figure 5h used for powering the coil B2. Figure 5i shows the currents $iB1$ and $iB2$ flowing through the coils B1 and B2, respectively. On both coils are implemented the current-controlled voltage-cancellation as described in the third control strategy. As two coils are involved, the activation time of the electronic power devices are coordinated for the sake of optimising their power losses. To cope with this objective, on a time base with half period $T1$, the bipolar voltage in Figure 5g is applied to coil B1 within a time $t1$ placed at the start of the half period $T1$. In the same way, the bipolar voltage in Figure 5h is applied to coil B2 within a time $t2$ placed at the end of the half period $T1$. With this co-ordination it is avoided the simultaneous coil-current overlapping through the electronic power devices, thus minimising the root mean square (RMS) current circulating through the common leg. A full wave shape overlap would happen if both coils were powered at the start of every half period. As the sum of both currents flows through the common leg $S3-S4$, when the currents do not fully overlap the root mean square (RMS) current circulating through the common leg is lower. Consequently, the working temperature of the power electronic devices belonging to the common leg is lowered, improving the reliability and integrability of the system.

The power level for coil B1 is set by the current peak $iP1$ depicted in Figure 5i. In the same way, $iP2$ limits the current level through the coil B2 and determines its power delivered.

If the demanded power of any coil is lower than the boundary power it will be applied to it the energy control described in Figure 4.

If on a time base $Tb$ in Figure 4, the coil B1 delivers the boundary power (BP_B1) within time $tb1$, the average power (AP_B1) delivered by B1 is:

$$AP_B1= BP_B1(tb1/Tb)$$

In the same way, if on the same time base $Tb$ the coil B2 delivers the boundary power (BP_B1) within time $tc1$, the average power (AP_B2) delivered by B2 is:

$$AP_B2= BP_B2(tc1/Tb)$$
If any of the coils demands a power higher than the boundary power and the other coil demands a power lower than the boundary power, that coil demanding higher than boundary power will follow the current-control voltage-cancellation strategy depicted in Figure 3 but that coil demanding lower than boundary power will follow the energy control depicted in figure 4.

As it has been described in the fourth control strategy, the working frequency is the same for both coils, thus, there are not intermodulation or sub harmonic frequencies and audible noise is avoided.

Finally, the control strategies proposed are able to be implemented in integrated programmable logic devices, thus, allowing maximum integrability, flexibility, programmability and reliability of the control system.

While the invention has been particularly shown and described with reference to several preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the true spirit and scope of the invention as defined by the appended claims.

Claims

1. Optimal control of the installed power delivered by a re-configurable structure topology based on a non-symmetric three-phase bridge wherein said topology is characterised by including one or two switches with a single-pole two-positions each wherein said topology allows optimising the installed power depending on the power demands, wherein said management is implemented into four control strategies, wherein said management yields lower working temperature in the electronic power devices, increasing the reliability and integrability of the system and lowering the heat sinking demands of the devices.

2. The invention according to claim 1 wherein said optimal management is characterised by allowing separated powering of two loads independently, wherein said loads are two coils which in the preferred embodiments constitute the two heating plates of an induction cooking hob, wherein said coils can be powered with regulated power up to their respective rated power.

3. The invention according to claim 1 wherein said control strategies are characterised by allowing to apply all the installed power for both coils and using it for driving any of the coils thus providing ultra-fast heating ability with a power capacity higher than the rated power of the coil without increasing the rating characteristics of the system.

4. The invention according to claim 1 wherein said control strategies are characterised by stating as first control strategy the positions of switches, thus, their respective activated or non-activated state versus the maximum power availability demanded, wherein said first control strategy is characterised by constraining all switch state possibilities to four cases, wherein said four cases corresponds to either both coils disconnected, either the first coil with ultra-fast heating, either the second coil with ultra-fast heating or both coils demanding power equal to or lower than their rated power.

5. The invention according to claim 1 wherein said control strategies are characterised by stating as second control strategy that used for providing ultra-fast heating, wherein said second control strategy is characterised by applying to a single coil a regulated power higher than rated, wherein said second control strategy is performed by applying a current-control voltage-switching.

6. The invention according to claim 1 wherein said control strategies are characterised by stating as third control strategy that used for powering any of the coils alone with regulated power equal to or less than its rated power, wherein said third control strategy is characterised by applying a current-controlled voltage-cancellation for power demands within the boundary power and the rated power and by applying the energy control for power demands below the boundary power.

7. The invention according to claim 1 wherein said control strategy states a boundary power as reference for switching between the current-controlled voltage-cancellation control and the energy control.

8. The invention according to claim 1 wherein said control strategies are characterised by stating an alternative method when the current-controlled voltage-cancellation strategy imposes large voltage-cancellation and the power demand is higher than the boundary power, wherein this alternative method is characterised by working with variable frequency and allowing the snubbers networks maintaining their functionality, wherein said alternative method allows the power losses in the electronic power devices to be optimised and maintained low.

9. The invention according to claim 1 wherein said control strategies are characterised by stating as fourth control strategy that applied when both coils B1 and B2 are simultaneously powered with power levels equal to or lower than their rated power, wherein said strategy is characterised by applying the current-controlled voltage-cancellation control if the power demands of both coils are higher than the boundary power, wherein said strategy is also char-
acterised by establishing a co-ordination of the switches activation time for the sake of optimising their power losses, wherein said co-ordination applies a bipolar voltage to one of the coil at the start of a half-period and to the other coil at the end of a half-period, wherein said co-ordination is characterised by avoiding the simultaneous coil-current overlapping through the electronic power devices and minimising the root mean square (RMS) current circulating through the common leg, wherein said co-ordination lowers the working temperature of the power electronic devices belonging to the common leg, improving the reliability and integrability of the system.

10. The invention according to claim 1 wherein said control strategies are characterised by stating as fourth control strategy that applied when both coils B1 and B2 are simultaneously powered with power levels equal to or lower than their rated power, wherein said strategy is characterised by applying the energy control to any of the coils demanding power lower than the boundary power while maintaining current-controlled voltage-cancellation control to any coils demanding power higher than the boundary power, wherein said energy control for power demands lower than the boundary power in both coils yields lower switching losses in the electronic power devices when compared to the current-controlled voltage-cancellation strategy.

11. The invention according to claim 1 wherein said control strategies are characterised by stating as fourth control strategy that applied when both coils B1 and B2 are simultaneously powered with power levels equal to or lower than their rated power, wherein said strategy is characterised by working both coils with the same frequency which avoids the generation of audible noise produced by intermodulation or sub harmonic frequencies.

12. The invention according to claim 1 wherein said control strategies are characterised by being able to be implemented in integrated programmable logic devices thus, allowing maximum integrability, flexibility, programmability and reliability of the control system.
FIG 1

FIG 2
TABLE 1

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TECHNICAL FIELDS SEARCHED (Int.Cl.)

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