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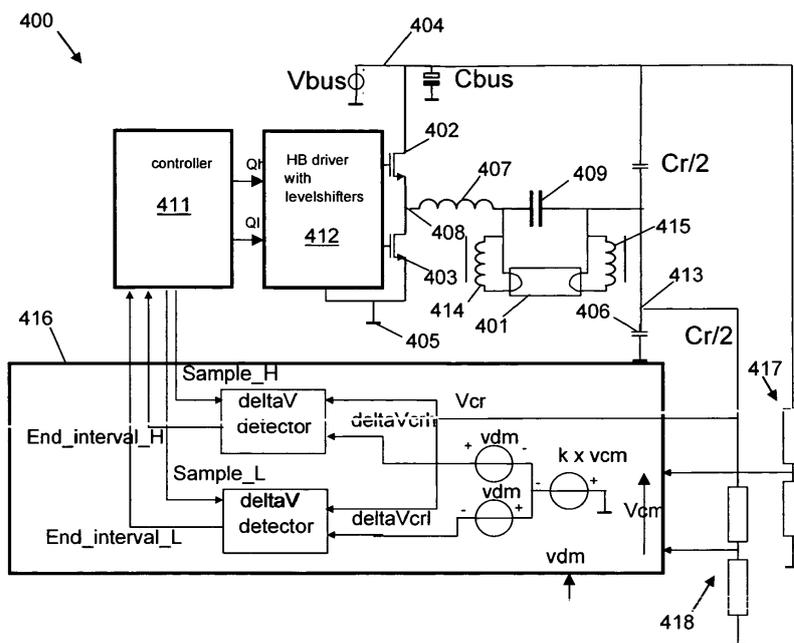
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(54) **Resonant converter for a gas discharge lamp**

(57) The invention relates to methods and apparatus for control of electrical lighting, in particular for powering a gas discharge lamp using a resonant power converter. Embodiments disclosed include a method of controlling a resonant power converter (400) to drive a gas discharge lamp (401), the resonant power converter comprising first and second series connected switches (402, 403) connected between first and second supply voltage lines (404, 405) and a resonance circuit comprising a capacitor (406) and an inductor (407), the resonance circuit con-

nected between a node (408) connecting the first and second switches (402, 403) and the second supply voltage line (405), the method comprising, in an operational mode, the sequential steps of: closing the first switch (402) to start a first conduction interval; and opening the first switch (402) to end the first conduction interval when a voltage across the capacitor (406) crosses a predetermined first voltage level, wherein controlling the predetermined first voltage level determines a power level provided to the gas discharge lamp (401).



**Fig. 4**

## Description

**[0001]** The invention relates to methods and apparatus for control of electrical lighting, in particular for powering gas discharge lighting using a resonant power converter.

**[0002]** The use of fluorescent, or gas discharge, lighting has become more prevalent and is likely to continue increasing due to advantages related to energy consumption compared with traditional incandescent lighting. However, gas discharge lighting requires a different type of power source from incandescent lighting. A block diagram of a basic fluorescent light driver 100 is illustrated in figure 1. An AC input 101 is connected to a rectifier 102, which provides a rectified signal to a storage capacitor 103. Energy is typically stored in the storage capacitor 103 around the peak voltage of the AC input in each half cycle. A ballast circuit 104 drives a half bridge switching circuit 105 with a switching signal and the half bridge switching circuit 1115 drives a resonant circuit 106 connected to a light fitting 107.

**[0003]** Compact fluorescent lighting (CFL), where fluorescent lights are used as direct replacements for existing incandescent light fittings, provide a particular challenge, in that all of the components necessary for driving the light together with the fluorescent light itself (i.e. components 102 to 107 of figure 1) are required in a package size preferably no larger than an existing incandescent light bulb.

**[0004]** Fluorescent lighting is usually non-dimmable, which is a disadvantage compared to conventional incandescent lighting. Dimmable solutions are therefore required. In addition, power factor requirements for fluorescent lighting, which present reactive loads, are becoming tighter as their use increases.

**[0005]** Existing solutions for fluorescent lighting drivers tend to use frequency as a way of controlling the power delivered to the light 107, by using the variation in energy transfer through the resonant circuit with frequency. One issue with frequency control however is stability, in particular when dimming to low levels, due to the non-uniform impedance characteristics of fluorescent lamps. Figure 2 illustrates a schematic plot of power as a function of frequency for a typical fluorescent lamp as an illustration of these impedance characteristics over a typical frequency control range (in this case over a range of 98 to 114kHz). The derivative of the power-frequency curve changes sign twice over the power range considered, becoming negative within a significant portion of the range. This type of characteristic makes stability of control of the power output problematic, because it is the derivative of the impedance which determines the loop gain of a frequency control loop.

**[0006]** To address the problem of stability of control, a faster control loop can be used, but there are practical problems with implementing such can be used be used, but used but there are practical problems with implementing such solutions. An alternative is a control method that uses the difference between a time interval during which

one switching element of a half bridge is conducting during a half cycle of a periodic voltage and a time interval during which a diode is conducting during the same half cycle.

**[0007]** A change to a capacitive mode of operation of a gas discharge lamp can occur when the lamp ignites, due to a change in lamp resistance causing the power-frequency characteristic to shift. Measures are therefore needed to rapidly change the output provided to the lamp to keep a driving circuit out of such a capacitive mode, which can result in destruction of the switching elements. In conventional methods of controlling power to gas discharge lamps, frequency control methods tend to sweep the frequency to a higher value to avoid the occurrence of a capacitive mode. This limits the problem, although by sweeping the frequency a dip in the delivered power occurs, which can turn the lamp off. A capacitive mode for a resonant power supply can be avoided by keeping the converter just within a "safe" side of a capacitive mode region, but while maintaining the maximum power possible. This can be realised by turning a conducting switch off before the current falls to zero in order to maintain sufficient energy to obtain a soft switching action of the opposite switch. The opposite switch may also be prevented from turning on as long as the current is not in the proper direction. This prevents charge build up in the body diode of the previous conducting switch being recovered in an uncontrolled way, which risks destruction of the switch.

**[0008]** Power factor correction is another requirement that needs to be addressed for gas discharge lamps, in particular for CFL applications above 20 W. Additional circuitry may therefore be necessary to improve the power factor of a CFL assembly. To reduce costs and the overall size of the assembly, single stage solutions are preferred. A "bridgeless boost" topology may be used to address this problem, advantages of which include a smaller number of components and a higher efficiency. A disadvantage is that the operating frequency is used for regulation of power delivered to the lamp, and the effect on the power factor correction stage and the resonant stage is different. Exemplary circuits for driving a gas discharge lamp using a resonant converter with and without a transformer are illustrated in figures 3a and 3b. Figure 3a illustrates a topology using a bridgeless boost, while figure 3b illustrates a topology with a 1:n transformer.

**[0009]** Another application area relates to HID (high intensity discharge) lamps or high pressure lamps. One of the issues with such lamps is that driving with an AC signal causes audible pressure waves in the gas, as a result of frequency components that correspond with certain resonant dimensions in the lamp. This effect can cause dangerous instabilities in the gas that can lead to uncontrollable mechanical resonance and ultimately destruction of the lamp. Existing methods therefore tend to use a low frequency signal of a few hundred Hertz to drive such lamps in order to avoid such high frequency

components causing pressure waves. This can result in more complex implementations.

**[0010]** In accordance with a first aspect of the invention there is provided a method of controlling a resonant power converter to drive a gas discharge lamp, the resonant power converter comprising first and second series connected switches connected between first and second supply voltage lines and a resonance circuit comprising a capacitor and an inductor, the resonance circuit connected between a node connecting the first and second switches and the second supply voltage line, the method comprising, in an operational mode, the repeated sequential steps of:

closing the first switch to start a conduction interval; and  
opening the first switch to end the conduction interval when a sensed voltage across the capacitor crosses a predetermined first voltage level, wherein controlling the predetermined first voltage level determines an amount of energy provided to the gas discharge lamp over the first conduction interval.

**[0011]** The invention provides a solution for driving a gas discharge lamp that addresses the various disadvantages of existing solutions, in particular those that use frequency control. Firstly, a more linear relation is possible between a control parameter determining the predetermined voltage level and the resulting converted power, thereby avoiding the problem of unstable frequency control methods. Secondly, the invention enables a straightforward pre-heat and ignition sequence for gas discharge lamps, allowing for a well controlled ignition of the lamp while avoiding issues arising from operating in a capacitive mode. Thirdly, the invention allows for a mode of operation at low duty cycles, allowing it to be combined with a bridgeless boost topology, or other single stage boost topologies. Fourthly, the invention offers a possible solution to the problem of pressure waves in HID and other high pressure gas lamps.

**[0012]** The predetermined voltage level may be defined in a number of different ways. Exemplary control methods may be, for example, in accordance with those disclosed in WO 2006/103606, W02009/037613 or WO 2010/073196. The predetermined voltage may be defined as an absolute voltage level, as described in the aforementioned publications, or as a differential voltage level. When using a differential voltage level, the voltage across the capacitor is sampled at the start of the conduction interval and this sampled voltage is compared with a current voltage value across the capacitor offset by a differential voltage level to determine when to end the conduction interval.

**[0013]** The method may further comprise, in the operational mode, the sequential steps of:

closing the second switch after opening the first

switch to start a second conduction interval; and opening the second switch to end the second conduction interval when the sensed voltage across the capacitor crosses a predetermined second voltage level, wherein the first and second conduction intervals alternate over time, the predetermined first and second voltage levels determining a power level provided to the gas discharge lamp.

**[0014]** As with the first conduction interval, the second conduction interval may be determined according to an absolute or differential voltage level.

**[0015]** The first and second conduction intervals are described herein as corresponding to the high side and low side conduction intervals respectively, i.e. where the half bridge node between the two switches is connected to the supply voltage line and to ground respectively. However, the reverse may also apply, i.e. with the first and second conduction interval referring to the low and high side conduction intervals respectively, with other changes being made accordingly, for example the direction in which the sensed voltage crosses the predetermined voltage levels for ending the conduction intervals being reversed. The timing of the first and second switches may also be reversed during operation.

**[0016]** The first and second switches are preferably opened and closed sequentially at a switching frequency that is determined by the predetermined first and second voltage levels, although other criteria may also be applied that affects the switching frequency. Having the switching frequency determined by the predetermined voltage levels, rather than controlling the switching frequency directly, allows for improved control of power through a gas discharge lamp, due to the variations in impedance of such lamps as a function of frequency.

**[0017]** The method may comprise sensing a current through the lamp and closing the first switch only when the current through the lamp is flowing in a direction that provides a reverse bias across a body diode connected across the first switch. This feature prevents damage or destruction of the second switch by preventing the first switch from being operated when a body diode connected across the second switch is forward biased.

**[0018]** The first and/or second conduction intervals may be determined by the predetermined first and/or second voltage levels to provide a duty cycle of power supplied to the lamp of less than 50% over successive switching cycles.

**[0019]** In some embodiments the first switch may be opened to end the first conduction interval after a predetermined wait time determined by a delay signal and once the voltage across the capacitor has crossed the predetermined first voltage level.

**[0020]** The first switch may be opened when the voltage across the capacitor is lower than the predetermined voltage level and when a sensed current through the lamp is below a threshold value. The threshold value may be

close to zero, for example being less than 10%, 5% or 1 % of a peak current value.

**[0021]** Over a plurality of successive switching cycles, the method may comprise the sequential steps of:

- a preheating stage wherein the predetermined voltage levels are set to heat the lamp electrodes below an ignition level of the lamp;
- an ignition stage wherein the predetermined voltage levels are increased until the gas discharge lamp ignites; and
- a continuous lighting stage wherein the predetermined voltage levels are reduced to a steady level to maintain operation of the gas discharge lamp at a desired power level.

**[0022]** Where the operational mode is considered to be a first operational mode, the method may further comprise, in a second lower power operational mode:

- closing the first switch to start a first conduction interval; and
- opening the first switch to end the first conduction interval after a predetermined wait time determined by a delay signal and when a sensed current through the resonance circuit crosses zero.

**[0023]** This feature is advantageous in the case where, when operating the lamp at low power levels, the resonance circuit becomes too damped to allow the sensed voltage to fluctuate enough to cross the predetermined voltage level in a negative direction. The predetermined wait time can therefore be used to prevent the lamp from turning off at low power levels as an alternative method of control to that in the first operational mode.

**[0024]** According to a second aspect of the invention there is provided a resonant power converter configured to drive a gas discharge lamp, the resonant power converter comprising:

- first and second series connected switches connected between first and second supply voltage lines;
- a resonance circuit comprising a capacitor and an inductor, the resonance circuit connected between a node connecting the first and second switches and the second supply voltage line, the resonance circuit having an output for connection to the gas discharge lamp; and
- a controller configured to operate the first and second switches according to the method of the first aspect of the invention.

**[0025]** According to a third aspect of the invention there is provided a fluorescent lamp assembly comprising the resonant power converter according to the second aspect of the invention connected to a gas discharge lamp.

**[0026]** The invention is described further below by way of exemplary embodiments and with reference to the ac-

companying drawings, in which:

figure 1 is a block diagram of a fluorescent lighting driver circuit;

figure 2 is a plot of output power as a function of switching frequency for a fluorescent lamp;

figure 3a is an exemplary circuit for a bridgeless boost topology resonant converter fluorescent lamp driver circuit;

figure 3b is an exemplary circuit for a resonant converter fluorescent lamp driver circuit with a 1:n transformer;

figure 4 is an exemplary circuit of a resonant converter according to an embodiment of the invention;

and

figures 5 to 10 comprise a series of plots of voltage and current levels as a function of time for an exemplary gas discharge lamp driving circuit under different modes of operation.

**[0027]** The invention in general relates to the control of a gas discharge lamp by a capacitor voltage control method. An embodiment of a driver circuit 400 is illustrated in figure 4. The driver circuit 400 comprises a controller 411, which provides high and low switching signals Qh, Ql to a half bridge driver 412. The half bridge driver 412 operates first and second switches 402, 403, which alternately connect a first supply voltage line 404 having a supply voltage Vbus and a second (or ground) supply voltage line 405 to a node 408 between the switches 402, 403. A resonance circuit comprising an inductor 407 and capacitor 409 is connected between the node 408 and the ground line 405, the inductor 407 in this case forming the primary side of a transformer. A sensing capacitor Cr/2 406 is provided as part of the resonance circuit. Typically the sensing capacitor 406 is one of a pair of capacitors connected between the ground line 405 and voltage supply line 404, although one capacitor 406 can be used instead, at the expense of possible increased electrical interference.

**[0028]** A gas discharge lamp 401 is connected to secondary sides 414, 415 of a transformer, the primary side 407 being connected to the node 408 between the switches 402, 403. Only the filaments of the lamp 401 are connected to the secondary winding of the transformer; the main current through the lamp 401 flows via the primary path comprising the inductor 407, lamp 401 and capacitor 406. In alternative embodiments the transformer may be omitted and the lamp driven directly by the switches 402, 403. A bridgeless boost topology, for example of the type illustrated in figure 3, may be used in alternative embodiments, with or without a transformer.

**[0029]** A voltage Vcr across the sensing capacitor 406 and a common mode voltage Vcm are provided to a calculation circuit 416, which is configured to provide signals to the controller 411 for driving the switches 402, 403 based on a power demand signal Vdm. The sensed voltage Vcr is typically divided by a capacitive divider (not

shown) to a level that can be handled by the calculation circuit 416. In this embodiment, the sensing capacitor 406 is also the main resonant capacitor. In general, a sensing capacitor will be placed in series with the current path. Variations may include placing the sensing capacitor in series with the primary side inductor 407.

**[0030]** The common mode voltage signal  $V_{cm}$  is provided from two pairs of resistive dividers 417, 418 connected across the voltage supply line 404 and ground 405, and between the sensing output node 413 and ground 405. This common mode voltage signal contains a DC offset of the signal at node 413, whereas the DC offset is absent from the sensed voltage signal  $V_{cr}$ .

**[0031]** At the start of a switching cycle, i.e. when switch 402 is closed, the voltage signal across the sampling capacitor 406 is sampled. The voltage then dips below this sampled voltage level, as a result of the direction of the current being reversed at the beginning of the conduction interval, before rising again until it reaches a higher voltage level, which triggers the switching signal to fall and the switch 402 to open. The switch 403 is then closed (typically after a short delay) and the other half cycle proceeds in the same way, with a different voltage level used. The voltage level used for the first and second half cycles may be equal and opposite, for example during steady state operation at a 50% duty cycle. Under other conditions, for example during startup or a change of operation, the voltage level for each half cycle may be different. A difference can be used to change the DC component of the sensed voltage over multiple cycles.

**[0032]** In the embodiment illustrated in figure 4, a predetermined voltage difference  $\Delta V$ , indicated as  $\Delta V_{crh}$  and  $\Delta V_{crl}$  for the high and low parts (or first and second parts) of each switching cycle, is used. This voltage difference, derived from a demand voltage signal,  $V_{dm}$ , is used to compare a reading of  $V_{cr}$  with a sampled version taken at the start of each half cycle. Using this method of control, there is no need to set a common mode term for  $V_{cr}$ , because only a difference in voltage is used, which is simpler to set. As the common mode term is not needed for taking the decision when to turn the conducting switch off, it eliminates the need for sensing the supply voltage  $V_{bus}$  by a capacitive divider and therefore allows for a simpler implementation. A further term  $V_{cr\_cm}$  can also be defined in order to obtain a correct duty cycle. This can be achieved by the use of a separate loop, for example using the actual duty cycle of the converter and regulating it to a desired duty cycle by adapting  $V_{cr\_cm}$ .

**[0033]** In alternative embodiments, a method of driving may be used according to WO 2006/103609, the disclosure of which is incorporated herein by reference.

**[0034]** A simulated result of operation of the driving circuit 400 of figure 4 is illustrated in figure 5, which shows the voltage across the lamp,  $V(vlamp)$  501, input current  $I(L2)$  502 (in a direction from the resonant tank to half bridge), the voltage at the half bridge node 408  $V(vhb)$  503, the voltage across the sensing capacitor 406  $V(vcr)$

504, the next switch-off criteria  $V(vcrhnext)$  505,  $V(vcrlnext)$  506, the voltage signal  $V(vdm)$  507 setting the power level, and the common mode voltage  $V(vcm)$  508. The voltage signal  $V(vcm)$  508 is used to adapt the DC component of  $V(vcr)$  504 by regulating it to half of the supply voltage, to provide power in the electrodes of the lamp in order to preheat the electrodes, given by the signal  $V(power\_electrodes)$  509 and power in the gas of the lamp, given by the signal  $V(powerburn)$  510.

**[0035]** Figure 5 further shows the sequence of preheat, ignition and burning according to an aspect of the invention. Between  $t=400ps$  and  $500us$ , the demand signal  $V(vdm)$  507 defines a low power level of approx 1 W while the lamp is not burning. This power heats up the electrodes of the gas discharge lamp. In practice this preheat phase typically takes about 0.5 to 1 s, but is shown in the simulation in figure 6 for only  $100\mu sec$  in order to show the principle. At  $t=500ps$  the  $V(vdm)$  signal 507 is increased, which increases the power provided to the lamp. This results in an increase of the lamp voltage 501 until the lamp ignites. From that moment onwards, the lamp voltage reduces because of the lamp resistance dropping from a high ohmic state to a low ohmic state of a few  $k\Omega$ .

**[0036]** Figure 6 shows further aspects of the simulation results, including the voltage signals  $V(vlamp)$  501,  $V(vdm)$  507,  $V(powerburn)$  510 and  $V(vhb)$  503, together values for the lamp resistance  $V(rac)$  601 and switching frequency  $V(fswitch\_khz)$  602. The switching frequency 602 is not the control input, as with previous solutions, but is the result and is determined by the voltage level at which, at the end of each half cycle, the switches 402, 403 are opened. As can be seen, as the demand signal 507 rises, the switching frequency 602 initially falls and then rises and stabilises as the power delivered to the electrodes 510 reaches a maximum.

**[0037]** As an addition to the above described capacitor voltage control method, the power set during the preheat, ignition and burning stages can be added as additional criteria for regulating or limiting the power. This may be achieved by sensing the lamp voltage during preheat and regulating or limiting the power delivered by control of the lamp voltage.

**[0038]** Figure 7 illustrates a further simulation of an exemplary feature concerning capacitive mode limitation. Where the power is increased during ignition, under certain conditions it is possible that the primary current  $I(L2)$  701 crosses zero before the end of a conduction interval. This is seen to occur at  $t=507\mu s$  (identified at point 702 in figure 7). The action is now to turn the relevant switch off before the current reverses. For sensing that the current reaches zero, the actual current can be sensed, for example by a sense resistor, but it is also possible to use the derivative of  $V(vcr)$  704, for example by means of a differentiating network sensing  $V(vcr)$ .

**[0039]** A second part of this capacitive mode feature is to prevent the switch from switching off as long as the current is not flowing in the correct direction. This prevents the switch from being switched off, and the opposite

switch from being switched on, too early at the beginning of the conduction cycle, i.e. while the current is still in the opposite direction. Switching off the conducting switch at this stage would mean that the body diode becomes forward biased. If then the opposite switch is turned on shortly afterwards, there is a risk that both switches can be destroyed. With reference again to figure 7, this means that the high side switch is prevented from being switched off until the current crosses zero, i.e. at  $t=502.8\mu\text{s}$  (identified at point 703 in figure 7), or at least when the current falls below a predetermined threshold value, which may be determined based on a peak value of the current, for example 10%, 5% or 1% of the peak current value.

**[0040]** Another exemplary feature relates to a mode of operation where, in combination with a gas discharge lamp load, a duty cycle of the conduction intervals can significantly differ from 50%, or frequencies significant below the resonant frequency can be used. Using the capacitor voltage control method, it is possible to turn a conducting switch off when the  $V(\text{vcr})$  criterion is met for the first time, as illustrated in figure 8. In this case the mode of operation occurs as described above.

**[0041]** It is also possible to add a second criterion, which can for example be a waiting time starting at the beginning of the conduction interval of a switch. As long as the second criterion is not valid, the  $V(\text{vcr})$  criterion is neglected. As soon as the second criterion is valid, the instance where the  $V(\text{vcr})$  criterion becomes valid is then taken as a new criterion to turn the conducting switch off. This is illustrated in figure 9. The high side switch is turned on at  $t=522\mu\text{s}$  (identified by line 901). The first time that the  $V(\text{vcr})$  criterion occurs is at  $t=526\mu\text{s}$  (identified by line 902). However, as the wait time has not elapsed (determined by signal  $V(\text{qhdel})$  903 going high), the system waits for the next instance when the  $V(\text{vcr})$  criterion is met. This is indicated in figure 9 by line 904 at  $t=537.8\mu\text{s}$ , which gives the same  $V(\text{vcr})$  905 as at  $t=526\mu\text{s}$  (at line 902) and therefore the same energy put into the resonant tank. This procedure could be repeated for the low side switch conduction interval, however in this example the low side conduction interval was determined using the first instant in time when the  $V(\text{vcr})$  criterion is met (at  $t=543\mu\text{s}$ ).

**[0042]** Using the above described method, it is possible to put the desired energy into the resonant tank every cycle, as the energy is set by the difference in  $V(\text{vcr})$  between the start and end of each conduction interval. It is also possible to set a desired time period for the converter independently. This results in the possibility of controlling the power delivered to the load by two independent parameters (i.e. by  $V(\text{vcr})$  and the operating frequency).

**[0043]** A further feature, which may be used in combination with the above feature, is particularly useful if the  $V(\text{vcr})$  criterion cannot be met. This can for example occur when the resonance is damped, as shown in the exemplary simulation result in figure 10. This damping occurs when the equivalent resistance of the lamp is low, for

example when operating the lamp at higher power levels. At  $t=342\mu\text{s}$  (identified by line 1001), the high side conduction cycle starts. At  $t=357\mu\text{s}$  (identified by line 1002), the  $V(\text{vcr})$  criterion (i.e. when  $V(\text{vcr})$  1003 crosses  $V(\text{vcrnext})$  1004 in a positive direction) is met for the first time. After that instant, the resonant tank is too much damped to let  $V(\text{vcr})$  cross  $V(\text{vcrnext})$  in a negative direction. Therefore the  $V(\text{vcr})$  criterion cannot be met anymore for the actual half cycle. Without further measures the converter would stop switching. Several actions may be taken to prevent the converter from stopping. According to a first option, a check is made of whether  $V(\text{vcr})$  1003 is lower than  $V(\text{vcrnext})$  1005 at the next negative zero crossing of the current. If this is not the case (for example at  $t=368\mu\text{s}$ , indicated by line 1006), then the  $V(\text{vcrnext})$  criterion cannot be further met. The high side switching (HSS) conduction interval is then finished at that moment ( $t_1$ ). In a general aspect according to this first option the first switch 402 (figure 4) is opened to end the first conduction interval after a predetermined wait time determined by a delay signal and when a sensed current through the resonance circuit crosses zero.

**[0044]** According to a second option,  $V(\text{vcr})$  is allowed to rise as much as possible after the point at the next negative zero crossing, in order to put the largest energy possible into the resonant tank. This is indicated in figure 10, where at  $t=375\mu\text{s}$  (indicated by line 1007) the primary current crosses zero, giving a maximum of  $V(\text{vcr})$  when the switch is turned off. Also a value of the primary current close to zero is an option to have some energy available for soft switching. In a general aspect according to this second option, the first switch 402 (figure 4) is opened to end the first conduction interval after a predetermined wait time determined by a delay signal and when the voltage across the capacitor 406 reaches a maximum.

**[0045]** According to a third option, a choice is made for a switch-off moment inbetween the first and second option. The HSS conduction interval is finished at that moment, for example at the moment the wait time has elapsed (determined by signal  $V(\text{qhdel})$  1008 going high). In a general aspect according to this third option, the first switch 402 (figure 4) is opened to end the first conduction interval after a predetermined wait time determined by a delay signal, after a sensed current through the resonance circuit crosses zero and before the voltage across the capacitor 406 reaches a maximum.

**[0046]** The same procedure is also applicable to the situation where, during the low side switch conduction interval, the low side switch is kept on during an extended interval.

**[0047]** The invention described herein can be applied in particular to CFL ballast applications, but may also be applied more generally for use in driving other kinds of gas discharge lamps.

**[0048]** Other embodiments are intended to be within the scope of the invention, as defined by the appended claims.

Claims

1. A method of controlling a resonant power converter (400) to drive a gas discharge lamp (401), the resonant power converter comprising first and second series connected switches (402, 403) connected between first and second supply voltage lines (404, 405) and a resonance circuit comprising a capacitor (406) and an inductor (407), the resonance circuit connected between a node (408) connecting the first and second switches (402, 403) and the second supply voltage line (405), the method comprising, in an operational mode, the repeated sequential steps of:

closing the first switch (402) to start a first conduction interval; and  
 opening the first switch (402) to end the first conduction interval when a voltage across the capacitor (406) crosses a predetermined first voltage level,  
 wherein controlling the predetermined first voltage level determines an amount of energy provided to the gas discharge lamp (401) over the first conduction interval.

2. The method of claim 1 wherein the method comprises, in the operational mode, the sequential steps of:

closing the second switch (403) after opening the first switch to start a second conduction interval; and  
 opening the second switch (403) to end the second conduction interval when a voltage across the capacitor (406) crosses a predetermined second voltage level,  
 wherein the first and second conduction intervals alternate over time, the predetermined first and second voltage levels determining a power level provided to the gas discharge lamp (401).

3. The method of claim 2 wherein the first and second switches are opened and closed sequentially at a switching frequency determined by the predetermined first and second voltage levels.

4. The method of claim 1 wherein a current through the lamp is sensed, the first switch being closed only when the current is flowing in a direction to provide a reverse bias across a diode connected across the first switch.

5. The method of claim 2 wherein the first or second conduction intervals are determined by the predetermined first or second voltage levels to provide a duty cycle of power supplied to the lamp of less than 50% over successive switching cycles.

6. The method of claim 1 wherein the first switch is

opened after a predetermined wait time determined by a delay signal.

7. The method of claim 1 wherein the first switch is opened when the voltage across the capacitor is lower than the predetermined voltage level as a sensed current through the lamp falls below a predetermined threshold value.

8. The method of claim 2 wherein, over a plurality of successive switching cycles, the method comprises the sequential steps of:

a preheating stage wherein the predetermined voltage levels are set to heat the lamp electrodes below an ignition level of the lamp;  
 an ignition stage wherein the predetermined voltage levels are increased until the gas discharge lamp ignites; and  
 a continuous lighting stage wherein the predetermined voltage levels are reduced to a steady level to maintain operation of the gas discharge lamp.

9. The method of claim 1 wherein the operational mode is a first operational mode, the method comprising, in a second lower power operational mode:

closing the first switch (402) to start a first conduction interval; and  
 opening the first switch (402) to end the first conduction interval after a predetermined wait time determined by a delay signal and when a sensed current through the resonance circuit crosses zero.

10. The method of claim 1 wherein the operational mode is a first operational mode, the method comprising, in a second lower power operational mode:

closing the first switch (402) to start a first conduction interval; and  
 opening the first switch (402) to end the first conduction interval after a predetermined wait time determined by a delay signal and when the voltage across the capacitor (406) reaches a maximum.

11. The method of claim 1 wherein the operational mode is a first operational mode, the method comprising, in a second lower power operational mode:

closing the first switch (402) to start a first conduction interval; and  
 opening the first switch (402) to end the first conduction interval after a predetermined wait time determined by a delay signal, after a sensed current through the resonance circuit crosses zero

and before the voltage across the capacitor (406) reaches a maximum.

- 12. A resonant power converter configured to drive a gas discharge lamp (401), the resonant power converter (400) comprising: 5

first and second series connected switches (402, 403) connected between first and second supply voltage lines (404, 405); 10

a resonance circuit comprising a capacitor (406) and an inductor (407), the resonance circuit connected between a node (408) connecting the first and second switches (402, 403) and the second supply voltage line (405), the resonance circuit having and output for connection to the gas discharge lamp; and 15

a controller (411) configured to operate the first and second switches (402, 403) according to the method of any one of claims 1 to 11. 20

- 13. A fluorescent lamp comprising the resonant power converter of claim 12 connected to a gas discharge lamp (401). 25

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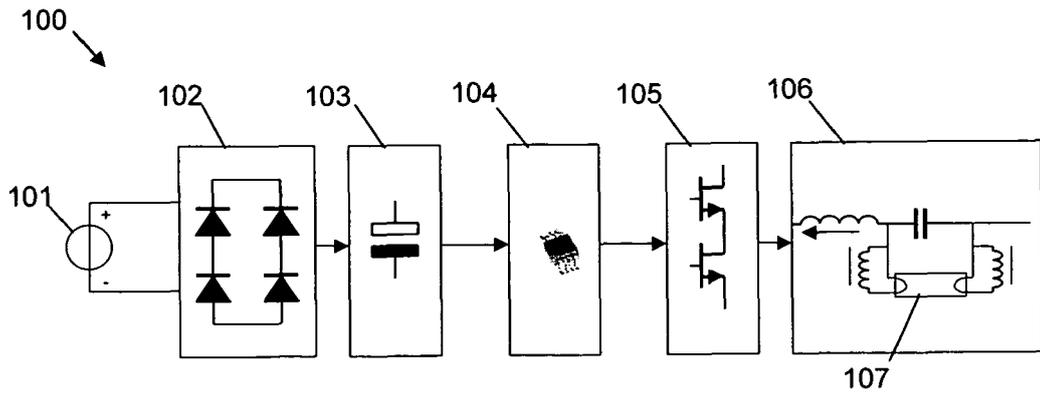


Fig. 1

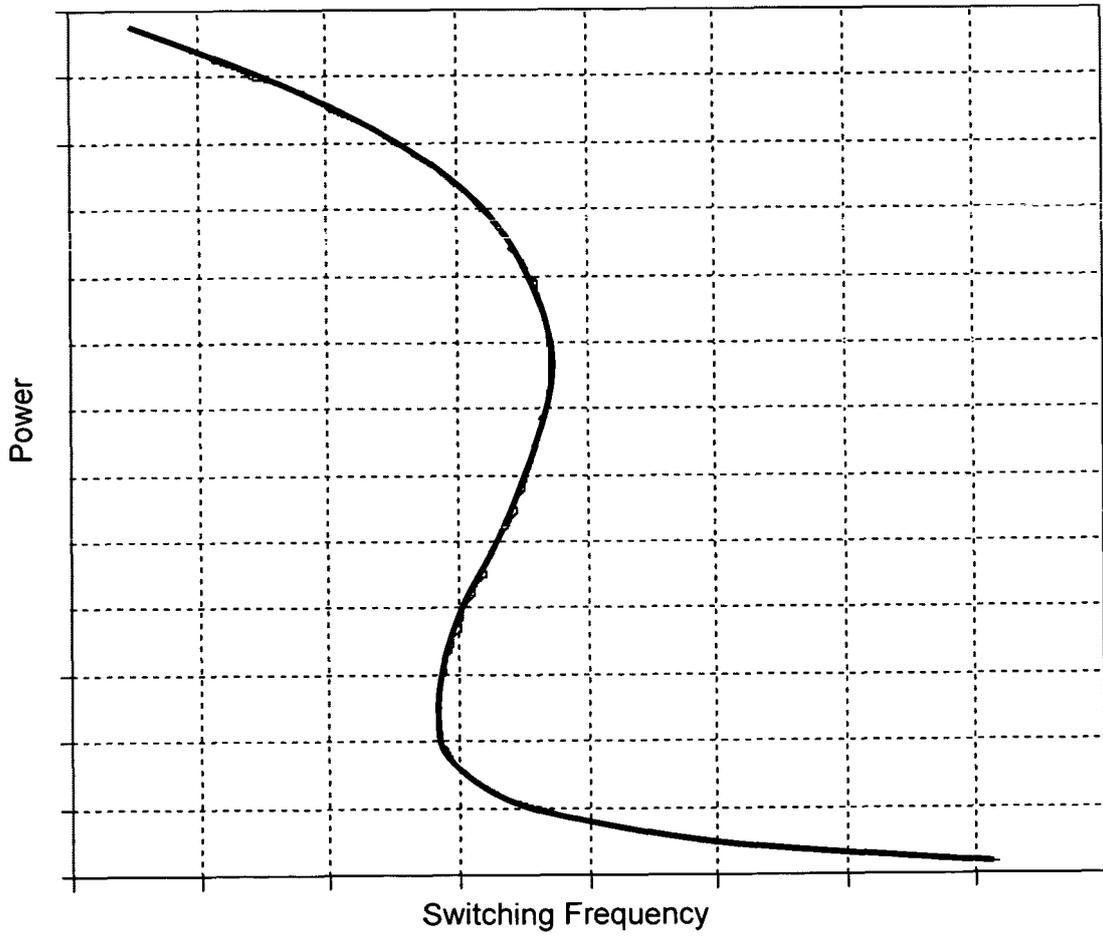


Fig. 2

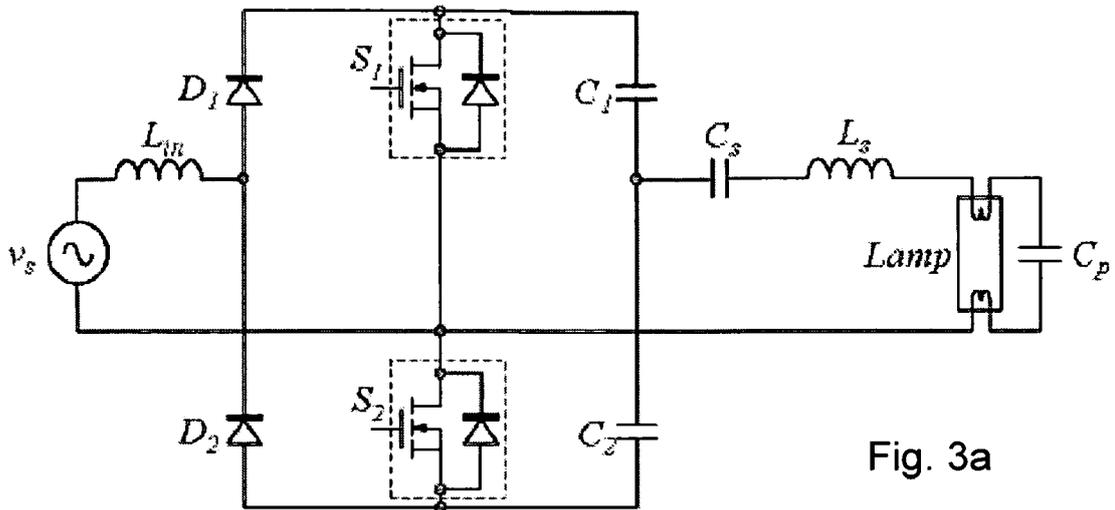


Fig. 3a

(a)

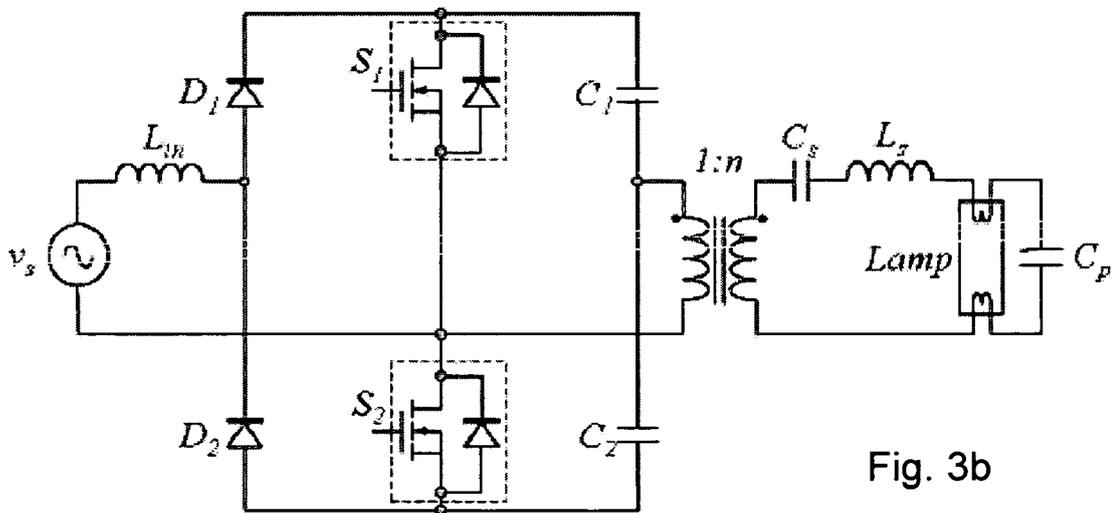


Fig. 3b

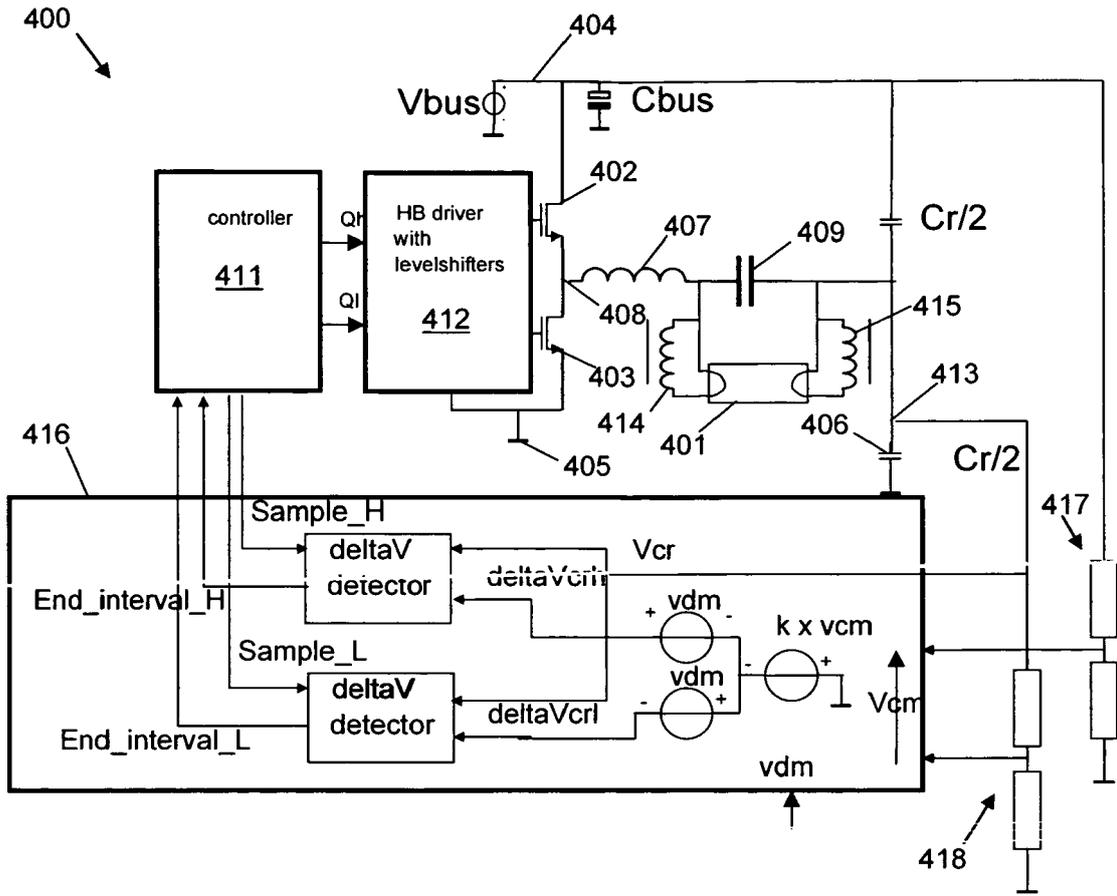


Fig. 4

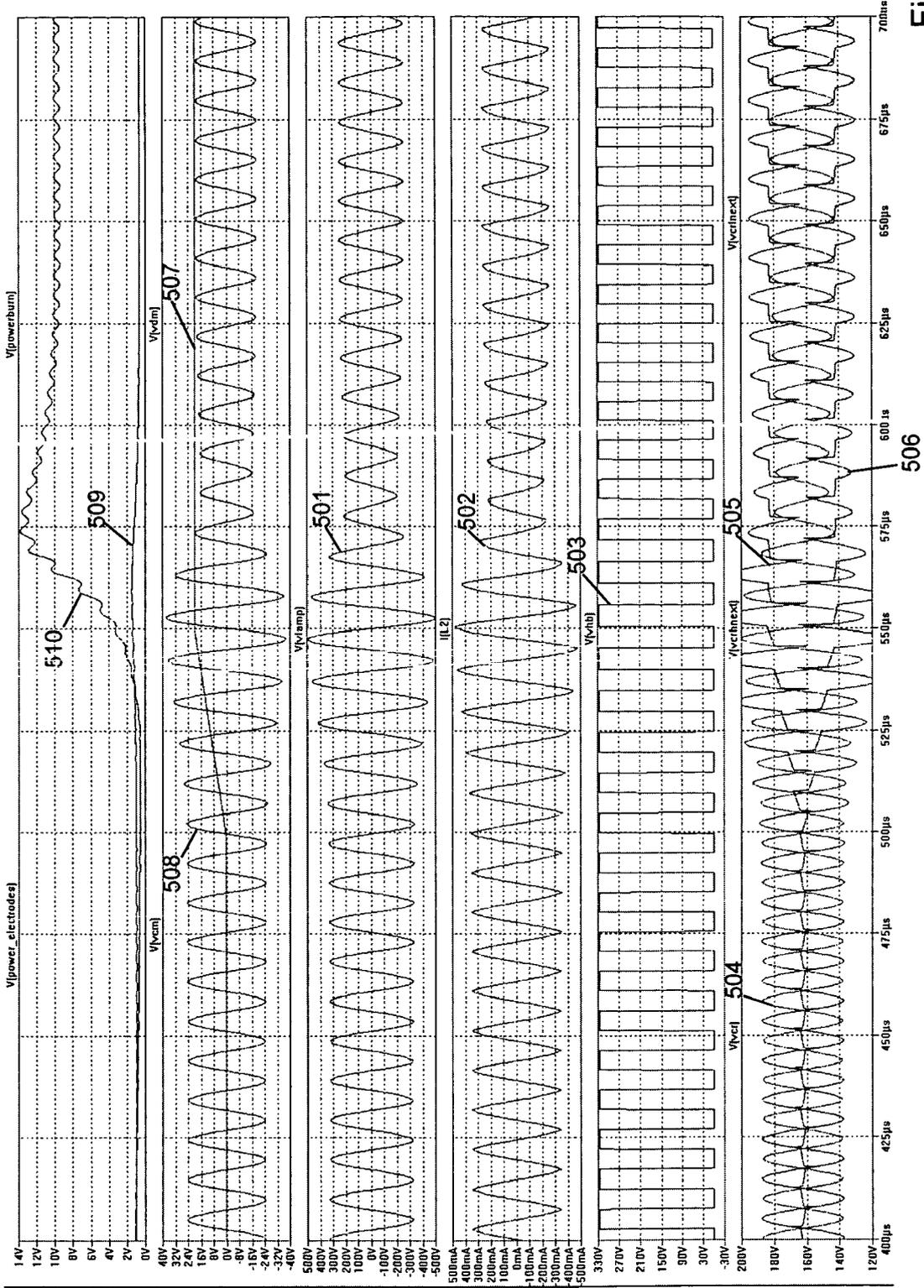


Fig. 5

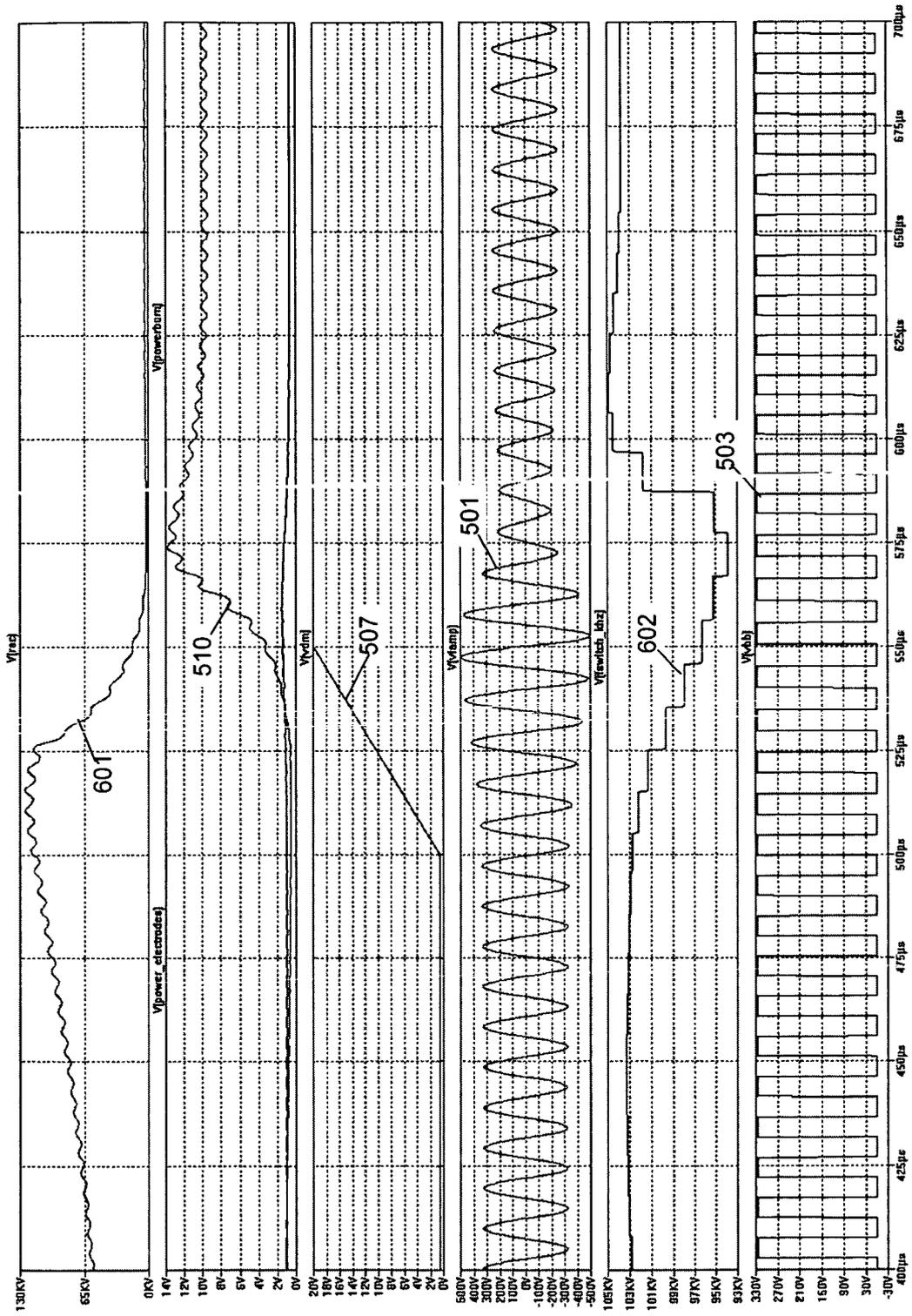
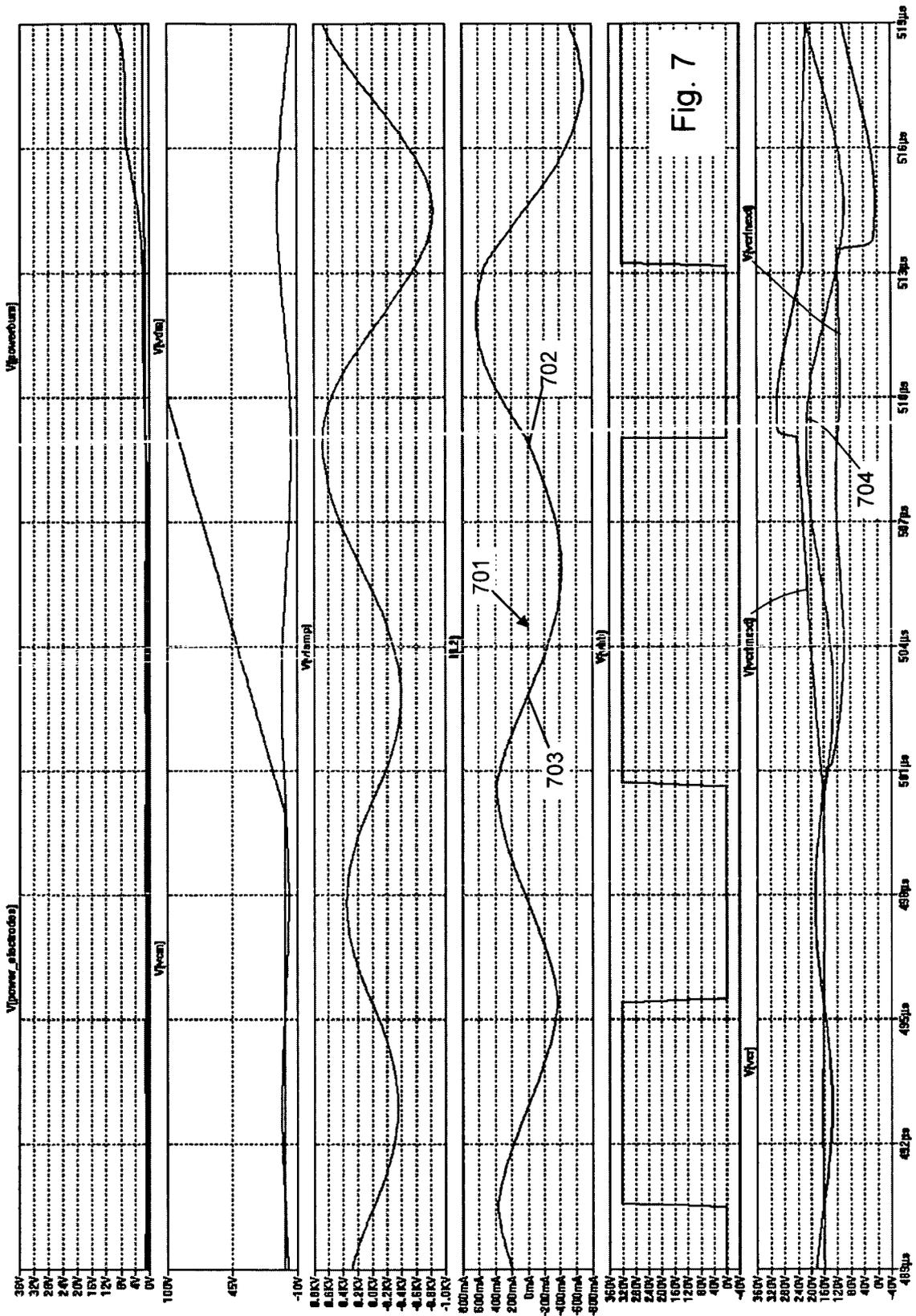


Fig. 6



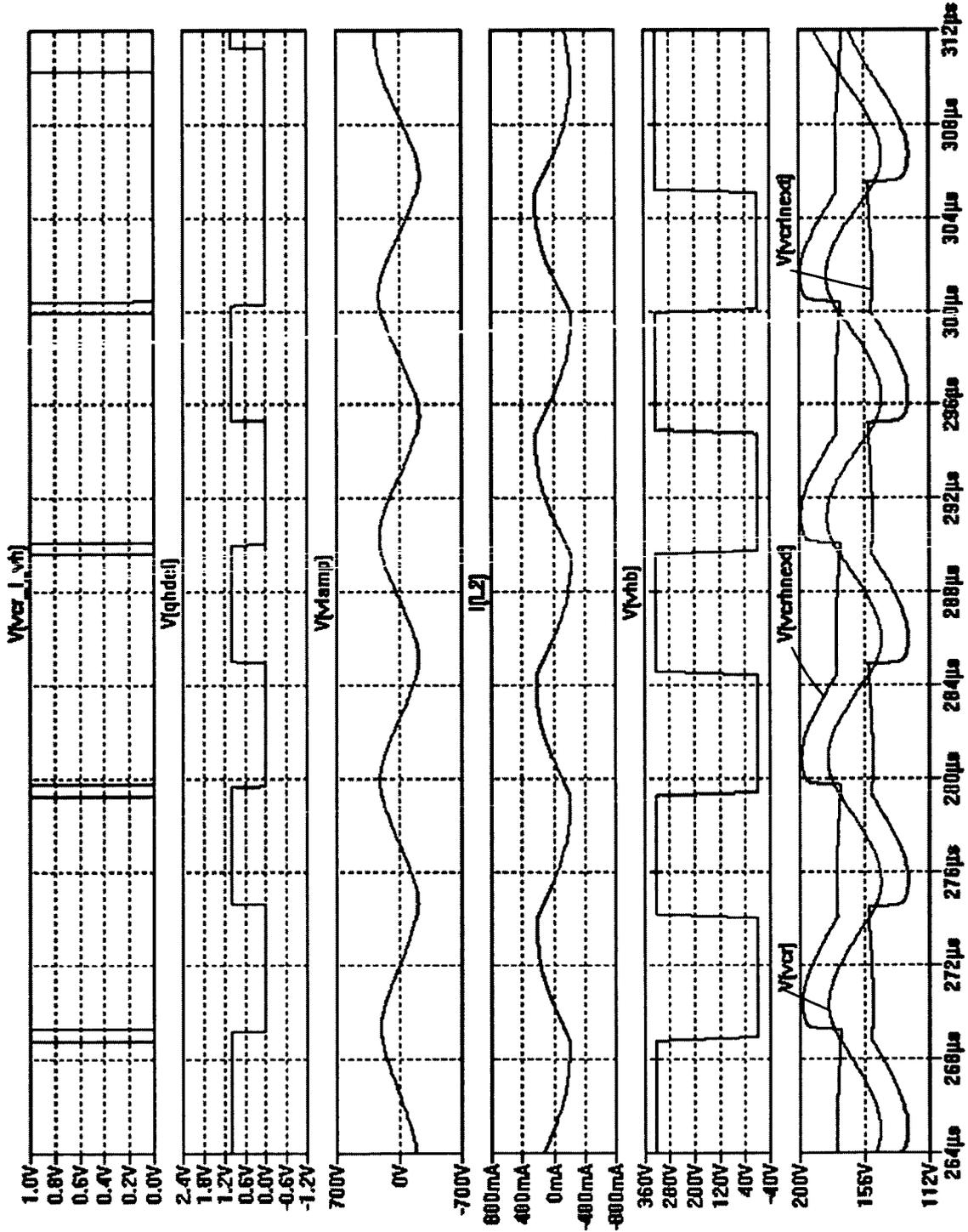


Fig. 8

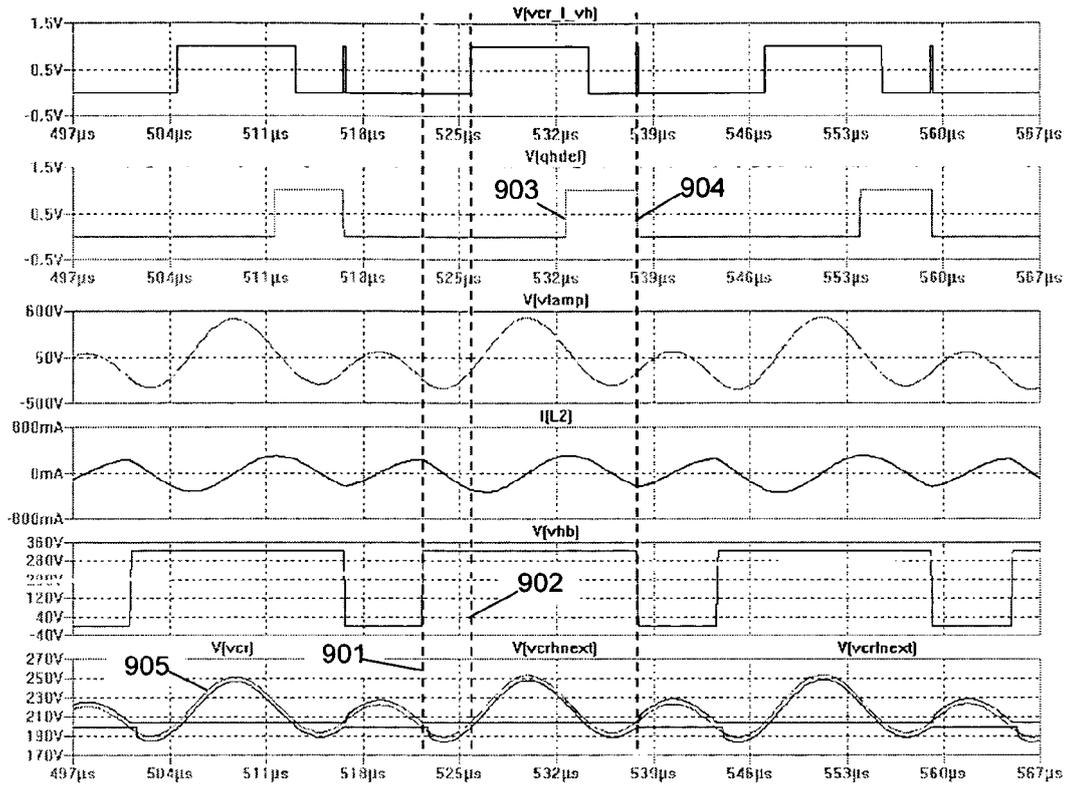


Fig. 9

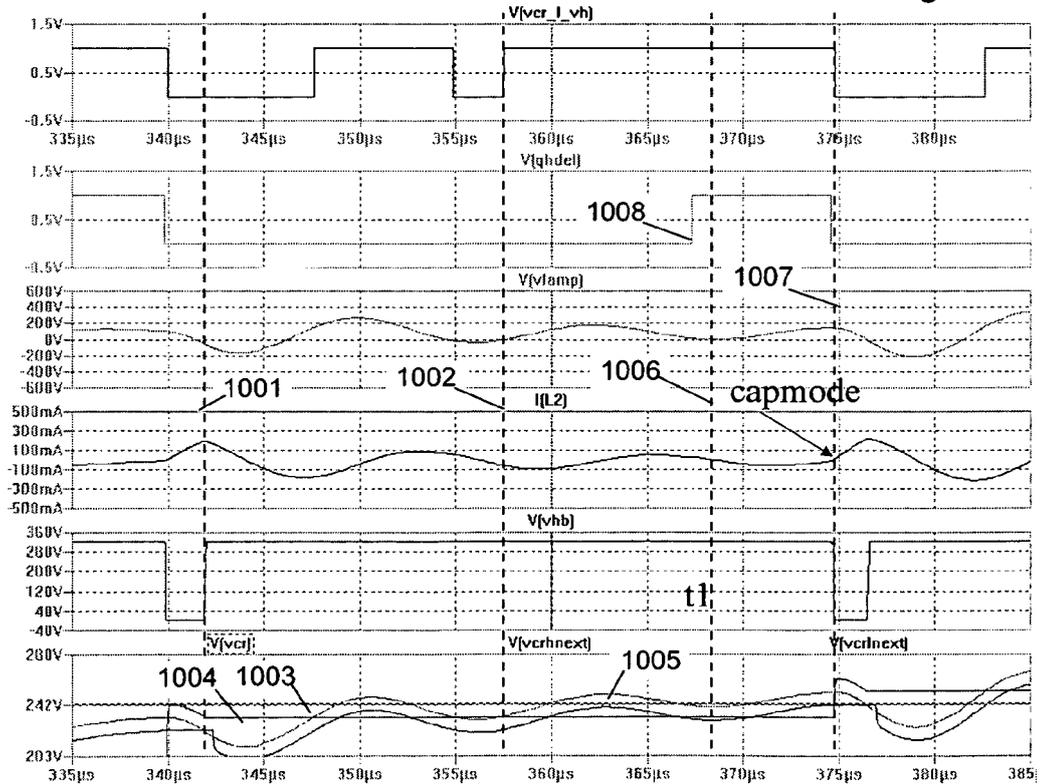


Fig. 10



EUROPEAN SEARCH REPORT

Application Number  
EP 11 25 0662

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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 2 January 2012	Examiner Ferla, Monica
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ..... & : member of the same patent family, corresponding document	

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EPO FORM 1503 03.82 (P04C01)

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