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(54) Operating electrical machines from a DC link

Betrieb elektrischer Maschinen von einer DC-Verbindung aus

Commande de machines électriques à partir d'une liaison CC

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(56) References cited:

EP-A- 0 752 753	**EP-A- 0 982 194**
WO-A-2006/098703	**DE-A1- 3 223 786**
DE-A1- 10 261 739	**US-A- 4 263 535**
US-A1- 2004 027 105	**US-A1- 2005 105 897**

- **RADUN A: "Generating with the switched reluctance motor" APPLIED POWER ELECTRONICS CONFERENCE AND EXPOSITION, 1994. APEC '94. CONFERENCE PROCEEDINGS 1994., NINTH ANNUAL ORLANDO, FL, USA 13-17 FEB. 1994, NEW YORK, NY, USA,IEEE, 13 February 1994 (1994-02-13), pages 41-47, XP010118593 ISBN: 0-7803-1456-5**

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Description

[0001] The present invention generally relates to a system and method for operating a plurality of electrical machines from a DC link. More particularly, though not exclusively, the present invention relates to the stability of such a DC link on which electronically switched machines are required to operate together.

[0002] One example of such switched machines is the switched reluctance machine. A general treatment of electrical drives which incorporate switched reluctance machines can be found in various textbooks, e.g. "Electronic Control of Switched Reluctance Machines" by TJE Miller, Newnes, 2001. More detail is provided in the paper "The characteristics, design and application of switched reluctance motors and drives" by Stephenson and Blake, PCIM'93, Nürnberg, 21-24 June 1993.

[0003] Figure 1 of the accompanying drawings shows a typical switched reluctance drive in schematic form, where the switched reluctance machine 12 is connected to a load 19. The DC power supply 11 can be either a battery or rectified and filtered AC mains or some other form of energy storage. The DC voltage provided by the power supply 11 is switched across the phase windings 16 of the machine 12 by a power converter 13 under the control of the electronic control unit 14. The switching must be correctly synchronised to the angle of rotation of the rotor for proper operation of the drive, and a rotor position detector 15 is typically employed to supply signals corresponding to the angular position of the rotor. The rotor position detector 15 may take many forms, including that of a software algorithm, and its output may also be used to generate a speed feedback signal. The presence of the position detector and the use of an excitation strategy which is completely dependent on the instantaneous position of the rotor leads to the generic description of "rotor position switched" for these machines.

[0004] Many different power converter topologies are known for this type of machine, several of which are discussed in the Stephenson paper cited above. One of the most common configurations is shown for a single phase of a polyphase system in Figure 2, in which the phase winding 16 of the machine is connected in series with two switching devices 21 and 22 across the busbars 26 and 27. Busbars 26 and 27 are collectively known as the "DC link" of the converter. Energy recovery diodes 23 and 24 are connected to the winding to allow the winding current to flow back to the DC link when the switches 21 and 22 are opened. A low-value resistor 28 may be connected in series with the lower switch to act as a current-sense resistor. A capacitor 25, known as the "DC link capacitor", is connected across the DC link to source or sink any alternating component of the DC link current (ie the so-called "ripple current") which cannot be drawn from, or returned to, the supply. In practical terms, the capacitor 25 may comprise several capacitors connected in series and/or parallel and, where parallel connection is used, some of the elements may be distributed throughout the converter.

[0005] Figure 3 shows typical waveforms for an operating cycle of the circuit shown in Figure 2 when the machine is in the motoring mode. Figure 3(a) shows the voltage being applied at the "on angle" (θ_{on}) for the duration of the conduction angle θ_c when the switches 21 and 22 are closed. Figure 3(b) shows the current in the phase winding 16 rising to a peak and then falling. At the end of the conduction period, the "off angle" (θ_{off}) is reached, the switches are opened and the current transfers to the diodes, placing the inverted link voltage across the winding and hence forcing down the flux and the current to zero. At zero current, the diodes cease to conduct and the circuit is inactive until the start of a subsequent conduction period. The current on the DC link reverses when the switches are opened, as shown in Figure 3(c), and the returned current represents energy being returned to the supply. The shape of the current waveform varies depending on the operating point of the machine and on the switching strategy adopted. As is well-known and described in, for example, the Stephenson paper cited above, low-speed operation generally involves the use of current chopping to contain the peak currents, and switching off the switches non-simultaneously gives an operating mode generally known as "freewheeling".

[0006] As is well known in the art, switched reluctance machines can be operated in the generating mode, in which the phase currents are mirror images (in time) of the motoring currents. Such systems are discussed in, for example, "Generating with the switched reluctance motor", Radun, Proceedings of the IEEE 9th Applied Power Electronics Conference, Orlando, Florida, 13-17 Feb 1994, pp 41 - 47. Figure 4(a) illustrates a current waveform when the system is motoring and Figure 4(b) illustrates the corresponding current waveform for generating. It will be seen from Figure 4(b) that the machine requires a "priming" or magnetising flux to be established (along with the necessary current to support this flux) before the larger current is returned to the DC link. In other words, some electrical energy is required from the DC link to prime the machine before it is able to convert the larger amount of mechanical energy back to the DC link. Part of the function of the DC link capacitor is to supply the ripple component of this current.

[0007] The waveforms shown in Figures 3 and 4 are of the "single-pulse" type, usually associated with high speed operation. Chopping waveforms are shown in Figures 5 and 6 for motoring operation. Figure 5(a) shows a phase current waveform where the conduction period begins in the centre of the minimum inductance region and ends at the centre of the maximum inductance region. During the conduction period, a suitable current controller maintains the current in a hysteresis band defined by I_u and I_l. When the upper current I_u is reached, the controller opens both switches and the current and flux fall under the action of the reverse voltage until the lower current I_l is reached, whereupon the chopping cycle begins again. The phase current of Figure 5(a) corresponds to the supply current of Figure 5(b), where it will be seen that the ripple current is high, with spikes of returned current each time the top of the hysteresis band is reached.

[0008] The effect of introducing freewheeling into this chopping regime is shown in Figure 6(a), where only one switch is opened when the upper current limit is reached. The rate of flux decay, and hence current decay is now much less, so the chopping frequency is reduced. Current is only returned to the supply at the end of the conduction period, when both switches are opened. This reduction in the ripple current associated with the supply current allows a reduction in the size of the DC link capacitor, and is often one of the main factors in deciding to use a freewheeling strategy of this type. Of course, the peak current drawn from the link at θ_{on} is unchanged, so any reduction in capacitor size will lead to an increase in the voltage dip in the bus at θ_{on}. With a single drive operating on its own DC link, this increased voltage ripple is generally of little consequence and is tolerated for the sake of the cost saving in capacitor size.

[0009] The voltage ripple on the DC link can be significant, however, when two or more drive systems are operated together. For example, Figure 7 shows a system where a prime mover 70 (e.g. an internal combustion engine) is mechanically coupled to and drives a switched reluctance machine 72 which operates in generating mode. The generator has its own power converter 74 and control electronics 75. The output of this generator appears on the DC bus 76 and is supplied to the power converter 77 of a second switched reluctance machine 78 which has a controller 79 and operates as a motor driving a load 80. Such a system could be found in, e.g., a marine application or in a hybrid electric vehicle. The DC link capacitor 82 is effectively the capacitor serving both power converters 74 and 77, though in practice it would be distributed between the converters in order to suppress transient effects associated with self-inductance of the layout of the components. The motoring and generating systems are now linked by a common DC bus, so features in the electrical waveform imposed on the bus by one system will be experienced by the other.

[0010] It will be appreciated that there is no requirement for the machines to operate at the same speed. The speed of the motor 78 will be a function of the load 80 and the performance demanded by the user. The speed of the generator 72 is determined by the prime mover 70. The speed of the prime mover is determined by the system designer, who can program the speed and torque so as to most efficiently provide the power required by the load 80. Thus the speeds of the generator and the motor are not linked in any simple way.

[0011] As described above, the generator draws its excitation from the DC bus at the beginning of each cycle of phase conduction. In order to generate the required output, the flux in the machine must reach the appropriate level before the switches open and energy return begins. Since the flux is the integral over time of the applied voltage, the exact level of DC link voltage at the moment of excitation is now important for correct operation of the generator. If the voltage dips because a phase of the motor has just been switched on and the DC link capacitor is unable to supply sufficient energy to maintain the link voltage, the excitation of the generator will be less than expected and the output from the generator in the second part of the cycle will be correspondingly less. This may lead to a longer depression of the DC link voltage, requiring the control system 75 of the generator to intervene and adjust the conduction angles to restore the output of the generator. There is clearly the potential for an instability to set in, requiring care in the design of the parameters of the control system, particularly the bandwidth, and in sizing the DC link capacitor.

[0012] Since the two machines are not in any way linked in terms of the frequency of one with respect to the other (i.e. they are 'frequency wild'), it is very difficult to test every combination of machine speeds and loads to ascertain correct system performance.

[0013] While the system is generally tolerant of small perturbations, aided by the energy stored by virtue of the inertia of the rotating parts, there are situations where the disturbance can be high on random occasions. For example, in the excitation pattern frequently used in high-output motors, two or more phases can have their conduction periods overlapping. The chopping action in these phases is effectively frequency wild, since the frequency will change through the conduction period. This additional pattern is superimposed on the existing complex voltage appearing on the DC link. If two phases are switched on together, there will be a much larger voltage dip on the DC link as energy is drawn from the DC link capacitor. This problem is magnified in arrangements where the generator feeds a plurality of drives, e.g. as shown in Figure 8. In Figure 8, the DC link now supplies a series of converters 77a, 77b, 77c which serve motors 78a, 78b, 78c driving loads 80a, 80b,80c. Unless these loads are mechanically linked, the motors will be frequency wild with respect to each other, so there is now a random chance of coincidence of a large number of phases being switched onto the DC link simultaneously. In this event, the voltage on the DC link will exhibit a severe dip and the generator may fail to receive any significant amount of excitation from the link when it next requires it. The DC link voltage will therefore collapse and the system will stall. This is extremely serious in many applications, especially where the loads are safety critical.

[0014] The only prior art solution to this problem is to add more and more capacitance to the DC link to support the voltage and suppress the voltage ripple. This has drawbacks. Firstly, the extra capacitance is costly to install, and needs extra space to house it. In many applications, space is not available and, in any case, the extra cost is unwelcome. Such capacitors have a finite life, unlike most other parts of the drive system, so the capacitors need to be renewed on a regular basis to maintain the integrity of the drive, and this represents a further cost associated with maintaining the drive. Secondly, the increased capacitance is now distributed among the generator and traction drives, linked by cables that have significant self-inductance. This introduces the likelihood of parasitic oscillations being generated on the DC link, which can themselves produce damaging effects and can lead to shut down of the drive.

[0015] There is therefore a need for a method of controlling the voltage ripple on the DC link to address this potential instability. In accordance with embodiments of the present invention, the foregoing disadvantages of known drive systems are overcome in a reliable and cost-effective manner.

[0016] The present invention is defined in the accompanying independent claims. Preferred features of the invention are recited in the claims respectively dependent thereon.

[0017] Other aspects and advantages of the invention will become apparent upon reading the following detailed description of exemplary embodiments of the invention and upon reference to the accompanying drawings, in which:

Figure 1 is a schematic drawing of a prior art switched reluctance drive;
Figure 2 is a prior art excitation circuit for the switched reluctance machine of Figure 1;
Figure 3(a) is a phase voltage waveform for the circuit shown in Figure 2;
Figure 3(b) is the phase current waveform corresponding to Figure 3(a);
Figure 3(c) is the supply current waveform corresponding to Figure 3(a);
Figure 4(a) shows a prior art motoring current waveform;
Figure 4(b) shows a prior art generating current waveform;
Figure 5(a) shows a phase current in the chopping mode;
Figure 5(b) shows the supply current corresponding to Figure 5(a);
Figure 6(a) shows a phase current in the chopping mode with freewheeling;
Figure 6(b) shows the supply current corresponding to Figure 6(a);
Figure 7 shows a generating system supplying a single motor;
Figure 8 shows a generating system supplying several motors;
Figure 9(a) shows a waveform of DC link voltage for the operation of the system of Figure 7;
Figure 9(b) shows a waveform of motor phase current for the system of Figure 7;
Figure 10(a) shows a waveform of DC link voltage where the current demand collapses the link;
Figure 10(b) shows the corresponding motor phase current;
Figure 11 shows phase current according to an embodiment; and
Figure 12 shows a flow chart depicting an embodiment of the invention.

[0018] The illustrations below refer to a system configured as shown in Figure 7 with 3-phase machines. However, machines with any number of phases could be used in accordance with the invention and the phase number of the generator and motor(s) need not be the same. Control of the respective machines 72 and 78 is implemented in software loaded in the memory 81 of controls 75 and 79. According to their respective control algorithms the power converter switches are actuated. In this embodiment, the technique is implemented in the software. Figure 7 also shows a monitoring device 83 which is arranged to monitor the DC link voltage. This is used for general system monitoring purposes, but is also used in relation to an embodiment disclosed herein. The monitoring device can take a number of different forms that will be known to the person of ordinary skill in the art and will not be elaborated on here.

[0019] Figure 9 shows the operating characteristics of a system as shown in Figure 7 but which is conventionally controlled. The motor is accelerating from a very low load at low speed to full load at higher speed. This could correspond to a vehicle operating under full acceleration demand, where the demand has a ramp to avoid exciting resonances in the drive train. The DC link voltage is shown as a function of time in Figure 9(a) and the current waveform for one phase of the motor is shown in Figure 9(b). The other phase currents are not shown, but will be interleaved with the waveform of Figure 9(b) at the appropriate spacing. In Figure 9(a) it will be seen that the voltage is essentially constant until the phase current begins to rise. The large periodic dips in the voltage correspond to the switch-on point for each incoming phase of the motor, indicating that the DC link capacitor cannot supply sufficient energy to maintain the voltage. The smaller perturbations on the waveform are due to a combination of the switching of the phases in the generator (which is at a much higher frequency) and the chopping action in the phases of the motor. In this particular example, the nominal voltage of 600V dips to 250V as the motor moves the load from rest, though the system survives this and recovers to successfully accelerate the load up to speed.

[0020] Figure 10 shows the same system of Figure 7 operating under slightly different conditions. The DC link voltage is shown as a function of time in Figure 10(a) and the current waveform for one phase of the motor is shown in Figure 10(b). In this example, the switching operations in the motor have coincided to produce a demand on the DC link that suddenly drags the voltage below the point where it is unable to supply sufficient excitation to the generator. The output of the generator fails to provide enough output to meet the system demand, so the link "stalls" to zero volts and the motor current collapses. This would represent a failure of the system to start and accelerate to the required speed. To address these stall conditions, the DC link needs to be stabilised against the random disturbances.

[0021] An embodiment, implemented in the control software, includes monitoring the DC link voltage using the monitoring device 83. A predetermined DC link voltage threshold is set at a level below which operation is considered to be hazardous because the risk of the system stalling is unacceptably high. The control system monitors the DC link voltage, switching the phases as normal. When the predetermined DC link voltage threshold is reached, it forces one or more of the conducting phases into a freewheel condition by opening one of the phase switches in response to a signal from the monitoring device 83. This immediately reduces the current demand from the DC link for that phase to zero (as previously shown in Figure 6(b)) yet maintains a significant level of current in the phase. The overall effect on the output of the motor is therefore relatively small. The control system continues to monitor the DC link voltage and, when it recovers to a value above the threshold, the phase(s) are put back into full conduction by re-closing the switch in response to a further signal from the monitoring device. Those skilled in the art will realise that a simple hysteresis band can be put around the threshold to avoid switching in and out of the stall prevention mode too frequently (commonly known as "chatter"). This is illustrated in Figure 11, where the control system has sensed a voltage dip as the first full block of phase conduction has begun, and a period of freewheeling has been inserted in the rising edge of the block to allow the DC link to recover. The flow chart for implementing this embodiment is illustrated in Figure 12.

[0022] This embodiment has the advantage that no action is taken until absolutely necessary, and even then the impact on the motor output is small, while the DC link is held in a stable and safe condition at all times. Effectively, this embodiment makes full use of the capacitance in the DC link by maintaining it at or just above the point of instability during conditions of high demand. Because of this, the capacitance on the link can be reduced to levels below that normally considered safe, so that a more economical system can be produced. The threshold voltage is predetermined, taking account of such factors as the number of machines in the system, the size of the generator relative to the motors, the speeds of the machines and their coupled inertias, the amount of capacitance, the reliability required from the system, etc. In one system operating on a nominal 650V bus, a threshold voltage of 320V is chosen, with a hysteresis band of 30V sitting above the 320V.

[0023] An alternative version of the above embodiment is to detect when the voltage threshold has been reached and then to put the phase(s) into full energy return by opening both phase switches. While this will force the flux and current down at a much faster rate and hence reduce the torque of the machine more, it has the benefit that the current being returned to the DC link will assist in recovering from the voltage dip. The system designer can therefore choose between the freewheel method giving smoother torque or the energy return method giving faster recovery. It is possible to combine these two variants to firstly put the phase(s) into freewheeling in the expectation that the voltage will recover, but secondly put the phase(s) into energy return if the recovery does not take place within a predetermined time. This predetermined time will be set principally in relation to the generator phase conduction period, which, for a machine with 12 rotor poles operating at 2000 rev/min, will typically be of the order of 2.5msec.

[0024] Embodiments include the computer program product stored on a computer readable medium as used in the system controllers. The medium may be solid state memory or other storage device enabling processing for controlling the machine to implement the control regime according to the disclosed embodiments. The controller may be a general purpose processor or other computer means running under the command of the program. Equally well, the embodiments can use a dedicated device, such as an application specific integrated circuit (ASIC).

[0025] The skilled person will appreciate that variation of the disclosed arrangements are possible without departing from the invention which is defined in the following claims.

Claims

1. A method of operating a plurality of electrical machines (72, 78) from a DC link, each machine (72, 78) having at least one phase winding (16), the method comprising monitoring the DC link voltage and, in the event that the DC link voltage decreases to a predetermined threshold, controlling the current in at least one phase winding (16) in at least one of the electrical machines (72, 78) to modify the current in the DC link, thereby to control the magnitude of disturbances in the DC link voltage caused by the combined load of the plurality of electrical machines (72, 78),
characterised in that at least one of the plurality of electrical machines (72, 78) is a switched reluctance machine and **in that** the current in the DC link is modified by freewheeling the current in at least one of the phase windings (16) of the switched reluctance machine.

2. A method of operating a plurality of electrical machines (72, 78) from a DC link, each machine (72, 78) having at least one phase winding (16), the method comprising monitoring the DC link voltage and, in the event that the DC link voltage decreases to a predetermined threshold, controlling the current in at least one phase winding (16) in at least one of the

electrical machines (72, 78) to modify the current in the DC link, thereby to control the magnitude of disturbances in the DC link voltage caused by the combined load of the plurality of electrical machines (72, 78),
characterised in that at least one of the plurality of electrical machines (72, 78) is a switched reluctance machine and **in that** the current in the DC link is modified by returning current from the at least one phase winding (16) of the switched reluctance machine to the DC link.

3. A method as claimed in claim 1 or claim 2 in which the DC link is supplied by a further electrical machine (72, 78) running as a generator.

4. A method as claimed in claim 3 in which the further electrical machine (72, 78) is a reluctance machine.

5. A method as claimed in claim 1 and claim 2, the method including freewheeling the said current and, subsequently, returning current from the at least one phase winding if the DC link voltage has not recovered after a predetermined period.

6. A computer program product stored on a computer readable medium which when installed on a processing device executes the method as claimed in any of claims 1 to 5.

7. A system for operating a plurality of electrical machines (72, 78) comprising: a power converter (74, 77) including a DC link to which the electrical machines (72, 78) are connected, each machine (72, 78) having at least one phase winding (16), means (83) for monitoring the DC link voltage; and means (75, 79) for operating the power converter (74, 77) to control the current in the at least one phase winding (16) in response to a signal from the means (83) for monitoring when the DC link voltage decreases to a predetermined threshold, thereby to control the magnitude of disturbances in the DC link voltage caused by the combined load of the plurality of electrical machines (72, 78), **characterised in that** at least one of the plurality of electrical machines (72, 78) is a switched reluctance machine and **in that** the means (75, 79) for operating the power converter (74, 77) are arranged to control the current in the at least one phase winding (16) by freewheeling the said current in response to the signal.

8. A system for operating a plurality of electrical machines (72, 78) comprising: a power converter (74, 77) including a DC link to which the electrical machines (72, 78) are connected, each machine (72, 78) having at least one phase winding (16), means (83) for monitoring the DC link voltage; and means (75, 79) for operating the power converter (74, 77) to control the current in the at least one phase winding (16) in response to a signal from the means (83) for monitoring when the DC link voltage decreases to a predetermined threshold,
thereby to control the magnitude of disturbances in the DC link voltage caused by the combined load of the plurality of electrical machines (72, 78), **characterised in that** at least one of the plurality of electrical machines (72, 78) is a switched reluctance machine and **in that** the means (75, 79) for operating the power converter (74, 77) are arranged to control the current in the at least one phase winding (16) by returning current from at least one of the phase winding (16) of the switched reluctance machine to the DC link in response to the signal.

9. A system as claimed in claim 7 or claim 8 including a further electrical machine (72, 78) connected to the DC link and arranged to be run as a generator.

10. A system as claimed in claim 9 in which the further electrical machine (72, 78) is a reluctance machine.

11. A system as claimed in claim 7 and claim 8, the means (75, 79) for operating the power converter being arranged to freewheel the said current and, subsequently, to return current from the at least one phase winding (16) if the DC link voltage has not recovered after a predetermined period.

Patentansprüche

1. Verfahren zum Betreiben einer Mehrzahl elektrischer Maschinen (72,78) von einem Gleichspannungszwischenkreis (DC link), wobei jede Maschine (72, 78) wenigstens eine Phasenwicklung (16) hat, wobei das Verfahren das Überwachen der Zwischenkreisspannung umfasst, und wenn die Zwischenkreisspannung auf einen vorgegebenen Schwellenwert abnimmt, das Regeln des Stroms in wenigstens einer Phasenwicklung (16) in wenigstens einer der elektrischen Maschinen (72, 78), um den Strom in dem Gleichspannungszwischenkreis zu ändern, um dadurch das Ausmaß von Störungen in der Zwischenkreisspannung, die von der kombinierten Last der Vielzahl elektrischer Maschinen (72, 78) verursacht werden, zu regeln,
dadurch gekennzeichnet, dass
wenigstens eine der Mehrzahl elektrischer Maschinen (72, 78) eine geschaltete Reluktanzmaschine ist, und dass der Strom in dem Gleichspannungszwischenkreis durch Freilaufen des Stroms in wenigstens einer der Phasenwicklungen (16) der geschalteten Reluktanzmaschine geändert wird.

2. Verfahren zum Betreiben einer Mehrzahl von elektrischen Maschinen (72, 78) von einem Gleichspan-

nungszwischenkreis, wobei jede Maschine (72, 78) wenigstens eine Phasenwicklung (16) hat, wobei das Verfahren das Überwachen der Zwischenkreisspannung umfasst, und wenn die Zwischenkreisspannung auf einen vorgegebenen Schwellenwert abnimmt, das Regeln des Stroms in wenigstens einer Phasenwicklung (16) in wenigstens einer der elektrischen Maschinen (72, 78), um den Strom in dem Gleichspannungszwischenkreis zu ändern, um dadurch das Ausmaß von Störungen in der Zwischenkreisspannung, die von der kombinierten Last der Vielzahl elektrischer Maschinen (72, 78) verursacht werden, zu regeln,
dadurch gekennzeichnet, dass
wenigstens eine der Mehrzahl elektrischer Maschinen (72, 78) eine geschaltete Reluktanzmaschine ist, und dass der Strom in dem Gleichspannungszwischenkreis durch Zurückführen von Strom von der wenigstens einen Phasenwicklung (16) der geschalteten Reluktanzmaschine zum Gleichspannungszwischenkreis geändert wird.

3. Verfahren nach Anspruch 1 oder Anspruch 2, wobei der Gleichspannungszwischenkreis durch eine weitere elektrische Maschine (72, 78) versorgt wird, die als Generator läuft.

4. Verfahren nach Anspruch 3, wobei die weitere elektrische Maschine (72, 78) eine Reluktanzmaschine ist.

5. Verfahren nach Anspruch 1 und Anspruch 2, wobei das Verfahren das Freilaufen des Stroms und nachfolgend das Zurückführen des Stroms von der wenigstens einen Phasenwicklung umfasst, wenn die Zwischenkreisspannung nach einem vorgegebenen Zeitraum nicht wiederhergestellt wurde.

6. Computerprogrammprodukt, das auf einem computerlesbaren Medium gespeichert ist, welches, wenn es auf einer Verarbeitungsvorrichtung installiert ist, das Verfahren nach einem der Ansprüche 1 bis 5 durchführt.

7. System zum Betreiben einer Mehrzahl elektrischer Maschinen (72, 78), das aufweist: einen Leistungsumsetzer (74, 77) mit einem Gleichspannungszwischenkreis, mit dem die elektrischen Maschinen (72, 78) verbunden sind, wobei jede Maschine (72, 78) wenigstens ' eine Phasenwicklung (16) hat, eine Einrichtung (83) zum Überwachen der Zwischenkreisspannung, und Einrichtungen (75, 79) zum Betreiben des Leistungsumsetzers (74, 77), um den Strom in der wenigstens einen Phasenwicklung (16) zu regeln im Ansprechen auf ein Signal von der Einrichtung (83) zum Überwachen, wenn die Zwischenkreisspannung auf einen vorgegebenen Schwellenwert abnimmt, um dadurch das Ausmaß von Störungen in der Zwischenkreisspannung, die von der kombinierten Last der Mehrzahl elektrischer Maschinen (72, 78) verursacht werden, zu regeln, **dadurch gekennzeichnet, dass** wenigstens eine der Mehrzahl elektrischer Maschinen (72, 78) eine geschaltete Reluktanzmaschine ist, und dass die Einrichtungen (75, 79) zum Betreiben des Leistungsumsetzers (74, 77) dazu ausgelegt sind, den Strom in der wenigstens einen Phasenwicklung (16) durch Freilaufen des Stroms im Ansprechen auf das Signal zu regeln.

8. System zum Betreiben einer Mehrzahl elektrischer Maschinen (72, 78), das aufweist: einen Leistungsumsetzer (74, 77) mit einem Gleichspannungszwischenkreis, mit dem die elektrischen Maschinen (72, 78) verbunden sind, wobei jede Maschine (72, 78) wenigstens eine Phasenwicklung (16) hat, eine Einrichtung (83) zum Überwachen der Zwischenkreisspannung, und Einrichtungen (75, 79) zum Betreiben des Leistungsumsetzers (74, 77), um den Strom in der wenigstens einen Phasenwicklung (16) zu regeln im Ansprechen auf ein Signal von der Einrichtung (83) zum Überwachen, wenn die Zwischenkreisspannung auf einen vorgegebenen Schwellenwert abnimmt, um dadurch das Ausmaß von Störungen in der Zwischenkreisspannung, die von der kombinierten Last der Mehrzahl elektrischer Maschinen (72, 78) verursacht werden, zu regeln, **dadurch gekennzeichnet, dass** wenigstens eine der Mehrzahl elektrischer Maschinen (72, 78) eine geschaltete Reluktanzmaschine ist, und dass die Einrichtungen (75, 79) zum Betreiben des Leistungsumsetzers (74, 77) dazu ausgelegt sind, den Strom in der wenigstens einen Phasenwicklung (16) durch Zurückführen von Strom von wenigstens einer der Phasenwicklungen (16) der geschalteten Reluktanzmaschine zum
Gleichspannungszwischenkreis im Ansprechen auf das Signal zu regeln.

9. System nach Anspruch 7 oder Anspruch 8, das eine weitere elektrische Maschine (72, 78) aufweist, die mit dem Gleichspannungszwischenkreis verbunden und dazu ausgelegt ist, als Generator betrieben zu werden.

10. System nach Anspruch 9, wobei die weitere elektrische Maschine (72, 78) eine Reluktanzmaschine ist.

11. System nach Anspruch 7 und Anspruch 8, wobei die Einrichtungen (75, 79) zum Betreiben des Leistungsumsetzers dazu ausgelegt sind, den Strom freilaufen zu lassen und nachfolgend Strom von der wenigstens einen Phasenwicklung (16) zurückzuführen, wenn die Zwischenkreisspannung nach einem vorgegebenen Zeitraum nicht wiederhergestellt ist.

Revendications

1. Procédé de commande d'une pluralité de machines électriques (72, 78) à partir d'une liaison CC, chaque machine (72, 78) ayant au moins un enroulement de phase (16), le procédé comprenant la surveillance de la tension de la liaison CC et, en cas de baisse de la tension de la liaison CC à un seuil prédéterminé, le contrôle du courant d'au moins un enroulement de phase (16) d'au moins une des machines électriques (72, 78) pour modifier le courant de la liaison CC, afin de limiter l'ampleur des perturbations de la tension de la liaison CC provoquées par la charge cumulée de la pluralité de machines électriques (72, 78),
caractérisé en ce qu'au moins une de la pluralité de machines électriques (72, 78) est une machine à réluctance commutée et en ce la modification du courant de la liaison CC comprend la mise en roue libre du courant dans au moins un des enroulements de phase (16) de la machine à réluctance commutée.

2. Procédé de commande d'une pluralité de machines électriques (72, 78) à partir d'une liaison CC, chaque machine (72, 78) ayant au moins un enroulement de phase (16), le procédé comprenant la surveillance de la tension de la liaison CC et, en cas de baisse de la tension de la liaison CC à un seuil prédéterminé, le contrôle du courant d'au moins un enroulement de phase (16) d'au moins une des machines électriques (72, 78) pour modifier le courant de la liaison CC, afin de limiter l'ampleur des perturbations de la tension de la liaison CC provoquées par la charge cumulée de la pluralité de machines électriques (72, 78),
caractérisé en ce qu'au moins une de la pluralité de machines électriques (72, 78) est une machine à réluctance commutée et en ce la modification du courant de la liaison CC comprend le renvoi du courant de l'au moins un enroulement de phase (16) de la machine à réluctance commutée à la liaison CC.

3. Procédé selon la revendication 1 ou la revendication 2, dans lequel la liaison CC est alimentée par une machine électrique supplémentaire (72, 78) fonctionnant comme un générateur.

4. Procédé selon la revendication 3, dans lequel la machine électrique supplémentaire (72, 78) est une machine à réluctance.

5. Procédé selon la revendication 1 ou la revendication 2, le procédé comprenant la mise en roue libre dudit courant, suivie du renvoi du courant de l'au moins un enroulement de phase si la tension de la liaison CC n'est pas revenue à l'issue d'un délai prédéterminé.

6. Produit-programme informatique stocké sur un support lisible par ordinateur et qui, lorsqu'il est installé sur un dispositif de traitement, exécute le procédé selon l'une quelconque des revendications 1 à 5.

7. Système de commande d'une pluralité de machines électriques (72, 78) comprenant : un convertisseur de puissance (74, 77) comprenant une liaison CC à laquelle sont connectées les machines électriques (72, 78), chaque machine (72, 78) ayant au moins un enroulement de phase (16), des moyens (83) pour surveiller la tension de la liaison CC ; et des moyens (75, 79) pour commander au convertisseur de puissance (74, 77) de contrôler le courant de l'au moins un enroulement de phase (16) en réponse à un signal émanant des moyens (83) de surveillance lorsque la tension de la liaison CC baisse à un seuil prédéterminé, afin de limiter l'ampleur des perturbations de la tension de la liaison CC provoquées par la charge cumulée de la pluralité de machines électriques (72, 78), **caractérisé en ce qu'**au moins une de la pluralité de machines électriques (72, 78) est une machine à réluctance commutée et **en ce que** les moyens (75, 79) de commande du convertisseur de puissance (74, 77) sont conçus pour contrôler le courant de l'au moins un enroulement de phase (16) en laissant ledit courant circuler librement en réponse au signal.

8. Système de commande d'une pluralité de machines électriques (72, 78) comprenant : un convertisseur de puissance (74, 77) comprenant une liaison CC à laquelle sont connectées les machines électriques (72, 78), chaque machine (72, 78) ayant au moins un enroulement de phase (16), des moyens (83) pour surveiller la tension de la liaison CC ; et des moyens (75, 79) pour commander au convertisseur de puissance (74, 77) de contrôler le courant de l'au moins un enroulement de phase (16) en réponse à un signal émanant des moyens (83) de surveillance lorsque la tension de la liaison CC baisse à un seuil prédéterminé, afin de limiter l'ampleur des perturbations de la tension de la liaison CC provoquées par la charge cumulée de la pluralité de machines électriques (72, 78), **caractérisé en ce qu'**au moins une de la pluralité de machines électriques (72, 78) est une machine à réluctance commutée et **en ce que** les moyens (75, 79) pour commander le convertisseur de puissance (74, 77) sont conçus pour contrôler le courant de l'au moins un enroulement de phase (16) en renvoyant du courant de l'au moins un des enroulements de phase (16) de la machine à réluctance commutée à la liaison CC en réponse au signal.

9. Système selon la revendication 7 ou la revendication 8, comprenant une machine électrique supplémentaire (72, 78) connectée à la liaison CC et conçue

pour fonctionner comme un générateur.

10. Système selon la revendication 9, dans lequel la machine électrique supplémentaire (72, 78) est une machine à réluctance.

11. Système selon la revendication 7 et la revendication 8, les moyens (75, 79) pour commander le convertisseur de puissance étant agencés pour mettre ledit courant en roue libre et pour renvoyer ensuite le courant de l'au moins un enroulement de phase (16) si la tension de la liaison CC n'est pas revenue à l'issue d'un délai prédéterminé.

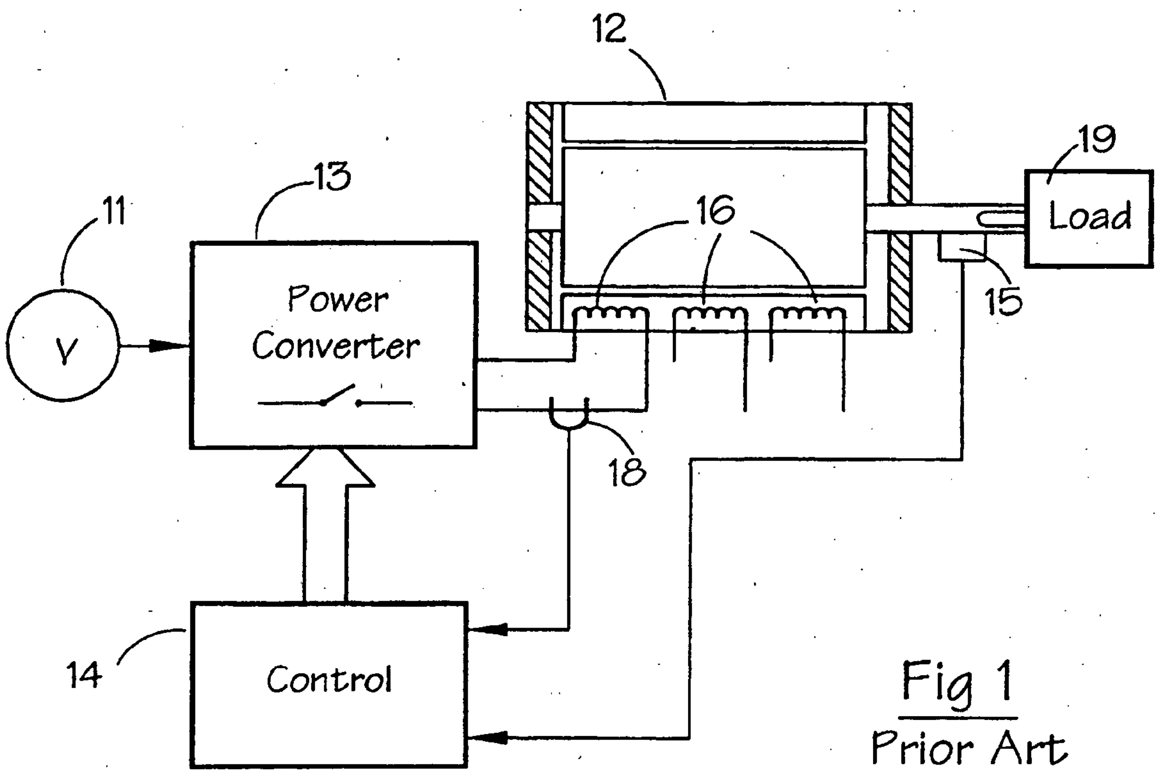


Fig 1
Prior Art

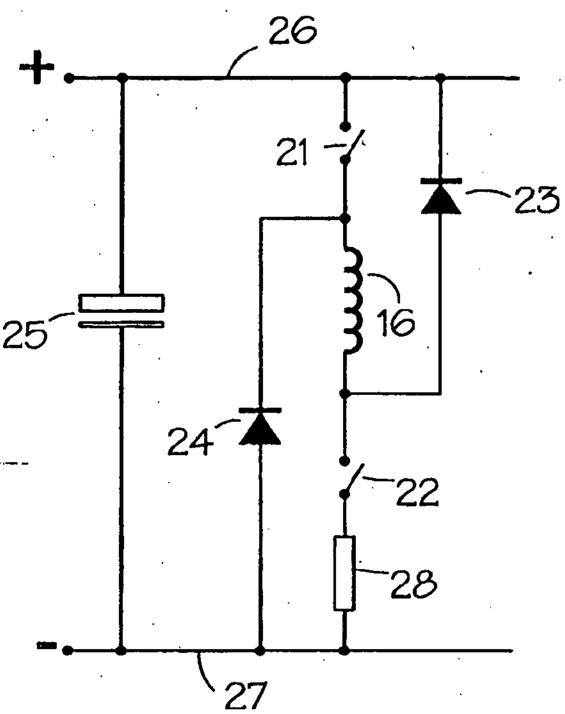


Fig 2
Prior Art

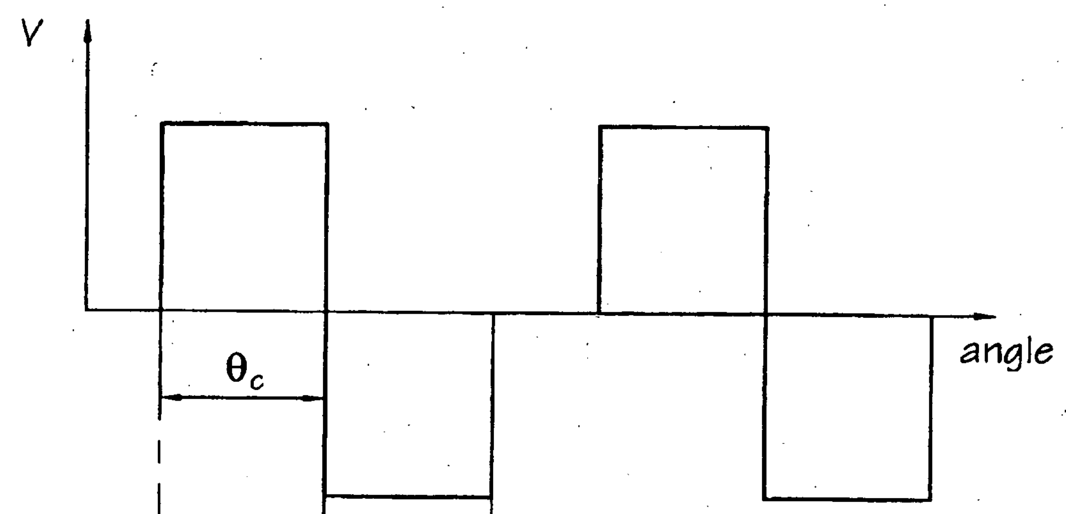


Fig 3(a)

Prior Art

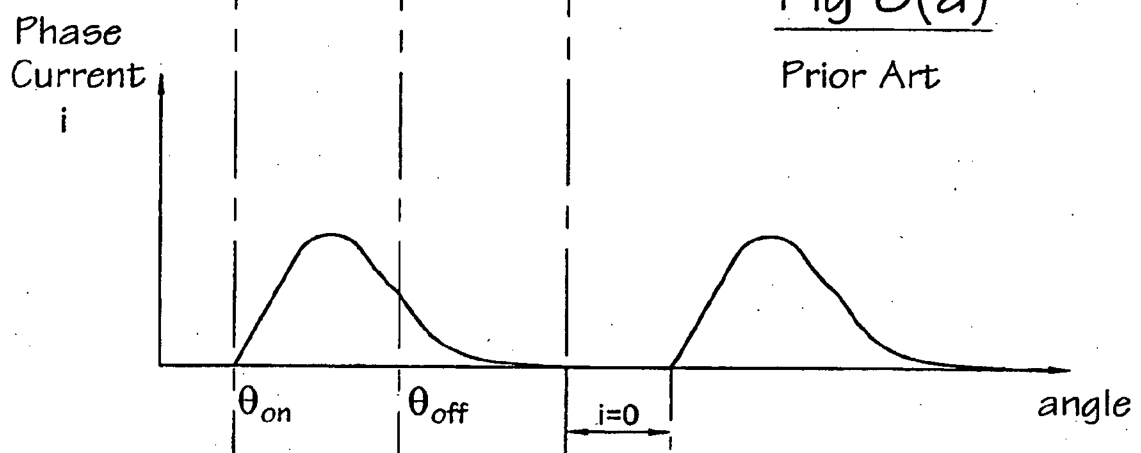


Fig 3(b)

Prior Art

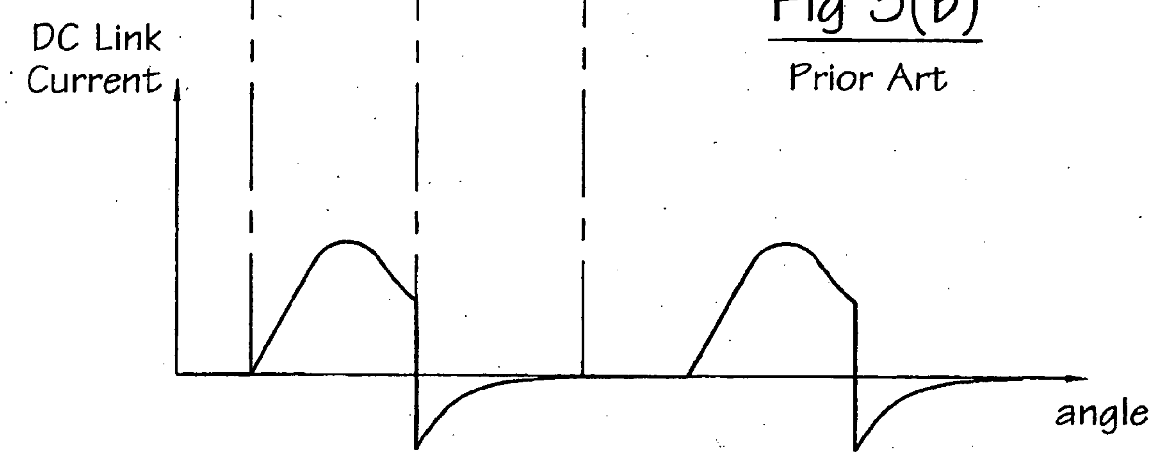


Fig 3(c)

Prior Art

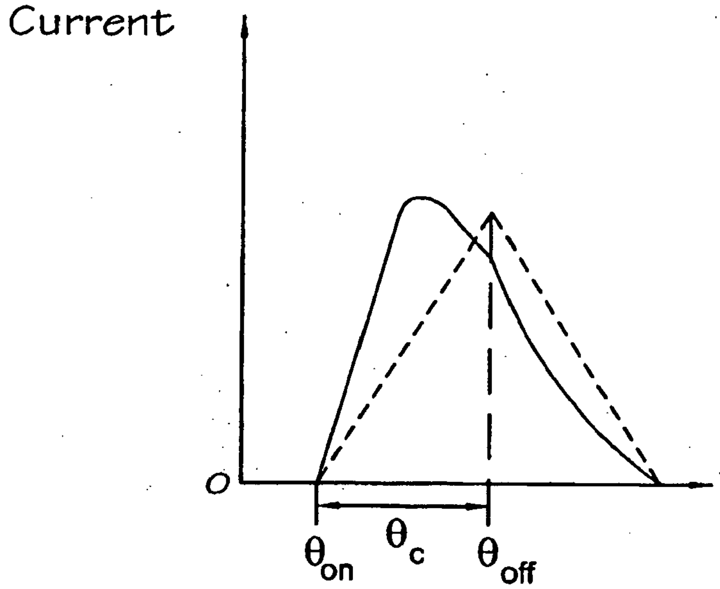


Fig 4(a)
Prior Art

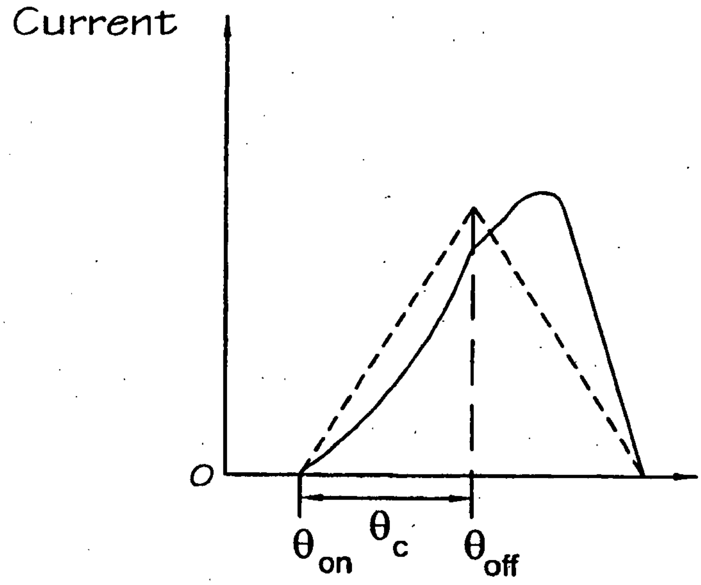


Fig 4(b)
Prior Art

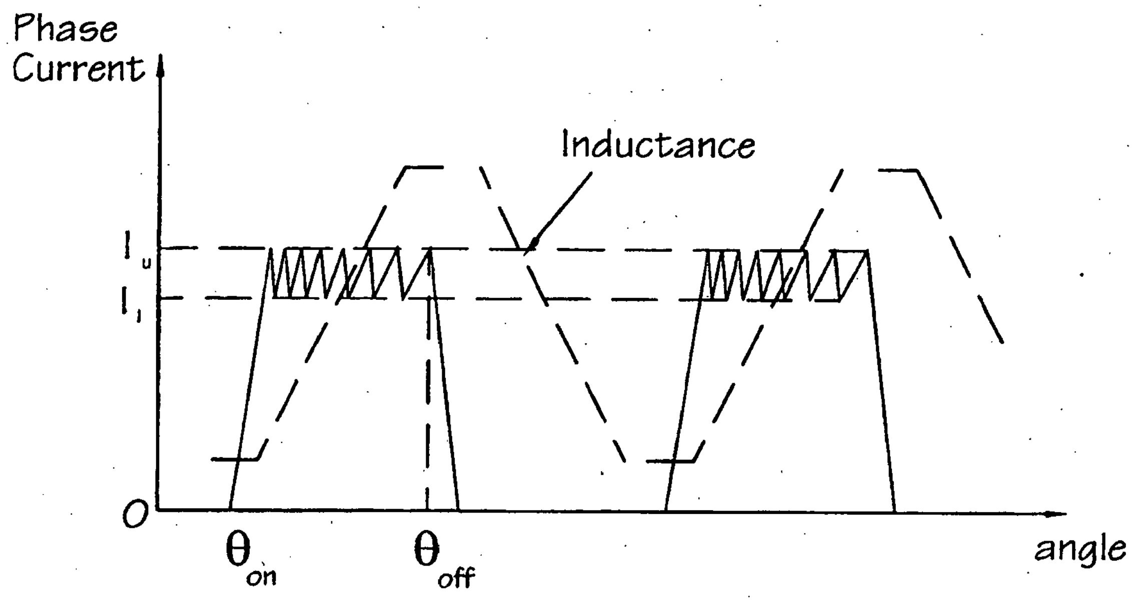


Fig 5(a)

Prior Art

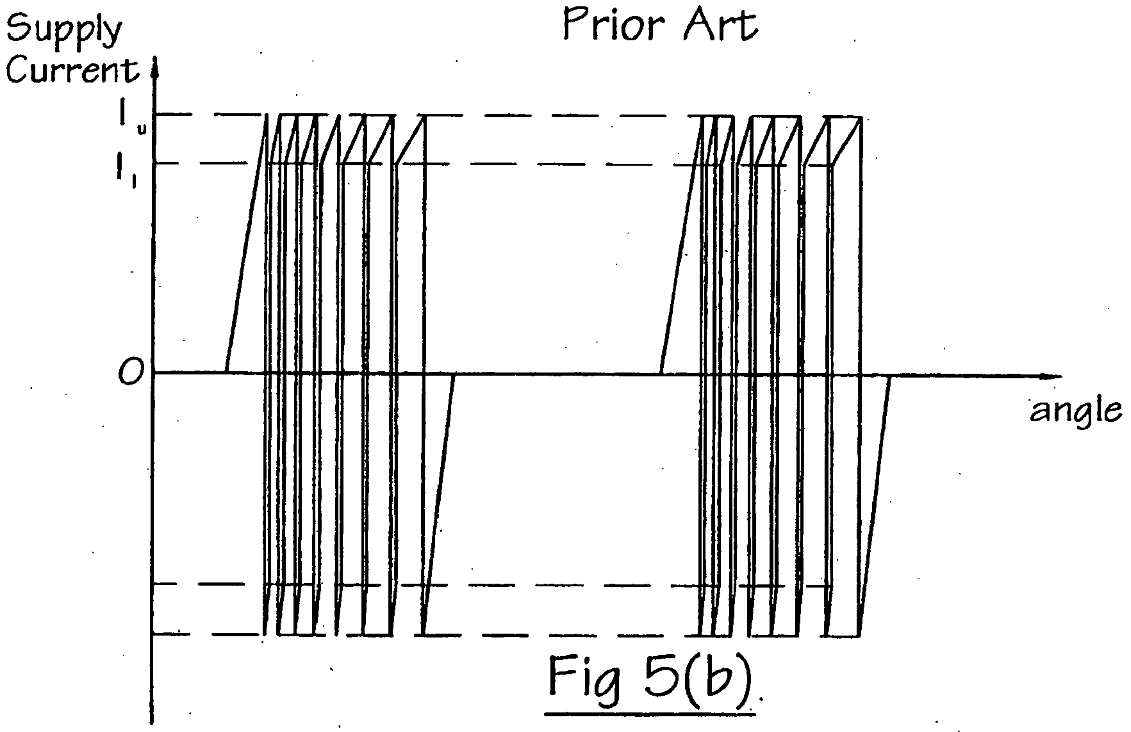


Fig 5(b)

Prior Art

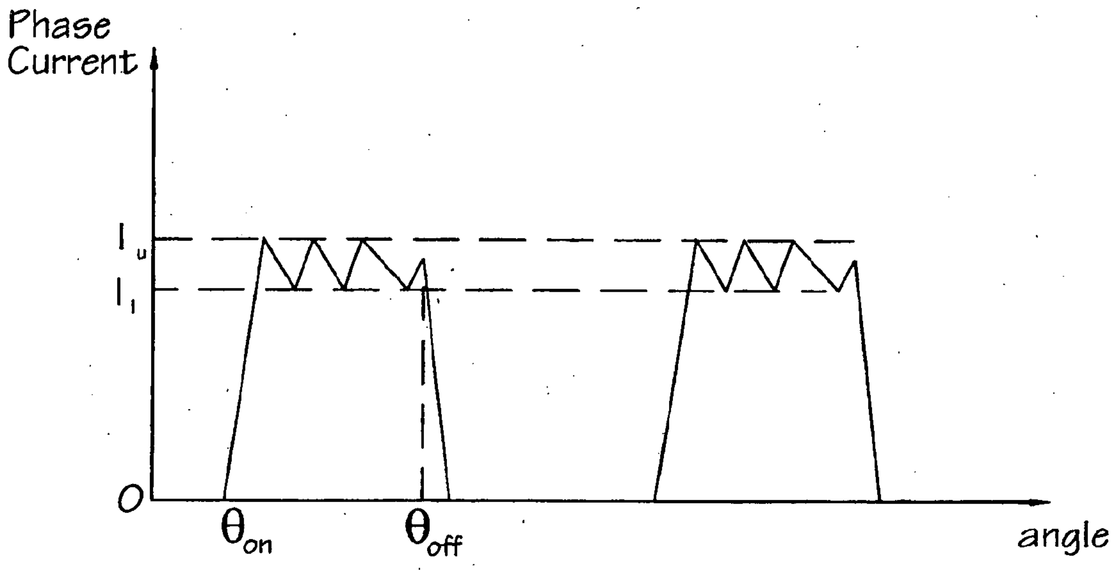


Fig 6(a)

Prior Art

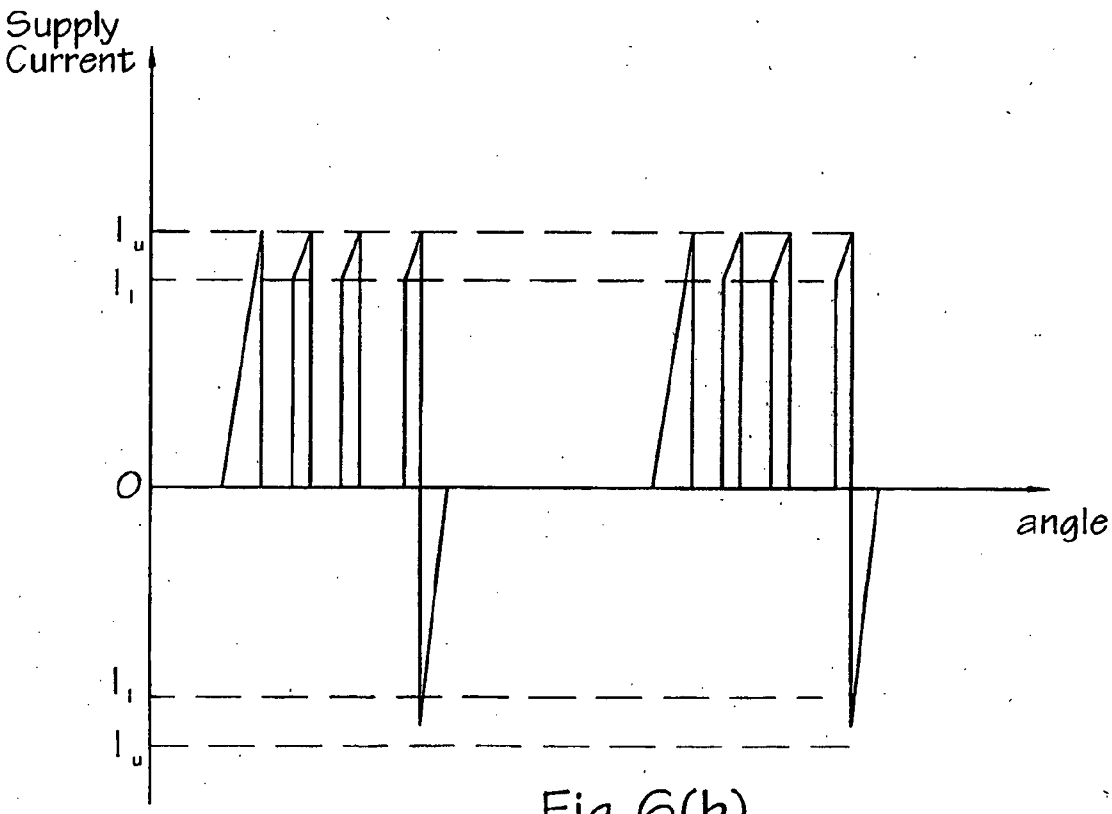


Fig 6(b)

Prior Art

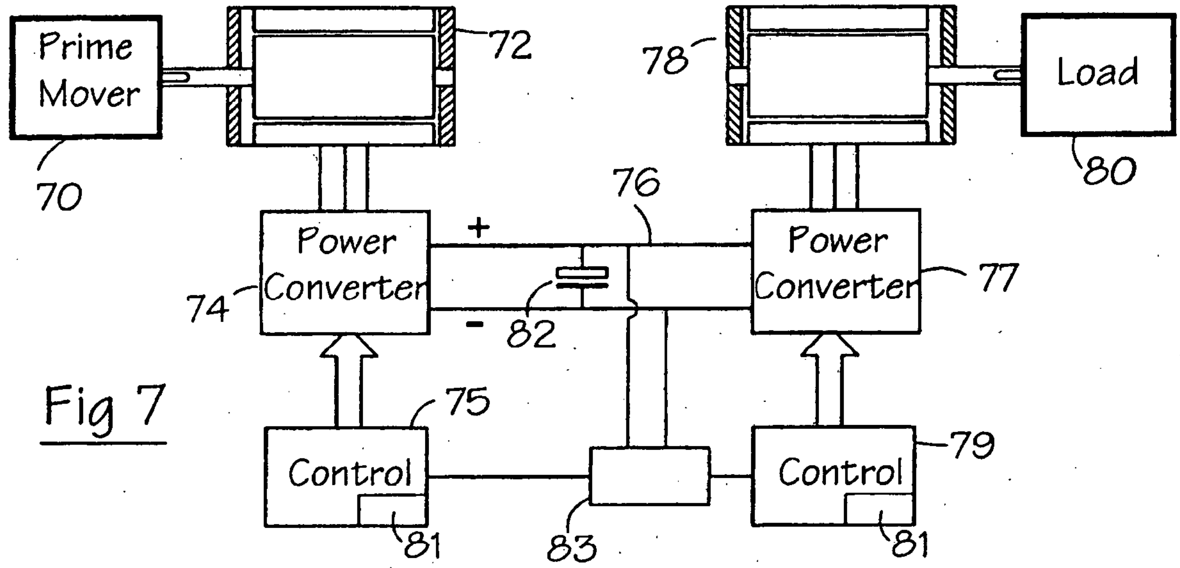

Prime Mover
70
72
78
Load
80
76
Power Converter
74
+
-
82
Power Converter
77
75
Control
81
83
Control
79
81

Fig 7

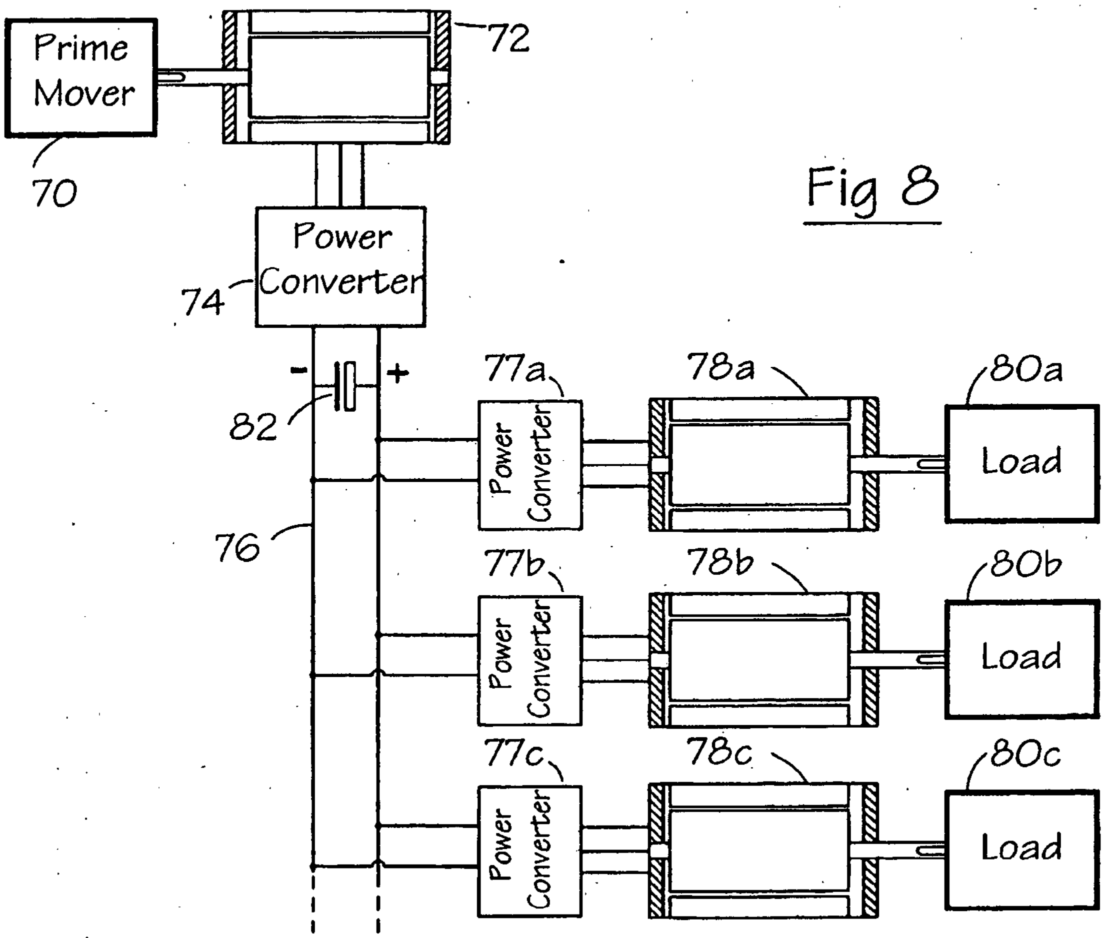
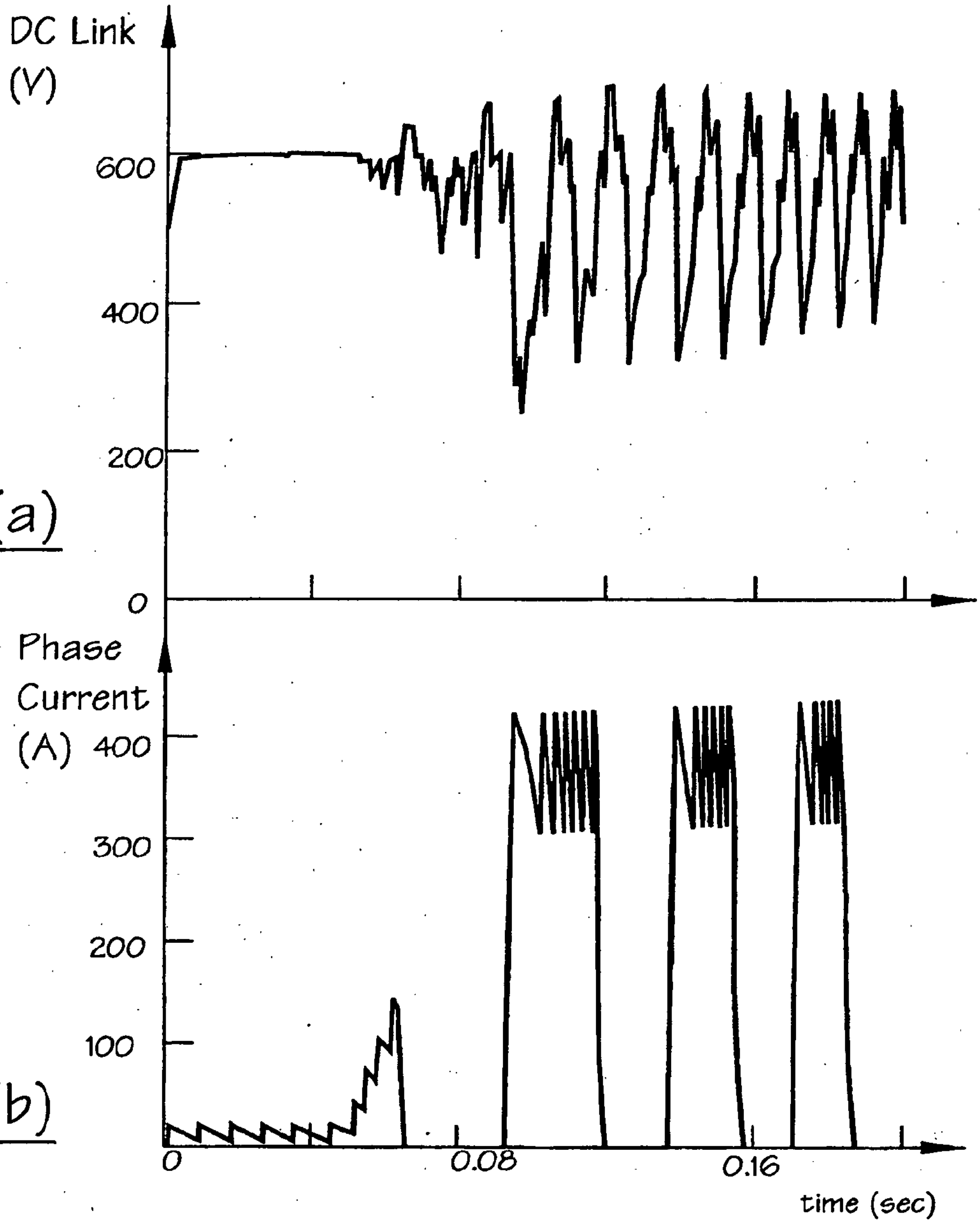

Prime Mover
70
72
Power Converter
74
-
+
82
76
77a
Power Converter
78a
80a
Load
77b
Power Converter
78b
80b
Load
77c
Power Converter
78c
80c
Load

Fig 8

Fig 9(a)

Fig 9(b)


DC Link
(V)
600
400
200
0
Phase
Current
(A)
400
300
200
100
0
0.08
0.16
time (sec)

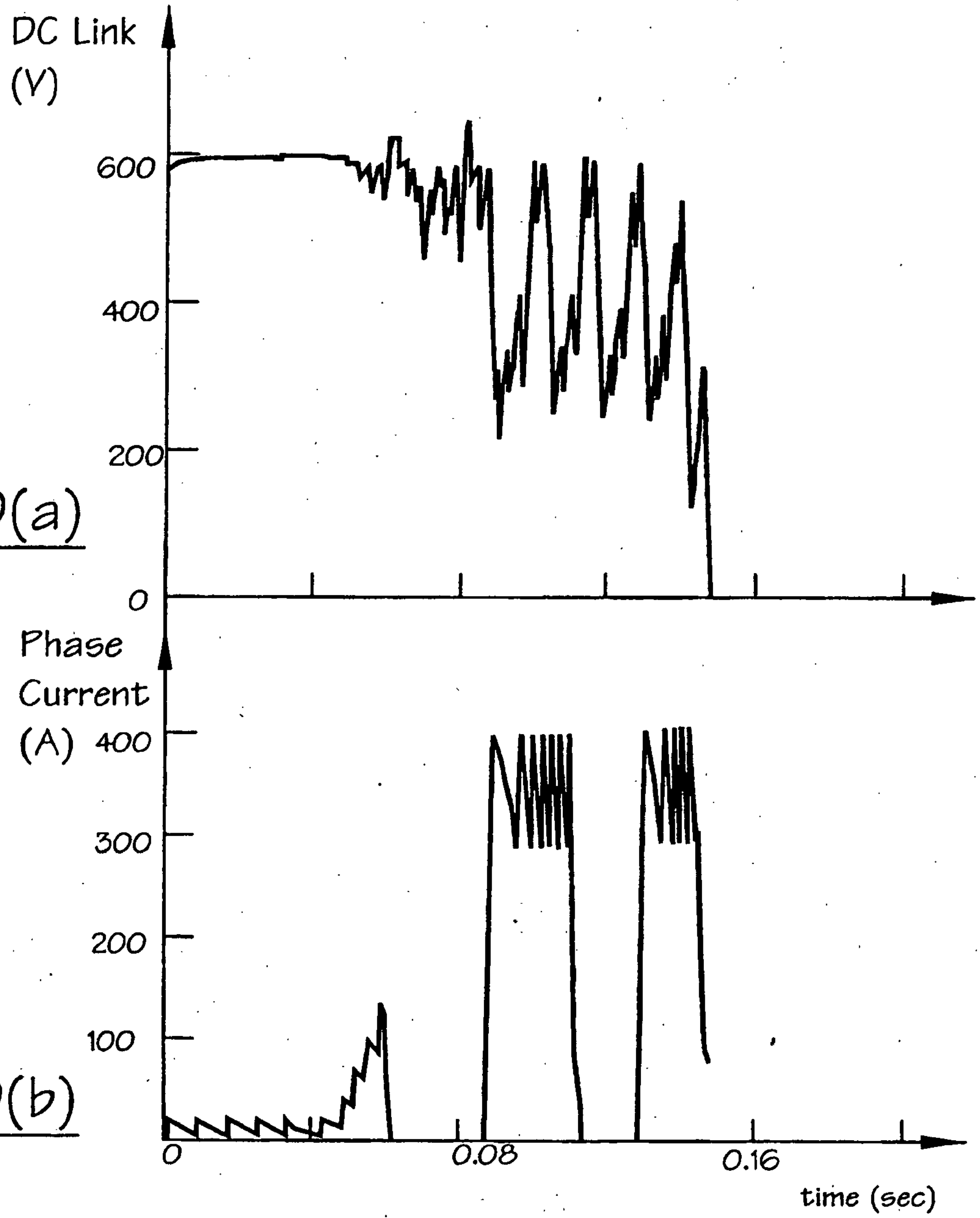


Fig 10(a)

Fig 10(b)

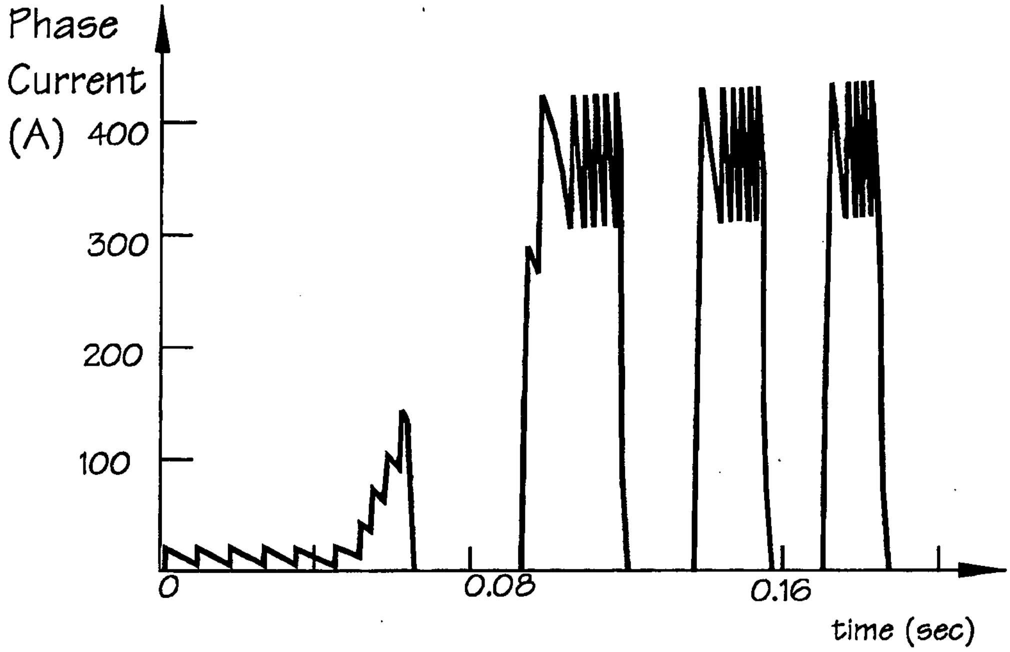

Phase
Current
(A)
400
300
200
100
0
0.08
0.16
time (sec)

Fig 11

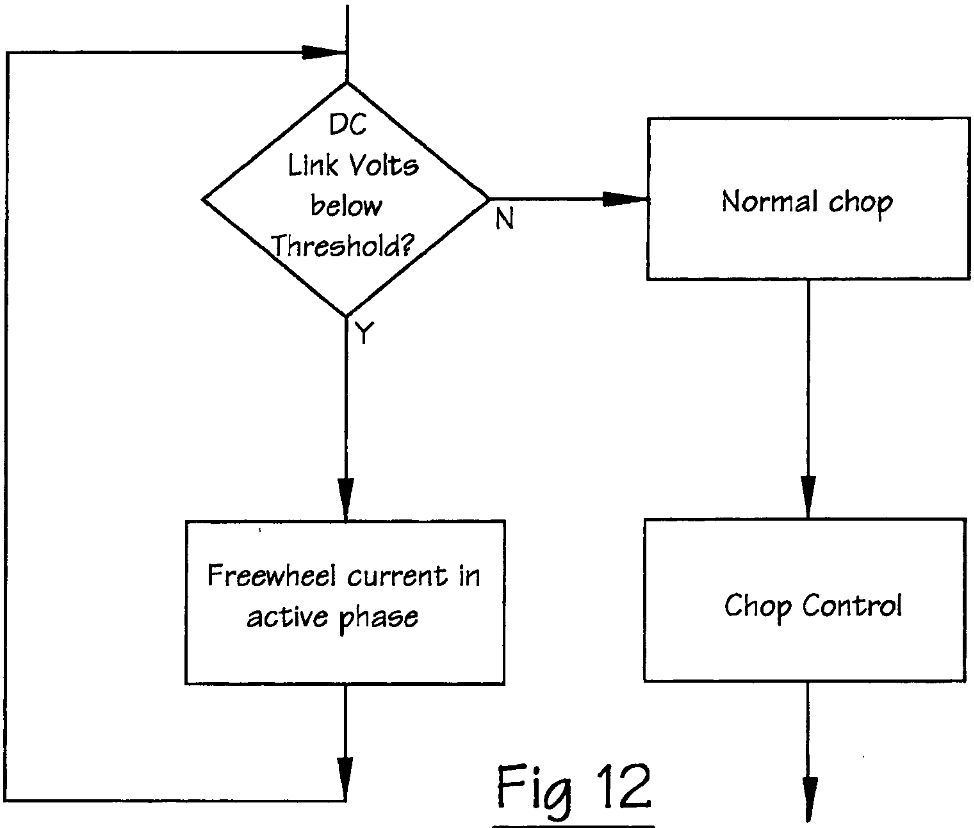

DC
Link Volts
below
Threshold?
N
Y
Normal chop
Freewheel current in
active phase
Chop Control

Fig 12

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **TJE MILLER.** Electronic Control of Switched Reluctance Machines. 21 June 1993 **[0002]**
- **STEPHENSON ; BLAKE.** The characteristics, design and application of switched reluctance motors and drives. *PCIM'93, Nürnberg,* 21 June 1993 **[0002]**
- Generating with the switched reluctance motor. *Proceedings of the IEEE 9th Applied Power Electronics Conference,* 13 February 1994, 41-47 **[0006]**