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D E C I S I O N
of 9 October 2001

Case Number: T 0251/99 - 3.5.2

Application Number: 96302188.6

Publication Number: 0738035

IPC: H02P 7/05

Language of the proceedings: EN

Title of invention:
Control circuit and system for a switched reluctance machine and method of operating

Applicant:
SWITCHED RELUCTANCE DRIVES LIMITED

Opponent:
-

Headword:
-

Relevant legal provisions:
EPC Art. 56

Keyword:
"Inventive step - no"

Decisions cited:
-

Catchword:
-

Case Number: T 0251/99 - 3.5.2

D E C I S I O N
of the Technical Board of Appeal 3.5.2 of 9 October 2001

Appellant: SWITCHED RELUCTANCE DRIVES LIMITED
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted 12 November 1998 refusing European patent application No. 96 302 188.6 pursuant to Article 97(1) EPC.**

Composition of the Board:

Chairman: W. J. L. Wheeler
Members: F. Edlinger
P. H. Mühlens

Summary of Facts and Submissions

I. The appeal is against the decision of the examining division refusing European patent application No. 96 302 188.6 for lack of an inventive step.

II. The following documents are referred to below:

D2: IEEE Transactions on Industry Applications, vol. 27, No. 6, November 1991, pages 1034-1047, XP000277291; S. Vukosavić *et al*: "SRM Inverter Topologies: A Comparative Evaluation"

D4: WO-A-95/02922 and EP-A-0 662 751 (D4', published under Article 158(3) EPC). D4' was published after the priority date of the present application, but the description is assumed to constitute a correct translation of the corresponding international application D4.

III. With a letter dated 5 October 2001, the appellant filed two new sets of claims 1 to 12 as auxiliary requests 2 and 3 respectively and, in the oral proceedings before the Board held on 9 October 2001, abandoned the set of claims 1 to 6 which had been filed with the statement of grounds of appeal as an auxiliary request.

IV. The appellant thus requested that the decision under appeal be set aside, and

- as main request, that the case be remitted to the first instance to grant a patent on the basis of claims 1 to 12 in the form refused by the examining division;

- or, as auxiliary request, on the basis of claims 1 to 12 of the then second auxiliary request, filed with letter dated 5 October 2001;

- or, as a further auxiliary request, on the basis of claims 1 to 12 of the then third auxiliary request, filed with letter dated 5 October 2001.

V. Each of the requests comprises three independent claims, respectively relating to "a control circuit" for a switched reluctance machine (claim 1), a "switched reluctance drive system" (claim 6) and a "method of controlling a system as claimed in any of claims 6 to 11" (claim 12).

(i) Claim 6 of the main request reads as follows:

"A switched reluctance drive system comprising: a switched reluctance machine (M) having a rotor (R) and a stator (S), respectively defining rotor and stator poles, and a phase winding (14) associated with the or each phase of the machine; an electrical power supply (10); first and second supply voltage input terminals (L,N) respectively connected across the power supply without a dc link capacitor connected across the terminals, the first input terminal being connected with one end of the winding; a switch arrangement (16) connected with the winding and operable to connect the winding with the second input terminal to create a primary winding current path; a capacitor (20); a thyristor (18), having a trigger input, the capacitor and the thyristor being serially connected across the winding and the switch arrangement to form a secondary winding current path; and a diode (22) connected to conduct from between the winding and the switch arrangement to between the thyristor and the capacitor, the capacitor being chargeable through the winding and the diode, when the switch arrangement is open circuit, to a voltage in excess of the voltage applied by the power supply across the first and second terminals and being dischargeable through the secondary current path when the switch arrangement is subsequently closed and the thyristor is subsequently triggered, the thyristor being operable to conduct in response to a trigger signal applied to the trigger input and to maintain conduction when the voltage across the capacitor is greater than the voltage across the first and second terminals and to become non-conducting when the voltage across the capacitor falls below a reference level."

(ii) Claim 6 of the (second) auxiliary request is based on claim 6 of the main request and has the following additional features or amendments (highlighted by the Board in bold characters):

"A switched reluctance drive system ... the first input terminal being **respectively** connected with one end of the winding **for the or each phase**; a switch arrangement (16) connected with the winding and operable to connect the winding with the second input terminal to create a primary winding current path; a capacitor (20) **for the or each phase**; a thyristor (18) **for the or each phase**, having a trigger input, the capacitor and the thyristor being serially connected across the winding and the switch arrangement to form a secondary winding current path **for the or each phase**; and a diode (22) connected to conduct from between the **or each** winding and **its** switch arrangement to between the **corresponding** thyristor and capacitor, the capacitor being chargeable ..."

(iii) Claim 6 of the further (third) auxiliary request has the same wording as that of the main request except that it relates to "A **single phase** switched reluctance drive system comprising: a switched reluctance machine (M) having a rotor (R) and a stator (S), respectively defining rotor and stator poles, and a phase winding (14) associated with the phase of the machine ... ".

VI. The contested decision (point 1 of the reasons) found that the subject-matter of claim 6 (same as that of the present main request) differed from the drive system disclosed in D2, Figure 1(e), only in that a switch means consisting of an NPN transistor (QA) and a serially connected diode (DA) in the secondary winding current path of the prior art was replaced by a thyristor. The known switch means and a thyristor as specified in claim 6 only constituted alternative switch means among which the person skilled in the art would have selected in accordance with the circumstances without exercising any inventive skill. The same objections applied to claim 1 because claim 6 comprised all the features of claim 1. Concerning the method specified in claim 12, the contested decision (point 2 of the reasons) set out that the known transistor switch and a switch arrangement (Q1) of a corresponding phase winding were likewise actuated to conduct at the beginning of a conduction angle and deactuated to cease conducting at the end of the conduction angle. Claim 12 thus also lacked an inventive step.

VII. The appellant essentially argued as follows:

(i) The present application related to switched reluctance drives for single phase motors used in mass produced articles where it was important to reduce costs and the space taken up by the components of the drive system. The power supply had a single high side connection line (output of the diode bridge 12) to which all the components of the single phase circuit were connected (Figure 2). If the teaching of the application was applied to a multi-phase switched reluctance machine, like components for the other phases would be connected to the same connection line, ie each of the phases would have its own serially connected capacitor (20) and thyristor (18), and a diode (22) connecting the winding (14) with the corresponding capacitor (Figure 2; column 6, lines 6 to 8, of the published application). Additional blocking diodes between the high side connection line and each winding were not needed and additional phase components would thus be connected directly in parallel since the application aimed at reducing the component count.

(ii) The closest prior art for such drive systems was to be seen in the classic inverter shown in Figure 1(a) of D2 because this circuit constituted a single-rail circuit. Such a circuit could easily be reduced to a single phase circuit by simply removing the components of the other phases. Starting from the circuit disclosed in Figure 1(a) of D2, it was not obvious to arrive at a much simpler circuit which only had one switch per phase and did not use a dc link capacitor.

(iii) Figure 1(e) of D2 did not constitute a suitable starting point because it disclosed a dual-rail circuit comprising a single capacitor (C) and switch means (QA, DA) whose mutual connection point was connected to a further high side line to which also the individual phases were connected. The duty of the capacitor and switch means was common to all of the multiple phases. Moreover, D2 (page 1042, section F, first paragraph, and page 1045, section VII, first paragraph) stated that single-rail circuits were preferable. It was thus not obvious to start from a dual-rail circuit as shown in Figure 1(e) of D2.

(iv) Even if Figure 1(e) of D2 was used as a starting point, it was not obvious to come to the subject-matter of the present application without the benefit of hindsight. Figure 1(e) did not disclose a thyristor. Instead, the circuit used a bipolar transistor (QA) which required an additional blocking diode (DA) and which was not operable to conduct in response to a trigger signal and to maintain conduction while the voltage across the capacitor was greater than the voltage across the supply voltage terminals. The transistor required constant control and could not be 'fired and forgotten'. Moreover, the circuit required a high side driver which had to cope with an isolation problem and had to carefully time the active switch off. This was not necessary with a normal thyristor which only required a trigger signal and switched off automatically when voltage conditions as specified in the claims were met. The term "thyristor" used in the claims referred to a normal thyristor of this kind. However, the appellant was prepared to remove the passage from the description (column 5, lines 53 to 57, of the published application) should the Board find that clarity was affected by the reference to insulated gate bipolar transistors or gate turn-off thyristors.

(iv) The person skilled in the art would not have used a simple thyristor in the circuit of Figure 1(e) because, in accordance with the teaching of D2 (page 1041), the capacitor voltage had to be kept within a relatively narrow band. Since a normal thyristor could not be switched off by a gate signal once it had been fired, it could not be used for regulating the capacitor voltage. Moreover, the transistor in the circuit of Figure 1(e) had to perform the additional function of providing a freewheeling path for demagnetization (State 3, page 1041) which had no correspondence in the simple operation of the drive system of the present application. Therefore, the person skilled in the art who was unimaginative and simply applied the teaching of D2 would discard using a thyristor as an alternative switch means because it simply did not work in the circuit of Figure 1(e) of D2. Furthermore, the authors of D2, who were considerably more than the average skilled person, stated at the beginning of section F on page 1040 that they believed the circuit of Figure 1(e) to embody the minimum component topology for the type of circuit. This proved that a circuit which had fewer components and a more rudimentary form of operation was not obvious to the person skilled in the art.

(vi) The disadvantage of a higher component count and a more complex operation also applied to the other drive systems of the state of the art. D4 used additional blocking diodes and presented solutions to the problem of avoiding ripples in the production of torque of multiphase reluctance machines. While it did show a capacitor and a thyristor serially connected across a phase winding, it did not give the skilled reader any teaching as to the advantage of using a thyristor for discharging the capacitor, nor did it give a hint to use a thyristor in the circuit disclosed in Figure 1(e) of D2.

(vii) While the state of the art related to more complex circuits and a higher flexibility of the circuits for industrial applications, the invention as claimed went a considerable step further in that it recognized that a simplified circuit and a more rudimentary way of operating the circuit could be used. Without considerable hindsight, there was no reasonable ground for supposing that such a novel circuit was naturally obvious when it was actually used in a different way.

Reasons for the Decision

1. The appeal is admissible.

2. Although it would be sufficient to show that a patent application does not comply with the requirements of the Convention if its broadest independent claim does not define inventive subject-matter, the Board, in view of the appellant's declared willingness to make further amendments if subject-matter was found to be patentable, will deal with claim 6 of each of the requests because these claims are more specific in terms of the operation of the drive system concerning the charging and discharging of the capacitor.

3. The term "thyristor" in its general meaning, when used in a patent claim to define a particular type of switch means, normally covers different subclasses, such as thyristors with or without extinguishing circuits and "gate turn-off thyristors" (see column 5, lines 53 to 57, of the published application, to which all the following references will refer if not otherwise stated). The appellant did not contest that a gate turn-off thyristor could be used in the circuit of Figure 1(e) of D2 in place of the switch means consisting of NPN transistor (QA) and diode (DA). A gate turn-off thyristor (or a thyristor with extinguishing circuit) is commonly used when forced turn-off on the thyristor is desired, ie when the thyristor has to be forcibly switched off before its current drops below a holding current level (eg when the voltage across the thyristor terminals reverses). A

thyristor of this type would therefore constitute a suitable alternative switch in the "chopper device" of Figure 1(e) of D2 and would not change the essential function of the known circuit, ie maintaining the capacitor voltage within a relatively narrow band, providing a magnetization path from the capacitor to the winding (State 2) and a freewheeling path for the winding (State 3; see D2, page 1041, left-hand column and page 1045, right-hand column, point 2, and Figure 13). The additional functions (voltage control and freewheeling) are not excluded by the wording of claim 6 of the main request. In this respect, the Board fully agrees with the reasoning of the decision under appeal (point 1) that bipolar switch means and thyristors, in the circuit of Figure 1(e), constitute alternative switch means among which the person skilled in the art would have selected in accordance with the circumstances without exercising any inventive skill.

4. However, the appellant has shown his willingness to limit the claimed subject-matter to a switched reluctance drive system which had fewer components and a more rudimentary way of operation, in particular a normal thyristor which only needed a trigger signal to be rendered conductive and could not be switched off until the voltage across the capacitor fell below a reference level (with respect to the voltage across the supply voltage terminals; see column 4, lines 34 to 38, and Figure 3 of the published application). In the following reasoning, the Board will therefore take these differences into account in so far as they are supported by the description of the application as filed.

4.1 The present application describes that, *inter alia*, the following effects are achieved by the circuits of the disclosed invention:

- to reduce the component count and/or the size of control circuits (column 1, lines 21 to 24);

- to avoid the use of a dc link capacitor which has an adverse effect on the power factor of the switched reluctance system, causing increased supply currents; this can be a particular advantage for domestic appliances in the USA where 120 volt mains supply is used (column 1, lines 17 to 20 and lines 25 to 32; column 5, lines 20 to 41); and

- to achieve a considerable reduction in the acoustic noise emitted by the machine, eg through less abrupt voltage changes across the winding (column 5, lines 42 to 46).

4.2 These effects are essentially achieved by charging the capacitor, at the end of the conduction angle, to a voltage that might reach twice the peak value of the rectified mains, thereby deenergizing the winding (column 4, lines 16 to 24 and lines 42 to 53; column 5, lines 6 to 9), and discharging the capacitor, at the beginning of the next conduction angle, to supply current to the phase winding until the capacitor voltage falls below the voltage of the power supply terminals (column 4, lines 25 to 41; column 5, lines 12 to 19).

4.3 The classic inverter drive explained in the context of Figure 1(a) of D2 has two switches per phase, a dc link capacitor and the same voltage available for magnetizing and demagnetizing (D2, page 1037, "III. Inverter Circuits", first paragraph; page 1038, last paragraph before "C. Circuit 2: Miller's Inverter"). The circuit of Figure 1(e) of D2 is described as a "new circuit" which eliminates a dc link capacitor and "is believed" to have a "minimum component topology" (D2, page 1040, section F). The capacitor (C) is charged at the end of the conduction angle to a voltage which is higher than the rectified power supply voltage and might reach twice the motor supply voltage. Part of the stored energy is discharged into the phase winding at the beginning of the next conduction angle (D2, page 1041, left-hand column, "State 2" and "State 4"; page 1042, "F. Summary", first paragraph). Figure 1(e) of D2 thus constitutes a circuit which has been developed from the known classic inverter, which has more features in common with present claim 6 than the circuit of Figure 1(a) of D2, and which achieves very similar effects as the drive system of present claim 6. Therefore, the circuit of Figure 1(e) of D2 constitutes closer prior art than the circuit of Figure 1(a) and may be used as a realistic starting point for judging whether the subject-matter of present claim 6 involves an inventive step.

4.4 The appellant's argument that a "dual-rail circuit" does not qualify as a suitable starting point has not convinced the Board. Firstly, the statement of D2 (page 1042, section "F. Summary") that "single-rail inverters" are "the choice for 380 V and 460 V industrial SRM drives" has to be seen in the context of the relatively high voltage ratings of at least twice the motor supply voltage. However, still according to D2 (page 1045, section VII), the dual-rail topology may find applications in low-power low-voltage drives. This applies to the preferred use of the present application. Secondly, considering a single phase drive system according to the further (third) auxiliary request, both the phase winding and the capacitor circuit would be connected to a single rail because there is no choice to make between a capacitor for each phase or a common capacitor for all phases. Both the known circuits (a) and (e) shown in Figure 1 of D2 would need to be adapted if they were to be used for a number of phases which is different from the three-phase drive circuits shown. Adaptation of a known circuit which achieves similar effects (Figure 1(e) of D2) would be the more natural choice both for a single and multi-phase drive systems.

4.5 The problem solved by the present application over the circuit of Figure 1(e) of D2 may be seen as finding a drive system which is simpler in its operation and allows a further reduction in the component count, in particular for domestic appliances used in a 120 volt ac mains supply (cf column 1, lines 13 to 24, and column 5, lines 20 to 26, of the application). Such problems arise as part of the routine work of a skilled person confronted with designing a new drive system for such appliances. Therefore, the posing of this problem does not contribute inventive considerations.

4.6 The Board agrees with the appellant that the person skilled in the art would not use a thyristor of a type which cannot be actively switched off in place of the transistor switch (QA) and the diode (DA) in the circuit of Figure 1(e) of D2 if he merely wished to reduce the teaching of D2 to practice because this transistor switch acts as a chopper to keep the capacitor voltage within a relatively narrow band (see point 3 above).

4.7 However, the person skilled in the art having the above problem in mind is assumed to search the available prior art for possible simplifications and is supposed to find D4, which relates to the same technical field of switched reluctance drives. Throughout the differently embodied electrical circuits, D4 (Figures 8, 9, 10 and 17) gives a similar teaching as D2 (Figure 1(e)) concerning the charging and discharging of a capacitor (47a) which forms part of a secondary winding current path. Magnetic energy is transferred from the armature coil into the capacitor to cause rapid demagnetization, and stored capacitor energy at a higher than supply voltage is discharged into a phase winding to cause rapid increase in current, both measures assisting in increasing the output torque with a given power supply (D4', Figures 7 and 23; column 3, lines 27 to 44; column 4, lines 44 to 56; column 6, lines 4 to 20; column 7, lines 27 to 43; column 8, lines 41 to 57; column 9, lines 19 to 27). The embodiment of Figure 17 has a capacitor (47a) and a normal thyristor (19a) serially connected across the or each phase winding (32a) and a switch arrangement (20a). The capacitor is charged through the phase winding and a diode (21a) when the switch arrangement is open circuit, and discharged through the secondary current path (19a, 32a, 20a) when the switch arrangement is subsequently closed (D4', column 29, lines 17 to 21; column 29, line 51 to column 30, line 33). With this type of thyristor, the capacitor discharge current cannot be switched off, once the thyristor is triggered and conductive unless the voltage across the capacitor falls below the voltage of the power supply terminals (D4', column 23, lines 23 to

31; Figure 7).

4.8 The person skilled in the art would recognize that a thyristor operated in the way as suggested in D4 has the advantage of less complex control circuits than that of D2, Figure 1(e), and needs no additional blocking diode in the secondary winding current path. At the same time, a thyristor as connected in Figure 17 of D4 offers the same advantages of rapid magnetization and demagnetization (D4', column 16, line 57 to column 17, line 4; D2, pages 1036 and 1037, bridging paragraph: "some functional requirements that an SRM should ideally meet"). In this respect, the statement of D2 (page 1040, section F) that the Figure 1(e) circuit was believed to be "a minimum component topology" has to be seen in the context of the five different circuits depicted in Figure 1. It does not discourage the skilled person from using a single switch instead of a diode and a transistor if the single switch provides the same functions (eg with a gate turn-off thyristor) or simplified functions (with a thyristor) in accordance with the teaching of D4. Moreover, in view of the similar operation of the capacitors in D2 and D4, the person skilled in the art would know from D2 that a dc link capacitor may be eliminated, as taught in D2, although this is not explicitly disclosed in D4. The subject-matter of claim 6 of the **main request** (taking account of the intended limitation to a normal thyristor) therefore results from an obvious combination of very similar teachings given in D2 and D4 and thus does not involve an inventive step (Article 56 EPC).

5. The **(second) auxiliary request** comprising amendments to clarify the dual-rail structure, as derived by the

appellant from column 6, lines 6 to 8, of the published application, refers to an electrical circuit where each phase winding has its own capacitor, thyristor and diode connected thereto (instead of a single capacitor, switch and diode which are common to all the phases as in D2, Figure 1(e)). However, this circuit structure corresponds to that disclosed in Figure 17 of D4 and would constitute the preferred choice in combination with a circuit that was adapted to operate in accordance with the principles disclosed in D4. The argument that D4, Figure 17, discloses additional blocking diodes (49) is not convincing in this context because such diodes are not excluded in the teaching of the present application, which only discloses the main components of a single phase and merely cursorily mentions that "the invention is applicable also to each phase of a multi-phase switched reluctance machine".

6. The **further (third) auxiliary request** introduces a limitation to a single phase switched reluctance drive system. The principles taught in both D2 and D4 are generally applicable to any number of phases and would produce essentially the same effects with single phase switched reluctance drive systems. While it is clear that neither of the above addressed circuits of D2 and D4 can be directly applied to a single phase system, the adaptation that needs to be done is nevertheless straightforward. It thus needs no inventive skill but only the normal technical competence of an unimaginative person skilled in the art. Since single phase switched reluctance machines were generally known, the adaptation of the disclosure of D2 and D4 to a single phase drive system would fall within the obvious modifications of this prior art.

7. For these reasons, the present application does not comply with the requirements of Articles 52(1) and 56 EPC.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

M. Hörnell W. J. L. Wheeler