METHOD AND APPARATUS FOR CONTROLLING THREE-PHASE ELECTRIC MOTOR

Abstract: Methods and control apparatus for operating a three-phase electric motor are described, in which the motor windings are switched between Star and Delta connections depending on torque requirements, and in which the motor windings are switched to a braking mode when braking torque is required. The electromagnetic torque of the motor is monitored, and a command to switch from Star to Delta is given when the electromagnetic torque rises to reach or exceed a threshold. A command to switch from Delta to Star is given when the electromagnetic torque falls to reach a second threshold. The invention discloses a method of determining instantaneous values for the electromagnetic torque of the motor based on measurements of phase current and phase voltage at particular instants in the voltage cycle. The application further discloses a method of timing the switching operation between Star and Delta configurations, or switching from Star or Delta configuration to a dynamic braking mode, to minimise inrush currents by monitoring the vector relationship between the EMF and the supply voltage and performing switching operations in each motor phase when EMF vector is aligned with the supply voltage vector. The application further discloses switching from Star to Delta or Delta to Star when the torque produced by the motor is substantially equal to the torque requirement of the load to maximise efficiency.
Published:
— with international search report (Art. 21(3))
— before the expiration of the time limit for amending the
  claims and to be republished in the event of receipt of
  amendments (Rule 48.2(h))

(88) Date of publication of the international search report:
18 January 2018 (18.01.2018)
INTERNATIONAL SEARCH REPORT

PCT/GB2017/000052

A. CLASSIFICATION OF SUBJECT MATTER

H02P1/32 H02P25/18 H02P3/24 G01R21/06 G01R31/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category* Citation of document, with indication, where appropriate, of the relevant passages Relevant to claim No.

A US 2011/006720 A1 (NAIMAN ARTHUR [IL])
13 January 2011 (2011-01-13)
paragraph [0003] ; figure 1
equation 7
paragraph [0029]
figure 2

paragraph [0087] ; figure 4
paragraph [0090] ; figure 5

A US 2014/070754 A1 (KOUV0 MI KK0 [FI] ET AL)
13 March 2014 (2014-03-13)
paragraph [0022]

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered new or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"P" document published prior to the international filing date but later than the priority date claimed

"T" document member of the same patent family

Date of the actual completion of the international search 12 December 2017

Date of mailing of the international search report 19/12/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Schurle, Patrick

Authorized officer

Form PCT/ISA/210 (second sheet) (April 2005)
<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>column 3, line 56 - line 60; figures 1,2,4</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>EP 1 492 142 A2 (EATON CORP [US]) 29 December 2004 (2004-12-29)</td>
<td>13,14</td>
</tr>
<tr>
<td></td>
<td>paragraph [0083] - paragraph [0085]; figures 29-31</td>
<td></td>
</tr>
</tbody>
</table>
# INTERNATIONAL SEARCH REPORT

## Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2. [X] Claims Nos.: 21, 25
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
   
   see SUBPART INFORMATION sheet PCT/ISA/21Q

3. [ ] Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [X] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

   1-14, 20

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

## Remark on Protest

- [ ] The additional search fees were accompanied by the applicant’s protest and, where applicable, the payment of a protest fee.
- [X] The additional search fees were accompanied by the applicant’s protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- [X] No protest accompanied the payment of additional search fees.

Form PCT/ISA/21 0 (continuation of first sheet (2)) (April 2005)
This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12, 20-25

A method of controlling the operation of a three-phase motor driving a load, wherein the motor is operable in both Star and Delta configurations, comprising the steps of: a. monitoring the electromagnetic torque (Term) produced by the motor; b. monitoring the rotation speed (n) of the motor; c. comparing the electromagnetic torque produced by the motor to a threshold value, and d. switching the motor from Star to Delta or from Delta to Star configuration on the basis of which comparison; wherein the electromagnetic torque (Term) produced by the motor is monitored by steps i. to viii.

2. claims: 13, 14

A method of switching from Star to Delta/Delta to Star connection a three-phase motor powered from a three-phase mains supply and driving a load, the method comprising the steps of: a. determining a value of the electromagnetic torque produced by the motor; b. determining whether the electromagnetic torque value is equal to or greater than a predetermined threshold value; c. determining whether the electromagnetic torque value is substantially equal to a current torque requirement of the load; and d. if the electromagnetic torque value is equal to or greater/less than a predetermined threshold value and the electromagnetic torque value is substantially equal to a current torque requirement of the load, then e. switching the motor from Star to Delta/Delta to Star connection by steps f.g.h/f.g.

3. claims: 15-19

A method of providing braking in a three-phase motor operating in Delta/Star configuration, in which thyristors are connected to connect the three-phase motor in Delta/Star configuration, the method comprising corresponding steps c.d.e/f/a,b,c,d,e.

---
Continuation of Box 11.2

Claims Nos.: 21-25

Independent claims 21,22,23 do not meet the requirements of Article 6 PCT in that they are not clear. The subject matter of the claims is defined by references to the drawings only, whereas Article 6 PCT specifies that the claims shall define the subject-matter for which protection is sought; see also Rule 6.2 (a) PCT. This should be done in terms of the technical features of the invention; Rule 6.3 (a) PCT. Since it is unclear which features of the drawings are intended to be included into the claims, a meaningful search of the whole claimed subject-matter could not be carried out (Article 17(2) PCT and PCT Guidelines 9.30).

Independent claims 24,25 do not meet the requirements of Article 6 PCT in that they are not clear. The subject matter of the claims is defined by references to the application only, whereas Article 6 PCT specifies that the claims shall define the subject-matter for which protection is sought; see also Rule 6.2 (a) PCT. This should be done in terms of the technical features of the invention; Rule 6.3 (a) PCT. Since it is unclear which features of the drawings are intended to be included into the claims, a meaningful search of the whole claimed subject-matter could not be carried out (Article 17(2) PCT and PCT Guidelines 9.30).

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.
<table>
<thead>
<tr>
<th>Patent document cited in search report</th>
<th>Publication date</th>
<th>Patent family member(s)</th>
<th>Publication date</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 2011006720 AI</td>
<td>13-01-2011</td>
<td>CA 2767198 AI</td>
<td>13-01-2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 102484437 A</td>
<td>30-05-2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 2452427 A2</td>
<td>16-05-2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2012533271 A</td>
<td>20-12-2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>KR 20120051669 A</td>
<td>22-05-2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RU 2012101710 A</td>
<td>20-08-2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2011006720 AI</td>
<td>13-01-2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 2011004369 A2</td>
<td>13-01-2011</td>
</tr>
<tr>
<td>US 2012223663 AI</td>
<td>06-09-2012</td>
<td>CN 102640413 A</td>
<td>15-08-2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DE 102009041878 AI</td>
<td>10-03-2011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 2476202 A2</td>
<td>18-07-2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2012223663 AI</td>
<td>06-09-2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WO 2011026792 A2</td>
<td>10-03-2011</td>
</tr>
<tr>
<td>US 2014070754 AI</td>
<td>13-03-2014</td>
<td>AU 2013204910 AI</td>
<td>27-03-2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CA 2824622 AI</td>
<td>10-03-2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CN 103684195 A</td>
<td>26-03-2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EP 2705972 AI</td>
<td>12-03-2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 6139347 B2</td>
<td>31-05-2017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>JP 2014054177 A</td>
<td>20-03-2014</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2014070754 AI</td>
<td>13-03-2014</td>
</tr>
<tr>
<td>US 4434394 A</td>
<td>28-02-1984</td>
<td>NONE</td>
<td>NONE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US 2005013085 AI</td>
<td>20-01-2005</td>
</tr>
</tbody>
</table>