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(54) **Method for restarting a synchronous permanent magnet motor still rotating**

Verfahren zum Wiederstarten eines noch rotierenden permanent-magnetischen Synchronmotors

Méthode de redémarrage d’un moteur synchrone à aimant permanent encore en rotation

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Description

[0001] The invention relates to a method for restarting a synchronous permanent magnet motor still rotating and connected to a drive unit with a variable output AC voltage.

[0002] In particularly, the invention concerns a method for resuming operation of a 3-phase synchronous permanent magnetic motor by phasing-in the variable output drive unit relative to the actual speed and rotational angle of the motor rotor, wherein the drive unit has a DC-link with a voltage measuring means and current measuring means on at least two of the output phases.

[0003] In prior art technique, phasing-in of a drive unit in relation to the actual speed and position of a rotating motor has been performed by using a voltage sensing and measuring device connected to the three output stage outputs. See for instance U.S. 5,475,292. Such a device complicates the drive unit unnecessarily, and since it is desirable to make the drive unit simpler, more reliable and less expensive it is an object of the invention to provide a drive unit having the same functional features without including this voltage sensing and measuring device.

[0004] Another prior art method is described in WO 95/34125 and comprises a phasing-in procedure for the AC section of an inverter drive relative to an AC main, without using a voltage sensing and measuring device. Instead, the phases of the AC main are short-circuited for determining the actual direction and speed of the AC section voltage. This known method, however, relates to a specific problem solution, namely to phase in the AC drive section to a mains in which the frequency variation normally is about no more than +/- 10 %. This means that it is fairly simple to estimate from start the short-circuiting duration to be used for safely determining the rotation frequency. This differs significantly from the problem being solved by the invention, namely to phase-in an inverter drive to a synchronous PM motor which could have a wide rotation speed variation.

[0005] A preferred application example of the invention is described below in further detail with reference to the accompanying drawings.

[0006] On the drawings

Fig. 1 shows a drive unit and motor circuitry according to the invention.

Fig. 2 shows a diagram illustrating current/time relationship during short-circuiting of the motor.

Fig. 3 shows a stator-referenced d / q diagram, illustrating the momentary current and angular position of the rotor at short-circuiting of the motor.

[0007] The drive unit shown in Fig. 1 is connected to a motor M and comprises a DC-stage which is powered by a battery or, dependent on the actual field of use, by an AC net source via a rectifier. A DC-BUS feeds a direct current to an output stage which comprises three phases U, V and W and six power switches T1 - T6 with free-wheeling diodes. A voltage measuring means is connected to the DC-BUS to detect the DC voltage.

[0008] A current measuring means (not shown per se) is connected to two of the output phases U and V so as to detect the instantaneous values of the motor phase currents I_U and I_V. The states of the power switches T1 - T6 are controlled in a conventional way by a PWM controller (not shown).

[0009] The operational features of the illustrated drive unit as well as the phasing-in procedure of the latter at restarting the motor is described below with reference to the accompanying drawing figures. At the start of this procedure, it is assumed that in an initial condition all six power switches T1 - T6 are in their off conditions, and the motor M is rotating at an unknown speed.

[0010] The phasing-in procedure comprises the steps of short-circuiting momentarily the output stage of the drive unit, thereby measuring the current variations in two of the motor phases. In Fig. 2, there is illustrated how the currents I_U and I_V in two motor phases vary over time during two momentary short-circuiting occasions performed within a certain time interval. The same current variations are illustrated in Fig. 3 in a d/q plane diagram. The measured current values in relation to the duration of the short-circuiting step and in relation to each other provides information of the actual speed and rotor position.

[0011] Referring to the diagrammatic illustrations, a first short-circuiting starts in point t_1, wherein the power devices T2, T4 and T6 are turned on and the currents I_U and I_V start rising. At t_2 the values of the currents I_U and I_V are sampled, and at t_3 the power devices T2, T4 and T6 are turned off. At point t_3A the currents are decreasing back to zero.

[0012] From the currents sampled in t_2, which are correlated to the angular rotor position in point t_2, the angle alpha_{t_2} may be calculated. See Fig. 3. The radius R of the circle going through the current curves at t_2 is proportional to the motor speed divided by the circuit inductance, which is the motor inductance and eventual externally connected filter, provided the time intervals are chosen so as to make the circuit resistance negligible. Thus, knowing the inductance in the motor circuit and the motor voltage constant it is possible to calculate the approximate motor speed.

[0013] It should be noted though, that in Fig. 3, the phase displacement during short-circuiting is illustrated in a somewhat exaggerated way in order to show more clearly the course of events.

[0014] In order to improve the speed calculation accuracy and to make a speed estimation without knowing the motor inductance, another short-circuiting steps may be performed at a later occasion. Accordingly, at t_4 the power devices T2, T4 and T6 are turned on, and the currents I_U and I_V start rising. At t_4A, the current values have increased to a certain extent, and at t_5 the current values are sampled.
At $t_6$, the power devices T2, T4 and T6 are turned off, and the current values start decreasing via point $t_6A$ back to zero. From the current samples taken at $t_5$, it is possible to calculate the angle $\alpha-t_5$, which is correlated to the angular position of the rotor at $t_5$.

Now, by dividing the angular interval: $\alpha-t_5 - \alpha-t_2$ by the time interval: $t_5 - t_2$ there is obtained the electrical speed of the motor $M$, which also gives the frequency to be used at phasing-in the drive unit.

These events may be repeated with successively larger intervals until there is obtained an accurate enough motor speed estimation.

In order to adjust the current response amplitude, the short-circuiting duration may simply be extended, i.e. the value of $t_2 - t_1$ and the value of $t_5 - t_4$. See Fig. 2.

For restarting the motor, the correct phase, frequency, and amplitude of the generated voltage has to be set to match the motor voltage. The generated phase and frequency are known by measurement, and the motor voltage is either calculated from: motor-frequency * motor-voltage-constant, or derived from the radius $R$ of the current circle. See Fig. 3.

The correct drive unit voltage output is either measured or estimated on the DC-BUS voltage.

When the PWM controller has been set to generate the matching voltage, frequency and phase of the motor, the actual switching of the power transistors can be established. The motor is now restarted, and the PWM controller and switches will from now on operate in the conventional way.

Claims

1. Method for restarting a three-phase synchronous permanent magnet electric motor having its rotor still at rotation, wherein the motor is connected to a drive unit having a DC-stage with a voltage measuring means, a variable voltage and frequency output stage having power switching devices, and a means for determining the current in at least two of the output phases from said drive unit, comprising the steps of:

   I) short-circuiting momentarily the motor with said output stage at two or more occasions at certain time intervals,
   II) detecting during said short-circuiting the current magnitude generated by the motor in at least two of the motor phases,
   and characterized by the following steps:
   III) calculating at a first short-circuiting a short-circuiting duration to be used at following short-circuitings or short-circuitings,
   IV) calculating an approximate motor speed,
   V) repeat step I) and II) at least once, calculating the motor speed by using said calculated short-circuiting duration,
   VI) calculating during said short-circuitings the phase angle generated by the motor,
   VII) synchronising the drive unit with the motor, and
   VIII) restarting the motor.

2. Method according to claim 1, wherein the voltage amplitude generated by the motor is calculated.

3. Method according to claim 1, wherein said means for determining the current in at least two of the output phases of said drive unit communicates directly with the motor phases.

4. Method according to claim 1, wherein said means for determining the current in at least two of the output phases of said drive unit communicates directly with said power switching devices.

5. Method according to claim 1, wherein said means for determining the current in at least two of the output phases of said drive unit communicates with said DC-stage.

Patentansprüche

1. Verfahren zum Wiederanfahren eines elektrischen Permanentmagnet-Dreiphasensynchronmotors, dessen Rotor sich noch in Rotation befindet, wobei der Motor an eine Versorgungseinheit angeschlossen ist, die eine Gleichstromstufe mit Mitteln zur Spannungsmessung, eine Ausgangsstufe mit variabler Spannung und Frequenz, die Leistungsschalteinrichtungen aufweist, und Mittel zum Erfassen des Stromes in wenigstens zwei der Ausgangsphasen der Versorgungseinheit besitzt, gekennzeichnet durch die folgenden Maßnahmen:

   I) der Motor wird mit der Ausgangsstufe zu zwei oder mehreren Zeitpunkten in bestimmten Zeitintervallen kurzzeitig kurzgeschlossen,
   II) während des Kurzschlieβens wird die den Motor erzeugte Stromstärke in wenigstens zwei der Motorphasen erfaßt,
   III) bei einem ersten Kurzschlieβen wird eine Kurzschlußdauer berechnet, die bei dem oder den nachfolgenden Kurzschlieβen verwendet wird,
   IV) eine ungefähre Motordrehzahl wird berechnet,
   V) I) und II) werden wenigstens einmal wiederholt, wobei die Motordrehzahl unter Verwendung der errechneten Kurzschlußdauer berechnet wird,
   VI) während der Kurzschlieβen werden die von dem Motor erzeugten Phasenwinkel berech-
Revendications

1. Procédé de redémarrage d’un moteur électrique à aimant permanent synchrone à trois phases dont le rotor est encore en rotation, dans lequel le moteur est connecté à un bloc de commande comportant un étage à courant continu avec un moyen de mesure de tension, un étage de sortie à tension et fréquence variables comportant des dispositifs de commutation de puissance, et un moyen de détermination du courant dans deux au moins des phases de sortie, à partir du bloc de commande, caractérisé par.

les mesures suivantes consistant à :

I) court-circuiter momentanément le moteur avec l’étage de sortie en deux ou plusieurs occasions, à certains intervalles de temps,
II) détecter, pendant le court-circuit, l’amplitude du courant généré par le moteur dans deux au moins des phases du moteur,
III) calculer, au moment d’un premier court-circuit, une durée de court-circuit à utiliser dans le court-circuit suivant ou dans les courts-circuits suivants,
IV) calculer une vitesse approximative du moteur,
V) répéter les étapes I) et II) au moins une fois, puis calculer la vitesse du moteur en utilisant la durée de court-circuit calculée,
VI) calculer l’angle de phase généré par le moteur pendant les courts-circuits,
VII) synchroniser le bloc de commande avec le moteur, et
VIII) faire redémarrer le moteur.

2. Procédé selon la revendication 1, dans lequel on calcule l’amplitude de la tension générée par le moteur.

3. Procédé selon la revendication 1, dans lequel le moyen de détermination du courant dans deux au moins des phases de sortie du bloc de commande, communique directement avec les phases du moteur.

4. Procédé selon la revendication 1, dans lequel le moyen de détermination du courant dans deux au moins des phases de sortie du bloc de commande, communique directement avec les dispositifs de commutation de puissance.

5. Procédé selon la revendication 1, dans lequel le moyen de détermination du courant dans deux au moins des phases de sortie du bloc de commande, communique avec l’étage à courant continu.
FIG 1

DC-BUS
T1 T3 T5
T2 T4 T6
U V W
M

$U_{dc}$

$I_u$

$I_v$