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INVESTIGATION AND DEVELOPMENT OF PERMANENT MAGNET SYNCHRONOUS MOTOR SERVO- AND ROBOT DRIVES USING DIRECT TORQUE CONTROL METHODS WITH SPACE VECTOR MODULATION

Thesis summary

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1. Introduction

Nowadays permanent magnet synchronous motors with sinusoidal field-distribution are one of the most commonly used types of motors in the field of servo- and robot drives. This can be contributed to the fact that these motors have a very high power-density and from the point of view of the construction they are perfectly suitable for motion control applications requiring high-precision.

One the most promising methods for controlling the electromagnetic torque of permanent magnet synchronous motors is called the direct torque control with space vector modulation (shortly: DTC-SVM).

In my dissertation the overload-capabilities of the DTC-SVM method are examined which is an issue that has not been investigated yet. During my research I have proven the followings:

1. The DTC-SVM has poor overload-capabilities.
2. The DTC-SVM has severe instability-problems during overloading.
3. The overload-capabilities of the DTC-SVM are heavily dependent on the speed.

Also, I have managed to find out the reasons for these problems.

In order to eliminate the overload-capability problems of the DTC-SVM I have developed new DTC-SVM methods which have the following features:

1. The new methods have far more superior overload-capabilities compared to those of the original method.
2. The new methods are stable during overloading.
3. The new methods are capable of practically the same excellent torque-control dynamic performance as the original method.
4. The torque-ripples produced by the new methods are practically identical to those of the original method.

The new methods have been validated by means of mathematical simulations carried out in Matlab-Simulink environment. The simulation investigations were based on the space vector equations of the motor and the differential equations describing the drive system.

The new DTC-SVM methods have effectively increased the overload-capabilities of the drive system. This results in a significant reduction of costs and provides us the feasibility of a more space-saving mechanical construction of the whole system. In addition, the increase in overload-capabilities results in a significantly increased dynamic torque which leads to a remarkably increased dynamic performance of the servo system and thus making a much faster positioning possible.

In the dissertation the aforementioned research results are presented and summarized. The fields of applications for each method are also given. The structure of the dissertation is as follows:

1. A short introduction of permanent magnet synchronous motor drives and that of the direct torque control.
2. Introduction of the DTC-SVM and a survey of its literature.
3. Presentation of my own research results regarding the DTC-SVM, investigation and analysis of the overload-capabilities of the DTC-SVM, which is an issue that has not been investigated yet.
4. Presentation and analysis of my newly developed DTC-SVM methods.
5. Summarization of my new scientific results. The fields of applications of my newly developed DTC-SVM methods and the areas that can be subjected to further research and development are also given.

2. New scientific results

Thesis 1

I have proven that during heavy overloading the original DTC-SVM suffers from severe instability-issues and the maximal overload-capabilities of method are significantly dependent on the speed of the motor. I have demonstrated that these problems occur because of the improperly created reference signal for the load-angle controller and the absence of the stator flux amplitude controller.

In order to eliminate the aforementioned problems of the original DTC-SVM I have developed a new DTC-SVM method which has significantly better overload-capabilities than those of the original method and its overload-capabilities are practically independent of the speed of the motor. The new method is called the Modified DTC-SVM (shortly: MDTC-SVM).

The new method remains stable even with overloads exceeding its maximal overload-capabilities. In addition, the new method has the same excellent dynamic torque-control capabilities as the original DTC-SVM method and there is no significant difference between the two methods from the point of view of the torque-ripple generated.

Publications assigned to the thesis: [J1], [C1], [C3]

Thesis 2

In order to further improve the overload-capabilities of the MDTC-SVM I have developed a new DTC-SVM method. This new method is called the Improved Modified DTC-SVM (shortly: IMDTC-SVM) and it has far more superior overload-capabilities compared to those of the original DTC-SVM method and even compared to those of the MDTC-SVM. This progression has been achieved by using a new stator flux amplitude reference controller and a new reference controller, by improving the load-angle controller and the stator flux amplitude controller and by applying an adaptive voltage vector calculator instead of a standard one.

The new method remains stable even with overloads exceeding its maximal overload-capabilities. In addition, the new method has the same excellent dynamic torque-control capabilities as the original DTC-SVM method and the MDTC-SVM while there is no

significant difference between the three methods from the point of view of the torque-ripple generated.

Publications assigned to the thesis: [J3], [C1], [C2]

Thesis 3

In order to reduce the computation requirements of the IMDTC-SVM and to simplify its control structure and to make the tuning of the complete control system easier I have developed two simplified forms of the standard IMDTC-SVM method. These methods are called the Improved Modified DTC-SVM Simplified Form XY (shortly: IMDTC-SVM SFXY) and the Improved Modified DTC-SVM Simplified Form DQ (shortly: IMDTC-SVM SFDQ).

Although the simplified forms have somewhat lower overload-capabilities than those of the standard IMDTC-SVM method, their overload-capabilities are still superior to those of the original DTC-SVM method and the MDTC-SVM. The simplified forms require much less computation than the standard IMDTC-SVM and are remarkably simpler in structure. The tuning of the complete control system is significantly easier only in the case of the IMDTC-SVM SFXY because in this case there are much less parameters to tune.

The simplified methods remain stable even with overloads exceeding their maximal overload-capabilities. In addition, the simplified methods have the same excellent dynamic torque-control capabilities as the original DTC-SVM method, the MDTC-SVM and the IMDTC-SVM while there is no significant difference between the five methods from the point of view of the torque-ripple generated.

Finally, I have given some important aspects about the generalization of the new methods for other motor types.

Publications assigned to the thesis: [J2], [J4], [J5], [J6], [C2]

3. Practical applications of the new methods

The new methods can be effectively used for increasing the dynamic performance of servo- and robot drives. The increased dynamic torque makes a more rapid speed-control and a much faster load-torque compensation possible. In addition, the drive is capable of handling much heavier loads.

In those drive systems where the maximal overload-capabilities and/or the maximal dynamic performance are the most essential requirements the IMDTC-SVM is the recommended method.

In those applications where reduced computation-requirements and simpler control structure are also important factors the utilization of either the IMDTC-SVM SFXY or the IMDTC-SVM SFDQ or the MDTC-SVM is recommended. The choice should be based on how much compromise the user is willing to make in overload-capabilities/dynamic performance.

The MDTC-SVM resembles the most to the original DTC-SVM method, therefore in the case of „conservative" users – if the requirements of the user in means of the overload-capabilities and the dynamic performance of the servo system are fulfilled – this is the recommended method. If there is a need for increased overload-capabilities and/or increased dynamic performance then the application of either the IMDTC-SVM SFXY or the IMDTC-SVM SFDQ is recommended. The choice should be based on the needs of the user. The IMDTC-SVM SFDQ has somewhat better overload-capabilities while the tuning of the complete control system in the case of the IMDTC-SVM SFXY is much easier.

4. Publications by the author

Articles in reviewed international journals:

[J1]: Tibor Vajsz, László Számel, György Rácz: A Novel Modified DTC-SVM Method with Better Overload-capability for Permanent Magnet Synchronous Motor Servo Drives, Periodica Polytechnica Electrical Engineering and Computer Science, Vol. 61, No. 3, pp. 253-263, 2017, doi: 10.3311/PPee.10428

[J2]: László Számel, Tibor Vajsz: The special characteristics of stepping motor drives and a new type of classification, Acta Polytechnica Hungarica, Vol. 13, No. 7, pp. 83-102, 2016, doi: 10.12700/APH.13.7.2016.7.5

Impact factor in the year of publication: 0.745

[J3]: Tibor Vajsz, László Számel: Improved Modified DTC-SVM Methods for Increasing the Overload-capability of Permanent Magnet Synchronous Motor Servo- and Robot Drives – Part 1, Periodica Polytechnica Electrical Engineering and Computer Science, Vol. 62, No. 3, pp. 65-73, 2018, doi: 10.3311/PPee.11744

[J4]: Tibor Vajsz, László Számel: Improved Modified DTC-SVM Methods for Increasing the Overload-capability of Permanent Magnet Synchronous Motor Servo- and Robot Drives – Part 2, Periodica Polytechnica Electrical Engineering and Computer Science, Vol. 62, No. 3, pp. 74-81, 2018, doi: 10.3311/PPee.11762

[J5]: Tibor Vajsz, László Számel, Árpád Handler: An Investigation of Direct Torque Control and Hysteresis Current Vector Control for Motion Control Synchronous Reluctance Motor Applications, Power Electronics and Drives, pp. 1-12, accepted for publication

[J6]: Tibor Vajsz, László Számel, Árpád Handler: Analysis of Direct Torque Control with Space Vector Modulation for Synchronous Reluctance Motor Motion Control Applications and a Comparison with Other Torque-Control Algorithms, Power Electronics and Drives, pp. 1-11, accepted for publication

Conference articles:

[C1]: Tibor Vajsz, László Számel: Overload-capability analysis of PMSM servo- and robot-drives using DTC-SVM methods: Part 1, 2018 IEEE 18th International Power

Electronics and Motion Control Conference (PEMC), pp. 730-736, doi: 10.1109/EPEPEMC.2018.8521929

[C2]: Tibor Vajsz, László Számel: Overload-capability analysis of PMSM servo- and robot-drives using DTC-SVM methods: Part 2, 2018 IEEE 18th International Power Electronics and Motion Control Conference (PEMC), pp. 737-743, doi: 10.1109/EPEPEMC.2018.8521944

[C3]: Vajsz Tibor, Számel László: Állandómágneses forgórészű szinkron motorok közvetlen nyomatékszabályozása (in English: Direct torque control of permanent magnet synchronous motors), V. Mechwart András Youth Conference, 2015, pp. 1-5, ISBN: 978-963-9299-27-6

[C4]: Tibor Vajsz, Lászó Számel: Nonlinear variable gain position control for permanent magnet synchronous motor servo- and robot drives, Proceedings of the Workshop on the Advances of Information Technology: WAIT 2017, pp. 111-115, ISBN: 978-963-313-242-5

[C5]: Tibor Vajsz, László Számel: An investigation of robust speed-controllers for permanent magnet synchronous motor servo drives, Proceedings of the Automation and Applied Computer Science Workshop 2015: AACS'15, pp. 117-128, ISBN: 978-963-313-187-9

[C6]: Tibor Vajsz, László Számel: Robust speed-control for permanent magnet synchronous motor servo drives, Proceedings of the Workshop on the Advances of Information Technology: WAIT 2015, pp. 78-82, ISBN: 978-963-313-178-7

[C7]: Tibor Vajsz, László Számel: Controlling of switched reluctance motor drives, XXXI. Kandó Conference 2015, pp. 1-19, ISBN: 978-963-7153-06-3

[C8]: Tibor Vajsz, László Számel, György Rácz: Simulation, analysis and comparison of field-oriented control and direct torque control, XXX. Kandó Conference 2014, pp. 1-17, ISBN: 978-615-5460-24-1

[C9]: Vajsz Tibor, Dr. Számel László, Rácz György: A közvetlen nyomatékszabályozás elve, megvalósítása, és főbb tulajdonságai aszinkron motoros hajtások esetében (in English: The principle, realization and main features of direct torque control in the case of AC induction motor drives), ENELKO 2014 XV. International Conference on Energetics and Electrotechnics, pp. 119-124, ISSN: 1842-4546

Articles in Hungarian Journals:

[JH1]: Vajsz Tibor, Számel László: Szinkron reluktancia motoros hajtások: 1. rész (in English: Synchronous reluctance motor drives: Part 1), Elektronet, 2017/1, pp. 30-31, ISSN: 1219-705 X (printed version), 1588-0338 (online)

[JH2]: Vajsz Tibor, Számel László: Szinkron reluktancia motoros hajtások: 2. rész (in English: Synchronous reluctance motor drives: Part 2), Elektronet, 2017/2, pp. 36-37, ISSN: 1219-705 X (printed version), 1588-0338 (online)