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Fault Detection and Identification for Permanent Magnet Synchronous Motor Drives

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Abstract

Automotive as well as aerospace applications often are safety related and demand drives with a high reliability. Since faults never can be avoided absolutely, faults have to be detected in order to employ emergency operation. This paper describes the considered electrical and electromagnetic faults of a permanent magnet motor drive and discusses a fault detection procedure afterwards. It will be shown that no extra sensor is necessary. Only the phase currents are monitored and the drain-source voltages v_{DS} of the MOSFETs are sensed. The v_{DS}-sensing permits a very fast protection of the power devices. The failure is reported to a µ-controller and a fault identification routine is started. Monitoring the phase currents allows to recognize deviations from the set values what implies abnormal operation. If a fault is detected, the faulted phase is turned off and the three phase machine is driven in two phase operation mode. Therefore each motor phase is supplied by a separate single phase converter bridge. The final paper will present experimental results with the set-up described below.

Summary

To detect motor or converter faults it is necessary to monitor the phase currents. An appropriate model is compared with the measured currents to detect abnormal operation. There are two general approaches known: neural network methods (e.g. [FIL-95], [SCH-94]) or knowledge based methods (e.g. [CRA-93], [STE-91]). The neural network based methods demand high computing capacity and are suited to detect faults that develop gradually. Knowledge based methods often use lookup tables and are therefore able to react very fast. This paper will present such a method.

Experimental set-up

Figure 1 depicts the block diagram of the experimental set-up. The converter consists of three single phase bridges, each supplies one motor phase separately. The machine has a special winding configuration in which every terminal is connected to the corresponding converter bridge.

Currents are controlled by a space vector controller in stationary αβ-coordinates [KAZ-91]. The outputs of the three-level hysteresis comparators address a switching table to select the appropriate voltage vector.

Fault conditions

Many different faults are possible, but not every fault condition will be treated within this paper. Mechanical faults concerning bearings, shaft etc. are not considered, neither faults of the position transducer. Power supply is assumed to be unaffected. Only electromagnetic and electrical faults of the motor and the converter are investigated. They can be summarized:

I power device short circuit
II power device open circuit
III winding short circuit (at the terminals or parts of the winding)
IV winding open circuit

I Power device short circuit:
This fault becomes serious as soon as the second switch of the same converter leg is turned on. The shorted d.c. link results in excessive currents. A very fast protection is necessary to prevent further damage.

II Power device open circuit:
With an open circuit of one power device the proper operation of a converter bridge is no longer possible. The other devices have to be turned off to prevent further damage due to overcurrents or overvoltages.

III Winding short circuit:
With the winding short circuit the d.c. link is shorted if the phase is turned on. The same overcurrent protection is needed as in I.

If only parts of the winding are shorted, the phase inductance decreases. Therefore the rise of current di/dt increases and gives information about the amount of damage.

IV Winding open circuit:
If a winding is open circuited, there is no current to generate any torque contribution. The difference between reference value and actual current value indicates the open circuit.

Fault detection procedure

A two step fault detection procedure is proposed. The first step contains the primary protection of the power devices. If a power device failure occurs, the affected device is turned off independent of the µ-controller. In the second step the failure is reported to the controller and a fault identification routine will be started.

As mentioned above the phase currents give information about winding open circuit or windings partly shorted. That's why the phase currents should also be monitored.

As soon as a fault is recognized the faulted phase is turned off and the operation mode of the drive is changed to two-phase operation.

Two-phase operation with a three-phase PMSM is described e.g. in [ELC-94]. If one phase is turned off due to an open circuit of a power device or a winding, the same fundamental magnetomotive force (m.m.f.) wave form and (nearly) the same performance can be obtained by the remaining two phases. Appropriate reference values for the other two phase currents will be necessary to get the same wave form. This can easily be done by changing the operating mode which is implemented in the switching table.

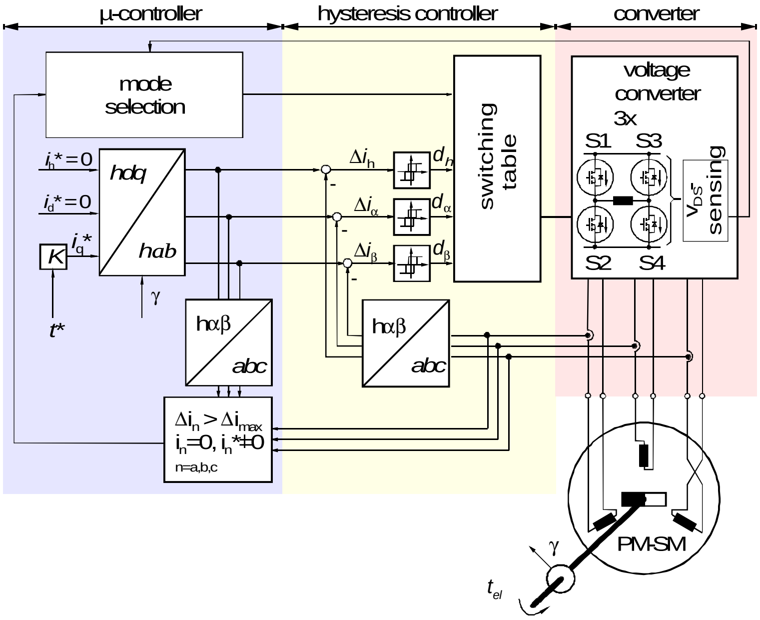

Figure 1: Experimental set-up

In contrast to other proposals no extra sensor is necessary.

Primary protection of the power devices – v_{DS}-sensing

The gate circuitry for the MOSFETs with v_{DS}-sensing is depicted in fig. 2. If the gate signal is zero there is no signal sensed. If there is a gate signal the MOSFET should be turned on. Diode *D* is forward biased and v_{sense} is

$$v_{sense} = \frac{R_3}{R_2 + R_3}\left(v_{diode} + v_{DS}\right),$$

a linear copy of the voltage v_{DS}.

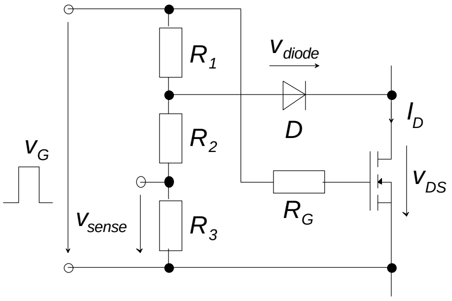

Figure 2: v_{Ds}-sensing

v_{DS} is $R_{DSon} \cdot I_d$, if the transistor is conducting (I_D is positive) and v_{Dr} (reverse conducting voltage) if the reverse diode is conducting. An overcurrent is indicated, if $v_{sense} > v_{sense,max}$. When the voltage rises above the threshold value, a protection circuit is triggered, the gate is turned off and the fault is reported.

When the MOSFET is open circuited v_{sense} is

$$v_{sense} = \frac{R_3}{R_1 + R_2 + R_3} \cdot v_G$$

and the gate drive is turned off as well.

Fault identification

The v_{DS}-sensing circuitry detects overcurrent and device open circuit. To distinguish between the two possibilities the fault identification procedure depicted in figure 3 is necessary.

If for example switch S1 reports a fault the error flag flag_S1 is set. There are four possibilities:

- overload
- overcurrent due to switch S2 being shorted
- open circuit of switch S1
- malfunction of the detection circuit

In normal three phase operation mode the error flags are observed. When an error flag is set, the four switches of the converter bridge are turned off and two phase operation mode is selected. Then the affected switch is turned on again. If the error flag is not set again, switches S1 and S4 are turned on to detect a winding short circuit that is indicated either by flag_S1 or flag_S4 reporting overcurrent. No error flag means overload or malfunction of the detection circuit of switch S1.

If the error flag is set again, switch S3 is turned on. If the phase current rises, a short of switch S2 will be identified. Otherwise switch S1 is open-circuited. The final paper will present experimental results.

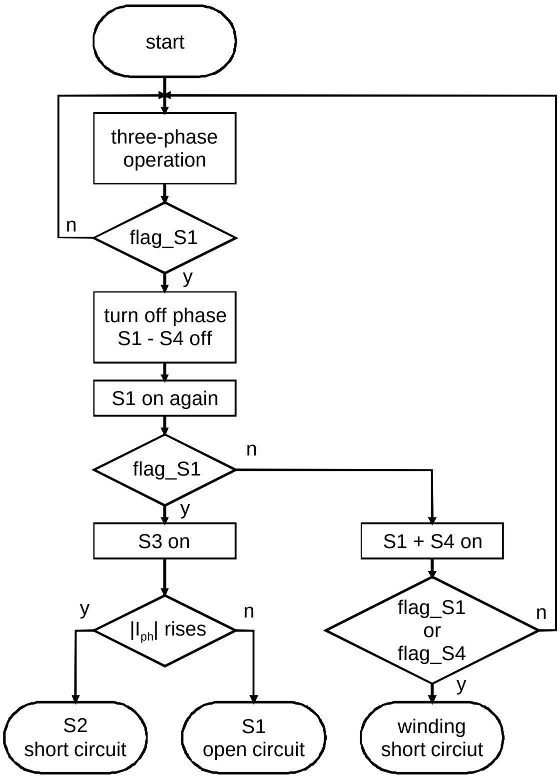

Figure 3: Fault identification procedure

References

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