Monitoring of the electrical resistance of a three phase machine applied for the vehicle

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Abstract. In the field of electrical machine diagnosis the finding of faults in the stator of the electrical machine is one of the greatest challenges. Stator faults have many possible reasons. They may be generated by shorts in the winding or circuit-breaks in one or more coils. In order to find that kind of faults, it is usually necessary to remove the electrical machine from the vehicle and to analyse the machine with external measurement devices. This approach is very expensive, time consuming and unnecessary, in the case that there is no fault. In the following paper, a method is described how the electrical resistances of the stator coils is estimated for diagnostic purposes. For the application of this method only the measurement system is used, which is usually installed in the vehicle. With using the internal sensors in the machine the cost and the time can be reduced. An removal of the electrical machine may be prevented and the using of external measuring equipment can be avoided.

1. Introduction

In the service area as well as for different purposes in research and development the knowledge about the healthiness of the electrical machine may be important. There are many approaches for the detection of stator faults during the operation of an electrical machine described in the literature. Most of them describe the detection of stator-faults with the so called motor current signature [2] analysis. The motor current signature analysis describes a method, which uses the three current sensors from the controlling of the electrical machine for the detection of faults in the electrical machine. The disadvantage of using this method is, that different faults have the same characteristic features. A separation of the various faults is therefore nearly impossible. If a fault can be detected during the operation, the question is, what kind of fault it is. The answer to this question is not very easy to provide. In the service area a dismounting of the electrical machine is usually preferred, so that the electrical machine can be tested with external measurement devices. But this procedure is not very effectively.

In this paper, a method is described to find stator faults in the electrical machine without any additional measurement devices and dismounting. It helps to reduce the
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![Diagram of electrical drive systems](image)

**Figure 1.** Main structure of electrical drive systems

cost and time at the fault search. The objective of the method is the diagnosis at stand still of the vehicle, to find shorts in the winding or circuit-breaks of one or more coils. For the application of this method, the electrical machine is controlled in specific switching states. In every switching state the measured electrical currents and the impressed voltages are determined. With these measurements a linear equation system can be solved and the resistances of the electrical machine can be calculated. For a healthy machine all three resistances must have the same value. If one or more resistances differ from the rest, the occurrence of a fault in the machine can be concluded. In the following sections the method described here will be explained in more detail.

2. The vehicle as test bench

The method described here is especially applicable for vehicles with an electrical powertrain. Usually such an electric powertrain consists of the components hv-battery, power electronic and electrical machine. This construction is shown in picture 1.

For the monitoring of the resistances, it is necessary to control the contactor of the hv-batterie as well as the switching states of the power electronic. To preserve the safety during the measurements it should be noted that by the application of the method high current impulses may be generated in the electrical machine. These may generate high torque impulses which may put the electrical machine in motion. However, such uncontrolled movements are not desirable and have to be prevented by for example the separation of the electrical machine from the wheels by a clutch or gear.

3. Diagnosis algorithmen

The diagnosis algorithmen [2] described here is based on the condition that there are three current sensors to measure the electrical current in the three phases and that a defined voltage in the electrical machine can be impressed by the power electronic. If both conditions are available the currents in the electrical machine can be controlled by a closed loop system or the voltages in the electrical machine can be set to a fixed point. Both control strategies are possible and have advantages and disadvantages. In this paper only the voltage control will be discussed. Independent of the control strategy
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The to be estimated resistances in the stator of the electrical machine can be calculated by the following equations

\[
\begin{bmatrix}
i_{U_i} \\
i_{V_i} \\
i_{W_i}
\end{bmatrix}
= \begin{bmatrix}
1 & 0 & -1 \\
-1 & 1 & 0 \\
0 & -1 & 1
\end{bmatrix}
\begin{bmatrix}
i_{UV_i} \\
i_{VW_i} \\
i_{WU_i}
\end{bmatrix}
\quad \text{with} \quad
\begin{bmatrix}
i_{UV_i} \\
i_{VW_i} \\
i_{WU_i}
\end{bmatrix}
= \begin{bmatrix}
u_{UV_i}/\hat{Z}_{UV} \\
u_{VW_i}/\hat{Z}_{VW} \\
u_{WU_i}/\hat{Z}_{WU}
\end{bmatrix}.
\]

If both equations are inserted in each other, the following expression can be obtained

\[
\begin{bmatrix}
i_{U_i} \\
i_{V_i} \\
i_{W_i}
\end{bmatrix}
\begin{bmatrix}
y_{U} \\
y_{V} \\
y_{W}
\end{bmatrix}
= \begin{bmatrix}
u_{UV_i}/\hat{Z}_{UV} \\
u_{VW_i}/\hat{Z}_{VW} \\
u_{WU_i}/\hat{Z}_{WU}
\end{bmatrix}.
\]

The form of the equation system described here can be used for the application of an onboard or offboard estimation. For the application in the vehicle, the equation system is solved as a whole by means of a recursive markov estimator in kalman-form [1] and can be described by the following three equations.

(i) Update the estimation by measurements

\[
\hat{B}^r = \hat{B}^m + K \cdot (Y^s - U^s \cdot \hat{B}^m)
\]

(ii) Compute the kalman gain

\[
K = P^m U^T s \cdot (R^s + U^s \cdot P^m \cdot U^T s)^{-1}
\]

(iii) Update the error covariance

\[
P^r = (I - K \cdot U^T) P^m + Q
\]

4. Measurements at the test bench and results

With the described monitoring system a test bench has been constructed which consists of a voltage source, a programmable power electronic, an electrical machine with \( p = 12 \) stator pole pairs and a measurement system. At the test bench various defined operation points are controlled by a voltage vector and the electrical currents \( i_U, i_V, i_W \) through the three stator windings are measured. The measurement is repeated for different circuit-breaks in the coils. It is examined a healthy machine without faults, a prepared machine with a circuit-break in one coil "1 Winding Break (WB)" and a circuit-break in two different branches "1 WB + 1 WB".

The results of the measurement is shown in figure 2. It can be seen, that a detection of one or more winding breaks is possible by analysis the estimated resistances \( R_{UV}, R_{VW} \) and \( R_{WU} \) of the stator windings. The comparison of figure 2b and 2e show, that the effect of a winding break in branch \( UV \) generates an increasing of the estimated electrical resistance \( R_{UV} \). The rising of the resistance value in one branch can also be described by the following equation

\[
R_{UVWBx} = p \cdot R_{UV}/(p - x)
\]
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The measurement results show, that especially by high current values the estimated resistances of the measurement are approached to the calculated resistances for the fault case. Same result can also be seen by faults in two branches (see figure 2i).

In addition, the results can be evaluated by a classification algorithm, to give the person in charge of the service area a direct feedback about the healthiness of electrical machine. An example of such a feedback is dispayed by the figures 2b, 2c, 2d, 2f, 2g, 2h, 2j, 2k, 2l.

5. References

[1] G. Welch and G. Bishop, *An Introduction to the Kalman Filter*, Department of Computer Science University of North Carolina at Chapel Hill, Juli 2006.

[2] M. D. Negrea, *Electromagnetic flux monitoring for detecting faults in electrical machines*, Helsinki University of Technology Department of Electrical and Communications Engineering Laboratory of Electromechanics, 2006.

[3] E. Bakhach and B. Rehfus *Diagnostic method for electric machine of motor vehicle, involves determining impedance of coils of stator in angular positions, and stopping it on occurrence of electric error of respective coil*, patent DE102013012861A1, Germany, 2014.