Condition monitoring and active fault compensation of electrical machines

Sustainable energy applications like wind turbines and electrical vehicles demand electrical machines with a high reliability in extreme circumstances in temperature (car in the sun), mechanical shocks (gust of wind, vehicles driving against the curbstones), humidity and salt (off-shore turbines, salt on the road in winter).

Although the wind turbine or the wheels of a car are ‘low speed’ applications, the electrical machines are usually ‘high speed’ (>1000 rpm). A gearbox couples the two together. The gearbox also protects the electrical machine from mechanical shocks. But a gearbox requires lots of maintenance and may reduce the reliability. Therefore, an evolution towards direct-drive applications is made (Figure 1). This means that the electrical machine is connected to the wheel of a car or to the blades of a wind turbine directly without a gearbox. This requires new electrical machines with low speed, high torque. The machines are no longer protected from mechanical shocks etc.

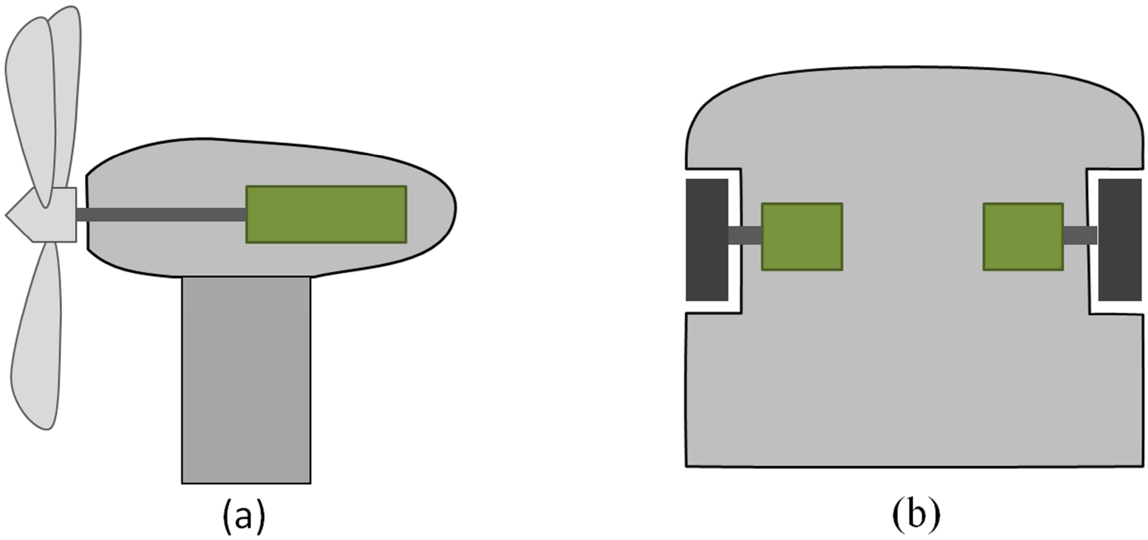

Figure 1: Sketch of a wind turbine (a) and a part of a car (b) using direct-drive technology

These direct-drive machines are subject to mechanical deformations of the shaft, which can lead to eccentricity. There are two types of eccentricity. With static eccentricity (Figure 2a) the axis is moved outside the middle of the machine. The eccentricity stays at the same place. With dynamic eccentricity (Figure 2b), the shaft is bent but still turns around the middle of the machine. This makes the smallest point move with the rotation of the motor.

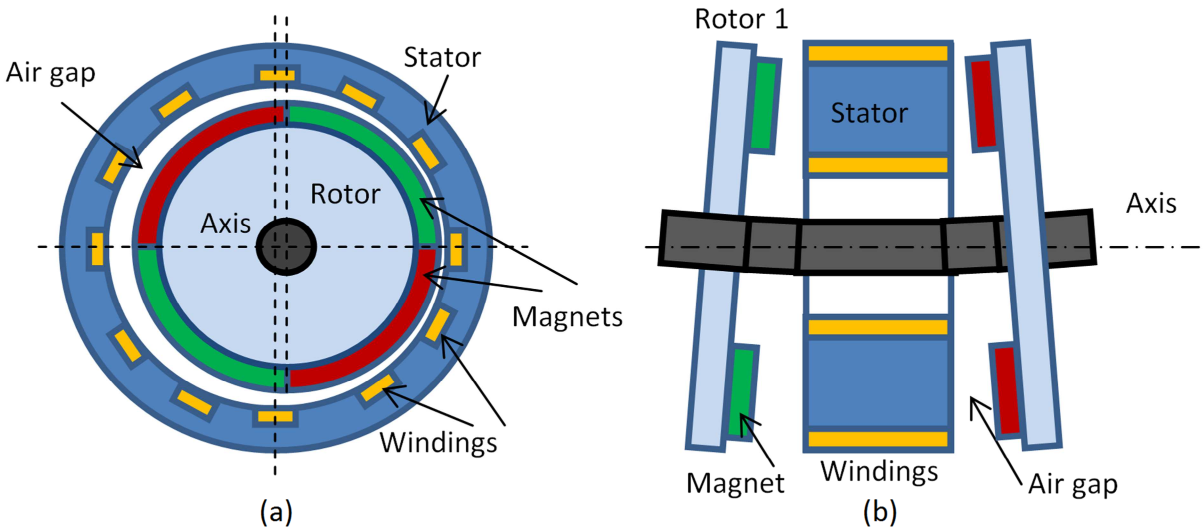

Figure 2: Representation of static (a) and dynamic eccentricity (b)

These faults can lead to mechanical stresses and vibrations on the axis and the entire structure. In order to manage these faults, condition monitoring is used. It checks the state of the machine and acts when an fault occurs.

There are three main parts in this research:

1. **Fault detection** The first part is developing a suitable system to measure the faults. Using a lot of sensors complicates the machine needlessly and rises the costs. By using measurements of electrical variables, faults like eccentricity and demagnetization of magnets can be measured indirectly.
2. **Fault prediction** The next step is the understand how a fault will progress in time. This allows to plan the maintenance: condition-based maintenance.
3. **Fault prevention** The last step is to use the control of the machine to counteract or minimize the effect of the fault. The machine can thus operate without putting more stress on the surrounding structure and maintenance can be postponed to a more suitable moment.

In the first stage, an analytical model is built. This model allows to simulate the electrical machine with applied faults. This model is used in the control of the real machine to evaluate the condition of the machine by simulating the machine in real-time. Figure 3 presents the computed distribution of magnetic field in an axial flux permanent magnet machine with partially demagnetized magnets.

This analytical model is then used in an inverse problem model. This model takes the Euclidean distance between the measured and the simulated voltages and currents values. By minimizing this distance in function of the fault parameters, the fault in the real machine can be detected.

In a next stage is studied how the control of the machine must be adapted in order to minimize the effect of one or more faults, like for instance permanent magnet demagnetization and eccentricity. “Model based predictive control” will be used for this purpose. Since multiphase machines (where “multi” means “more than three”) offer more possibilities to adapt the currents and magnetic field to obtain the desired behavior in case of a fault, the studied axial flux permanent magnet machine will be transformed into a multiphase machine first.

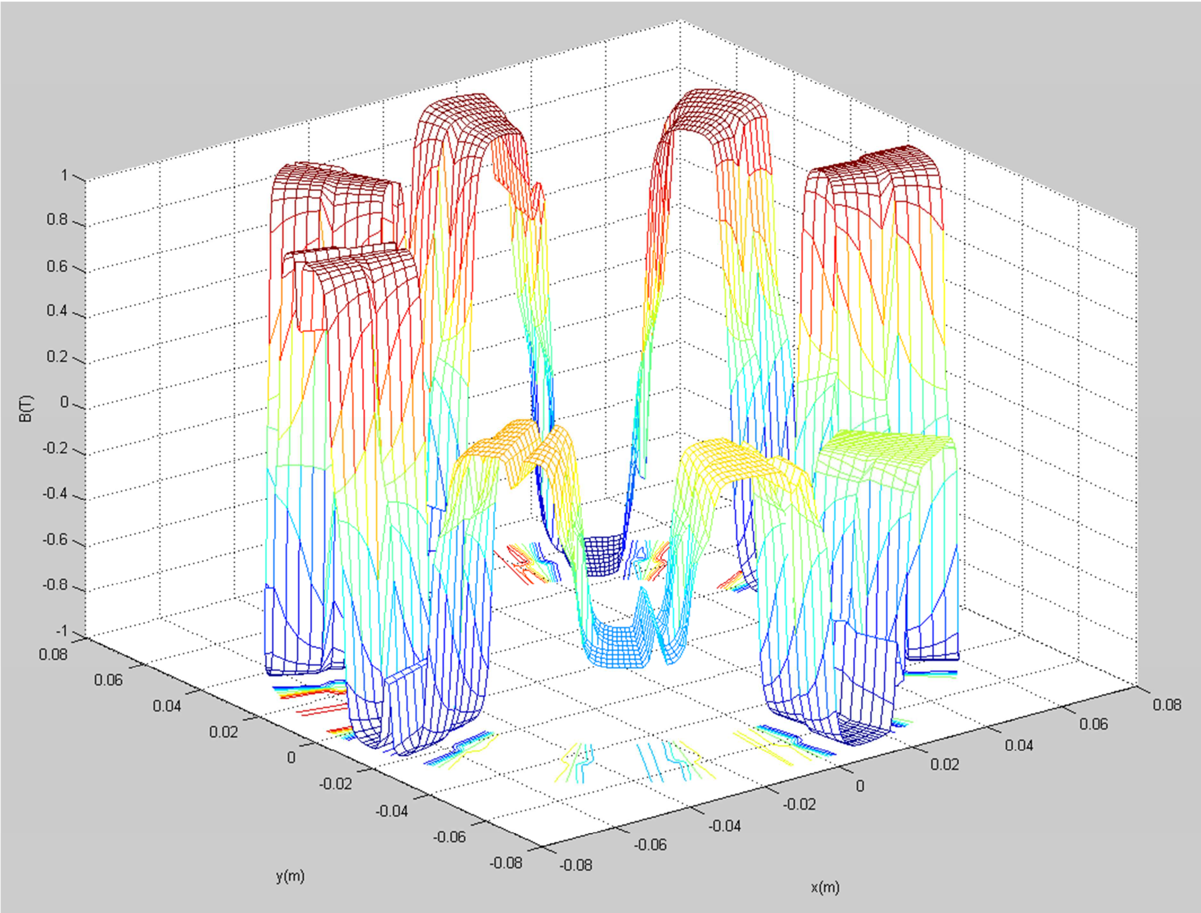

Figure 3: Magnetic field of an axial flux permanent magnet machine. The field is generated by magnets only (no stator current). Some magnets are partially demagnetized, reducing the magnetic field generated by these magnets.

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