

Axial Flux Permanent Magnet Generator for Wind Power Applications.

Asko PARVIAINEN, Lappeenranta University of Technology, Finland, Pentti KONTKANEN, Kylmätec Ky, Outokumpu, Finland.

Small-scale wind power plants are an attractive choice to generate electrical power on rural areas where the installation of the distribution network is not economically reasonable. In such locations, e.g. on small islands, wind power plants or solar sells or both together can be used to charge batteries or in direct heating purposes. Concerning stand-alone windmill applications the rated power of which is below 10 kW, the use of permanent magnet machines as a generator has been studied intensively during the last decades. Recently, Lappeenranta University of Technology design and manufactured low-speed axial flux permanent magnet generator designed to use in a 1.6 kW windmill application. During the design of the generator, FLUX 3D finite element software was an essential tool to verify the performance of the design before building up the prototype generator. The prototype generator is installed to the pilot power plant, which has been on operation since November 2003. Figure 1 presents the experimental power plant and illustrates the used generator concept.



Figure 1. Experimental wind power plant and the used single sided axial flux permanent magnet generator.

Axial flux PMM with duple layer concentrated winding

The generator was realized with a duple layer concentrated winding. Concentrated stator windings are an effective solution to reduce Joule's losses in low-speed permanent magnet machines, thus to improve the overall efficiency of the machine. By combining the concentrated winding and axial flux permanent magnet machine, which offers a high torque to volume ratio, a high performance electrical machine is obtained. Short end-windings decrease also the overall external diameter of the axial flux machine. Thereby the overall space, required by the generator, is decreased which is a highly desired feature for the wind power generators.

Permanent magnets are Nd-Fe-B magnets and are installed directly on the surface of the solid iron rotor disk. As a drawback of the single sided construction, illustrated in figure 1, there appears quite a large uncompensated attractive force between the rotor and the stator, which has to take into account while design the mechanics. According to the performed 3D finite element analysis the attractive force between the stator and rotor is 6800 N for the generator under no-load condition with nominal air gap.

FE-model of the machine

For the point of the modeling, the geometry of the axial flux machine is an actual 3D problem, which cannot be reduced to the 2D plane if an accurate electromagnetic analysis is required. Thereby, the machine is modeled as a 3D problem by using FLUX 3D FE-software. The used FE-model is illustrated in figure 2 as well as the air gap side view of actual prototype machine. Due to the used consternated 3-phase winding, one cannot model only one pole since one rotor pole does not represent the symmetry on a stator side as it does with

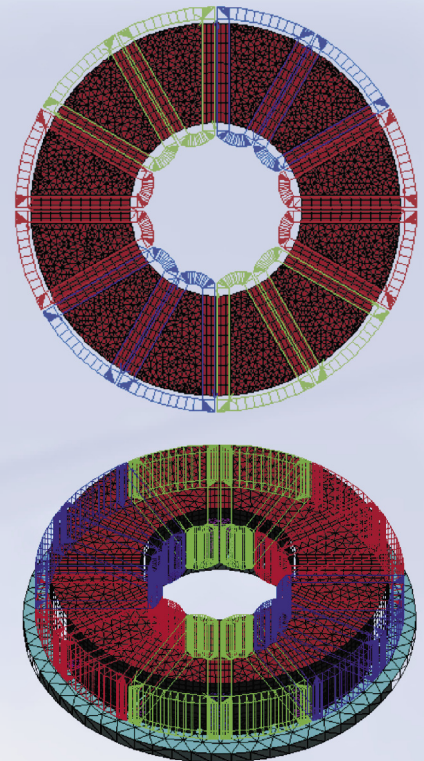


Figure 2. The used 3D FE-model and an actual generator stator presented from the air gap side. The used generator structure includes 12 slots in a stator and 14 poles in a rotor.

conventional integral slot 3-phase windings. In this case the whole geometry was described even though the size of the FE-problem comes very large. The total amount of second order volume elements used in a FE-model was 116878. Computations were performed with mechanical sets in order to model the rotation and with circuit coupling. 3D FEA was performed both under load and no-load conditions giving

(continued on page 5)

Axial Flux Permanent Magnet Generator for Wind Power Applications. (continued)

Asko PARVIAINEN, Lappeenranta University of Technology, Finland, Pentti KONTKANEN, Kylmätec Ky, Outokumpu, Finland.

information, for example, from phase voltages, torque ripple and torque production capability of the generator.

Results

Since the 3D-FE problem was coupled to the circuit, it was possible to analyse the performance of the machine in actual operation conditions by introducing a time transient FE-model. Figure 3 compares the measured no-load phase voltage (for the hot machine) to the calculated one as well as measured and calculated phase currents under load condition. The similarity between the obtained curvatures is excellent, however the amplitudes of the measured ones are lower. This is mainly related to the permanent magnet operation temperature; it is slightly higher than the calculated one, giving actually lower B_r for the Nd-Fe-B magnet than the used one was in a FE-model.

One important property for the direct-driven wind power generator is a torque quality. Low cogging torque is required in order to allow the turbine start easily even with low wind speeds. Secondly, low amplitude for the torque pulsations is required also under load condition. Even though the presented design uses totally open slots, which were introduced due to the extreme simplicity of the manufacturing of the winding, a low torque ripple was achieved. Figure 4 presents the obtained electromagnetic torque from the computation under load condition. The peak-to-peak value of torque ripple is around 3 % from the rated torque, which can be considered as a good result for the structure used.

Conclusions

A direct drive axial flux PM generator designed to small-scale wind power application was described shortly. The 3D-finite element analysis, performed by using FLUX 3D, was an essential tool to verify the performance of the generator before manufacturing of the

prototype machine. A comparison between the measurements and the results offered by the 3D-FEA shows good agreement. Even though the 3D-FE model for the fractionally wound PM machine is relatively large, it can be solved in a reasonable time and thus it offers very detail and useful information for the designer about the performance of the design.

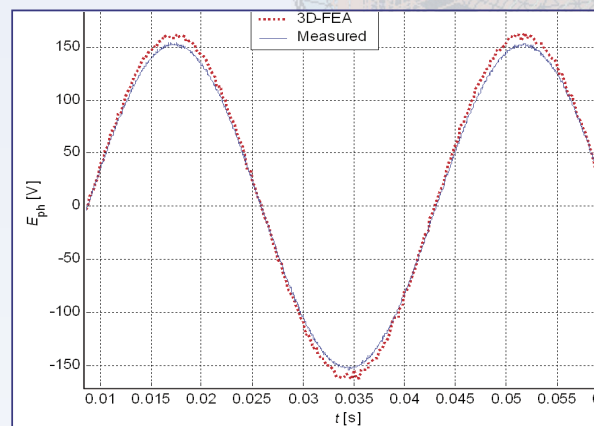


Figure 3. Measured and calculated phase voltage and measured and calculated phase currents with resistive load.

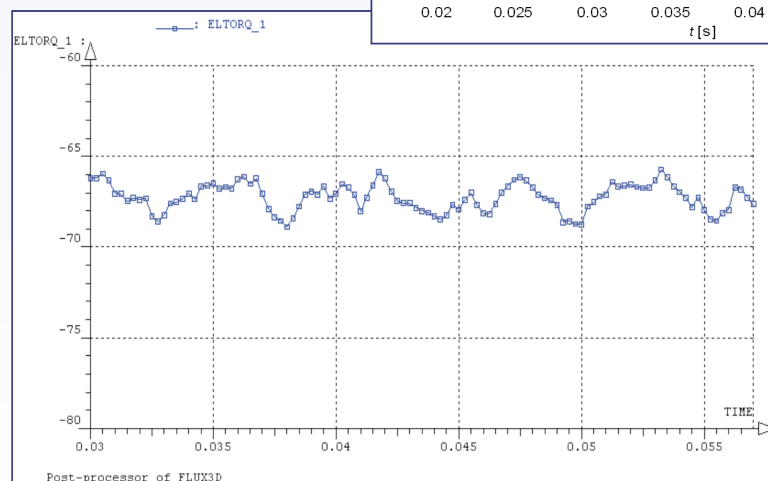


Figure 4. Electromagnetic torque of the generator with resistive load.