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Sensorless switched-reluctance generators: a technology ready for aerospace applications

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Commercial, combat, and cargo aircraft face an ever-increasing demand for more electrification, a concept called "More Electric Aircraft." Actually today's modern aircraft consume something between 10 and 60 kilowatts of electricity depending on their size and architecture. The mechanical and hydraulic loads used for the past decades cannot efficiently meet these growing demands.

The engineering challenges include developing a powerful electric generator that is not bulky and cumbersome. Compactness and low weight is of paramount importance in the aerospace industry. This requirement of high power with a minimum size leaves only one option, "Operation at Ultra High-Speed." Fortunately, the prime mover for such super high-speed application is right at hand, namely "the jet turbine."

Another engineering issue is that the generator for this application has to endure high temperatures yet still present mechanical integrity at speeds faster than 100,000 rpm. An additional critical design specification is the essential nature of fault-resilient structure and survivability, which is not a matter of luxury, but is essential, given the high-impact of the aerospace application.

All of these requirements place switched reluctance motor drives in a favorable position. In fact, experts at the US. Air Force Research Laboratories at Wright Patterson Air Force Base in Dayton, Ohio, were among the first to pursue this possibility and have come a long way in establishing this technology. Electro Standards Laboratories (ESL) is now developing technologies to provide the aerospace industry with a compact and efficient sensorless switched-reluctance generator that takes into consideration all of the demands and constraints of the "More Electric Aircraft."

One advantage of the sensorless switched-reluctance generator is its continued operation in the event of a failure in one of the phases. The device's modular structure and the accompanying converter enable it to do this. In this modular system with redundancy built into the design, failure in some modules can be tolerated even under a diminished performance. To accommodate failures in the sensor systems, a self-organizing controller consisting of monitoring elements that analyze the operational condition of various sensors is part of the design. Upon detection of a failure in one sensor, the faulty part disengages and the most appropriate control activates.

Another advantage of the switched-reluctance generator is the reliable and fast buildup of voltage. Magnetizing current for buildup of a significant induced voltage needs to be supplied to SR coils. By tuning the turn-on and turn-off instants and according to the inductance profile of the machine, designers can obtain optimal solutions for magnetizing current at various speeds.

The efficiency of the switched-reluctance generator is an added benefit. Electro Standards Laboratories has the methodologies to minimize iron losses that occur with high-speed applications. ESL has also found it important to use low-loss lamination with adequate thickness on the stator and rotor. In lab experiments, optimizing its commutation boosted the productivity of the machine.

The structural integrity of switched-reluctance generators at super-high speeds is critical. Radial and torsional vibration is of great significance at speeds of 100,000 rpm and faster. Although SR-machines are rugged, radial deformation of the rotor can occur and must be considered in the selection of the material and the design of the rotor stack. Also, to avoid the occurrence of a possible mechanical resonance, the natural frequencies of the combined rotor, shaft, and jet turbine need to be far from the frequency of the mechanical excitation as dictated by the speed of the shaft.

Electro Standards Laboratories is developing the sensorless control technology required for super-high speeds. With position sensorless techniques, the encoded position data in the form of electromagnetic quantities can be recovered fast enough to commutate the machine. As the speed of the drive increases, faster speed of computation and A-D conversion is required to maintain the same resolution in the detected rotor position. Today, state-of-the-art processors offer an impressive speed of 150 million instructions per second along with a fast 12-bit A-D conversion time. For instance, using an 8/6 SR configuration, the available time for detection of turnoff instant at 200,000 rpm equals 12.5 microseconds, which allows for 25 samples (each sampling followed by 1,125 assembly instructions).

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