



Background

In March 2005 the Windflow 500 prototype turbine suffered significant damage. A series of unforeseen events occurred during a severe frontal weather change, leading to the turbine experiencing extreme overturning moments during shut-down under high yaw angle and subsequent failure of the gearbox holding-down bolts. Francis was on site at the time, monitoring the turbine operation.

Among the multiple measures taken to prevent a recurrence, were the developments of

1. A bolted joint capable of absorbing high impact energy
2. Control system strategies to prevent entry into the particular unfavourable operating mode
3. Shut-down strategies that would keep the turbine rotor aerodynamically stable even in these unfavourable modes.

Francis's involvement in these measures included:

1. Investigation of the role of impact energy in the failure. This included developing and running **multiple degree-of-freedom dynamic models** of the turbine system, using Visual Basic for Applications.
2. Identification of operating modes that could lead to the aerodynamic instability by means of a **D-FMEA** analysis. He ran a parametric study of all practically conceivable operating scenarios and weather conditions, applying occurrence probability ratings based on a fault analysis and identifying key indicators of potential problem areas.
3. Development of the "controlled torque" shut-down – a set of **protective control system algorithms** that would enable to the rotor to be kept aerodynamically stable and prevent teeter instability and stall in extreme operating conditions by means of intelligent pitching and brake application.
 - a. Fault-finding and identification of problem areas, aerodynamic basis for instability, and safe operating modes, employing D-FMEA
 - b. Iterative process of identifying effective preventive procedures, including model runs of proposed control system changes
 - c. Coding control system changes in PLC language
 - d. Francis ran tests on the second generation rebuilt turbine in winds gusting over 100 km/h, with forced yaw offset and confirmed results were effective in reducing teeter impacts and conformed well to expected performance.