Model 0A Wind Turbine
Generator FMEA

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Model OA Wind Turbine Generator FMEA

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Abstract

This report presents the results of Failure Modes and Effects Analysis (FMEA) conducted for the Wind Turbine Generators. The FMEA was performed for the functional modes of each system, subsystem, or component. The single-point failures were eliminated for most of the systems. The blade system was the only exception. The qualitative probability of a blade separating was estimated at Level D—remote.

Many changes were made to the hardware as a result of this analysis. The most significant change was the addition of the safety system. Operational experience and need to improve machine availability have resulted in subsequent changes to the various systems which are also reflected in this FMEA.

Introduction

The NASA Lewis Research Center conducted research and development of large horizontal axis wind Turbine Generators for the Department of Energy as one phase of the overall Wind Energy Program. Wind turbines ranging in size from 100 to 3200 kW were designed and built as part of this program. The object of the program was to develop wind turbines which would generate electricity at a cost which is competitive with alternative generating methods, particularly oil.

This paper describes some of the changes that resulted from using the Failure Modes and Effects Analysis (FMEA) as a systems safety and reliability analysis tool for the 200 kW, MOD OA Wind Turbine Generators (WTG). Reference 1 further describes the logic for this approach. This analysis was originally done by the Reliability and Quality Assurance Office at NASA Lewis Research Center. Later, the government contracted with W.L. Tanksley and Associates to revise and update their analysis.

The complete FMEA resulted in several modifications to the original MOD OA WTG design. These included changes to the microprocessor (hardware and software), the safety system, the yaw system, the drive train, the supervisory system and the electrical system. The analysis was limited to a level of detail that would assure safe, reliable, machine operation. The MOD OA portion of the program has now been completed and the machines have been removed.

Machine Description

A photograph of one MOD-OA machine, located on Culebra Island, Puerto Rico, is shown as Fig. 1. Nearly identical machines were located in Clayton, New Mexico; Block Island, Rhode Island; and Oahu, Hawaii. The blades measured 125 ft, tip-to-tip. The hub center was 100 ft above ground level. The blades rotated at 40 rpm. The blades were mounted on the rotor hub, as shown in the cutaway drawing included as Fig. 2. The pitch actuator pitched the blades through a set of bevel gears located inside the hub. The hub was attached to a low-speed shaft which was connected to a speed increaser gearbox. A fluid coupling, attached to the 1800 rpm output shaft of the gearbox helped dampen out power oscillations. A high-speed shaft then transmitted power to V-belts which drove a synchronous alternator. The machine was housed in an 8-ft diameter nacelle.
After synchronization, the blades remained in the full power position. The microprocessor signaled the pitch controller to start pitching the blades, gradually increasing rotor speed. When the alternator reached synchronous speed, the pitch controller was locked and did not allow the blade pitch to be adjusted. The microprocessor or servo controllers were doing.

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The safety system, as the name implies, measured the difference between the actual wind direction and the nacelle direction to keep the machine aligned with the utility grid. After synchronization, the blades remained in the full power position, generating increasing power as the wind increased until the full output of 200 kW was reached at a wind speed of 24 mph. As winds increased further, the blades gradually feathered, spilling some power position, generating increasing power as the wind increased.

If the wind speed dropped below 10 mph, the machine was shut down. If the wind speed increased above 40 mph, the machine was shut down to avoid high-blade loads. When the wind speed dropped back to 35 mph, the machine was restarted. The microprocessor also monitored several noncritical variables to shut the machine down if necessary.

The first closed loop servo system regulated the pitch of the blades. Blade pitch regulated machine speed from initial blade rotation until synchronization with the utility grid and regulated the power generated after synchronization. The difference between the actual wind direction and the nacelle direction was measured by the pitch controller to start pitching the blades, gradually increasing rotor speed.

The safety system, as the name implies, measured the difference between the actual wind direction and the nacelle direction to keep the machine aligned with the wind. The machine operated with the blades downwind and was kept aligned within 15° of the wind direction.

The level of detail in the computational portion of the FMEA required. For catalog, off-the-shelf components, only expected types of failures were considered. A remote-operated valve was considered to be in the failed open or failed closed position only. Pressure containment and distribution systems were considered as having failed when the system pressure had dropped below the minimum safe operating level. A hand valve was considered part of the containment system and could fail if the improper position would not be detected. The more likely failures, particularly those having severe consequences, were considered for possible redesign or the addition of redundant components.

The FMEA was used to study these changes and upgraded to include the final design.

Combined FMEA Procedure

Numerous reliability, quality assurance, and system safety techniques were considered. A FMEA, preliminary hazards analysis, and operations hazard analysis are very similar and many of the form entries are the same. The modified FMEA was chosen to be the main tool for listing and analyzing each component for the various possible failure modes. On some previous projects, one person or team has simultaneously reviewed the hardware for a system safety and a reliability analysis, see Ref. 2. The results have been listed on a sample FMEA form, see Fig. 3. Fault tree analysis was performed for possible failure modes, causes, and effects on the machine reliability as well as on personnel safety. The necessary corrective action was then determined independently.

This combined FMEA technique works quite well and saves a significant number of manhours.

There is one drawback to this technique. It is easy to list failures that are not safety problems, but it is also easy to overlook safety problems which are not caused by equipment failures. Some examples of safety problems which could have been overlooked are the three listed below:

1. Personnel getting caught in rotating machinery.
2. Electrical shock hazards due to exposed terminals.
3. Operating errors.

These safety-related items can also be handled using the combined FMEA method. The reviewer has to make a conscious effort to consider each of the hazards as a possible failure mode. Hazards would be categorized as follows:

1. Lack of proper safeguards in the design.
2. Lack of operator training to follow procedures.
3. Lack of human engineering causing operator error.

This FMEA was primarily identified at identifying those critical failure modes that could result in major damage to the system. The analysis was organized to help limit the number of similar events that could occur. The system was analyzed so that no major damage should occur because of a single-point failure or a single failure following an undetected failure. The analysis was qualitative in nature and was used to determine the cause and effect for each failure mode and what could be done to correct the problem.

The FMEA was determined for the functional modes of each system, subsystem, or component. The electrical and electronic portions of the FMEA were limited to the package level, showing only constant high level output or zero output. Wiring harnesses, cables, and electrical connectors were considered to be part of the output or input and were not considered separately.

The level of detail in the mechanical portion of the FMEA required. For catalog, off-the-shelf components, only expected types of failures were considered. A remote-operated valve was considered to be in the failed open or failed closed position only. Pressure containment and distribution systems were considered as having failed when the system pressure had dropped below the minimum safe operating level. A hand valve was considered part of the containment system and could fail if the improper position would not be detected. The more likely failures, particularly those having severe consequences, were considered for possible redesign or the addition of redundant components.

Many changes were made to the hardware as a result of this analysis. The most significant change was the addition of the Safety System. Operational personnel and the need to improve machine availability resulted in additional changes to the various systems.

Results

While performing the FMEA, it soon became obvious that the worst possible failure would be significant overspeed, since this could result in throwing a blade. The consequences of all of the other failures were relatively minor by comparison. Based on this conclusion, disk brakes were added to the high-speed shaft very early in the design to stop the rotor, even if the blades remained in the full power position. The brakes were designed to activate if electrical power was lost. It would also have been desirable to have the brakes activate upon loss of brake actuation pressure, but only one machine was converted before the end of the program. The brakes were applied for two main conditions:

1. Overspeed due to failures
2. To hold the blades still for maintenance

The analysis pointed out a number of items that were to be considered as primary safety devices. The reliability of these systems had to be maximized. Factors to be considered in attaining maximum reliability were: Redundancy, minimum electrical path, quality of components and periodic verification of system operation. These items included the following:
ITEM | FAILURE MODE | CAUSE | EFFECT | CORRECTIVE ACTION | REMARKS
---|---|---|---|---|---
1. ALARM CIRCUIT | 1A. INADVERTENT REMOVAL OF SIGNAL TO SSRI. | 1. ELECTRONIC FAILURE. | 1A. NO START OR EMERGENCY SHUTDOWN. REMOVING SIGNAL FROM SOLID STATE RELAY 1 (SSR1) DE-ENERGIZES RELAY K1 WHICH DE-ENERGIZES RELAY K2. DE-ENERGIZING K2 OPENS C2, REMOVES THE GENERATOR FIELD, FEATHERS BLADES AND TURNS OFF THE PITCH HYDRAULIC PUMP. | 1. NONE REQUIRED—REPAIR AS NECESSARY | 1B. PERIODIC CHECKOUT REQUIRED.
2. EMERGENCY SHUTDOWN | 2A. FAILS OPEN. | 2. SWITCH ELECTRICAL OR MECHANICAL FAILURE. | 2A. NO RESET IN THE EVENT OF AN EMERGENCY SHUTDOWN. | 2. NON REQUIRED—REPAIR AS NECESSARY. | 1B. PERIODIC CHECKOUT REQUIRED.

The next problem that surfaced resulted from the basic design of the machine. The Safety System was located in the control building at ground level. Most of the sensors were located in the machine nacelle on top of the tower. Since the machine must yaw to stay in alignment with the wind, the signals were routed through slip rings. The FMEA analysis revealed some potential failures in the slip rings (shorts or opens, depending on circuitry) that could override or bypass a Safety System shutdown signal. As a result, several redundant sensors were added in the nacelle that acted totally within the nacelle and did not rely on the slip rings for a shutdown signal path. In fact, they were designed to shut the machine down regardless of what signals the microprocessor was sending to the machine. These sensors included overspeed, low-speed shaft vibration switches, low-blade emergency feather pressure, and low-rotor brake pressure. Allignment of the machine with the wind was also important. The direction of the nacelle was compared to the wind direction to keep the machine aligned with the wind. The FMEA pointed out the need for a redundant yaw error signal, which was added.

There was concern that an intruder would go up into the nacelle and get caught in the rotating machinery. The only access route up into the nacelle was by using an open elevator-type device. When the elevator was not being used, the power was turned off from inside the control room and interlocked with the safety system.

Conclusions

The performance of the FMEA for the 200 kW Wind Turbine Generator accomplished several objectives. As is usually the case with this type of tool, the act of performing a systematic, detailed review of the design was very useful. The FMEA indicated the need for a number of design changes:

1. Disk brakes on high-speed shaft
2. Primary safety devices
   a. Overspeed
   b. Vibration
   c. Feather pressure
   d. Brake pressure
   e. Yaw error
   f. Alternator over/reverse current
3. Redundant sensors
4. Intruder alarm

The final FMEA also gave project management personnel a qualitative indication of the degree of program and safety risk that they were accepting with this design. Since this was an evolutionary R&D project, there were a large number of changes proposed for the machine. With the completed FMEA, it was easy to review the safety and reliability implications of each proposed change. By using this technique, it was shown that the increased safety and reliability risk of some of the proposed changes did not justify the change. Most of the proposed changes did not increase the risk and in some cases, decreased the risk. Finally, the FMEA was revised to reflect all approved changes.

In summary, the FMEA performed for this project served several very useful functions. The benefits far outweighed the cost of performing the FMEA.
References


**Title and Subtitle**
Model 0A Wind Turbine Generator FMEA

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**Supplementary Notes**

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This report presents the results of Failure Modes and Effects Analysis (FMEA) conducted for the Wind Turbine Generators. The FMEA was performed for the functional modes of each system, subsystem, or component. The single-point failures were eliminated for most of the systems. The blade system was the only exception. The qualitative probability of a blade separating was estimated at Level D-remote. Many changes were made to the hardware as a result of this analysis. The most significant change was the addition of the safety system. Operational experience and need to improve machine availability have resulted in subsequent changes to the various systems which are also reflected in this FMEA.

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