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Integrating Certification into the U.S. Department of Energy/National Renewable Energy Laboratory Turbine Research Program

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INTEGRATING CERTIFICATION INTO THE U.S. DEPARTMENT OF ENERGY/NATIONAL RENEWABLE ENERGY LABORATORY TURBINE RESEARCH PROGRAM

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ABSTRACT

The Wind Turbine Research Program conducted for the U.S. Department of Energy (DOE) by the National Renewable Energy Laboratory (NREL) employs a comprehensive engineering development process which includes regular design, testing, and documentation reviews throughout the process. This process follows accepted international procedures, including the International Standards Organization ISO 9001. International wind turbine certification practice typically requires a review of only the final design and testing results of a wind turbine system. Using this approach, if the design does not meet requirements, the designer is faced with the lengthy and inefficient process of rerunning engineering calculations or tests or even redesigning major components. NREL has recognized the similarity between its development process and international certification practice and has integrated the two. The result is a comprehensive engineering development process, which enables subcontractors participating in the DOE/NREL Wind Turbine Research Program to develop a mature product, which is ready for commercialization and certification.

This paper describes the NREL development process, certification requirements, and the benefits of integrating them together.

INTRODUCTION

International certification has become a requirement for U.S. manufacturers to compete in many foreign markets. At present there are three international certification bodies active in the European wind turbine industry: Germanischer Lloyd (1), Det Norske Veritas and Risø (2) and CIWI (3). Each certification body has developed its own rules and requirements for Type Certification but they generally have the same goal: to review the design documentation and assure that the turbine has been designed with engineering discipline, in accordance with recognized industry standards, and will function reliably throughout its specified life. Most turbines installed in Europe must be certified by one of these bodies to its own set of rules and requirements.

Over the past five years, the European Community (EC) has encouraged harmonization of the different certification rules in order to facilitate trade within Europe. This has resulted in active standards development programs on the international level. The International Electrotechnical Commission (IEC) has supported the development of several standards, which will hopefully be the basis for a set of harmonized standards. These include

1. Wind Turbine Generator Systems: Certification Requirements [WG9 tenth Committee Draft (10CD)] Wind Turbine Generator Systems: Safety of Wind Turbine Generator Systems (IEC 1400-1 Edition 2) [WG7 , Final Draft International Standard (FDIS) sent out for national vote]
2. Wind Turbine Generator Systems: Safety of Small Wind Turbine Generator Systems (IEC 1400-2 [FDIS])
3. Wind Turbine Generator Systems: Power Performance Measurement Techniques (IEC 1400-12) (WG6 FDIS)
4. Wind Turbine Generator Systems: Acoustic Noise Measurement Techniques (IEC 1400-11) (WG10 FDIS)
5. Wind Turbine Generator Systems: Testing Methods for Rotor Blades (IEC1400-23) (WG8 CD)
6. Wind Turbine Generator Systems: Power Quality Requirements for Grid Connected Wind Turbines (IEC1400-21)(WG10 CD)
7. Wind Turbine Generator Systems: Mechanical Load Measurement Techniques (IEC1400-13) (WG11 CD).

While each European country's certification procedures depend on national requirements, the above international standards will be the basis for an international certification procedure, as described in item 1 of the above list.

IEC 1400-1 specifies "external conditions" (wind and environmental) and normal and abnormal operating conditions that must be satisfied for different design classes. ISO quality (17, 18, 19) and limit state design (20) procedures are also specified and clarified for the wind turbine design application. European certification bodies will take a step towards harmonization by adopting this standard in addition to their own national requirements in the future by law.

Wind turbine certification is not required by U.S. utilities, customers, or local governments. As a result, most U.S. turbine manufactures have not pursued certification. Now that the international market is stronger than the domestic market, there is greater interest from U.S. manufacturers to certify their wind turbines. However, there is no U.S. certification body nor is there an established set of standards on which to base a certification process.

The American Wind Energy Association (AWEA) has been active in developing national standards for 15 years. This process has resulted in useful standards but they are not used by the international community because it is felt they are not sufficiently proscriptive. AWEA has decided to support the IEC standards development process as these standards will be valuable for international marketing.

Several U.S. companies have participated in the DOE/NREL Turbine Research Program (TRP). This program has a well-established design review process with regular design reviews and test readiness reviews as prototype turbines evolve from conceptual to final design stages. In many ways this program parallels European certification programs. With minor modifications, the TRP has aligned its requirements to match the IEC certification requirements. Companies who participate in this program can now expect to finish the program with all the documentation and reviews needed to satisfy the IEC certification requirements as they are developed.

DOE/NREL TURBINE RESEARCH PROGRAM

There has always been debate on how to approach the wind turbine design and development process. Some favor an analytical approach with very little testing. In this case, testing is used only as a verification of the final design analysis predictions. Others favor an empirical approach in which components are designed with very little analysis and tested to meet very basic design loads. Each component is developed

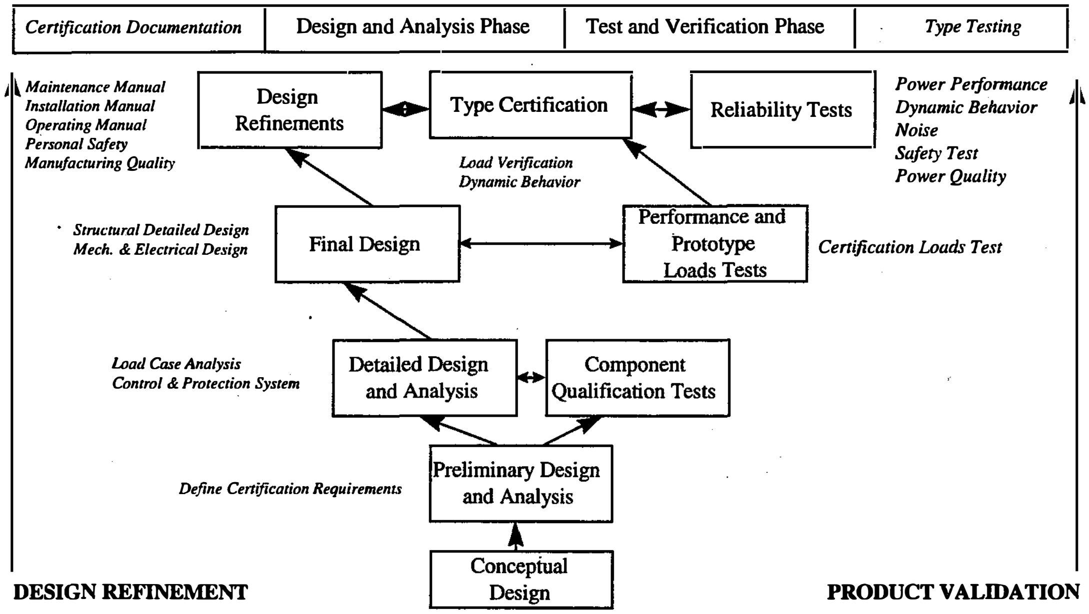

Figure 1 NREL DEVELOPMENT PROCESS

experimentally until a prototype can be built using the tested components. The prototype test results are then used to develop more complete design loads, which include dynamic loading.

Both approaches have advantages and disadvantages. Analytical tools can be used to iterate the design to an optimum configuration efficiently, before building components, and to simulate design conditions that are extremely unlikely to occur during a test program. The disadvantage of this approach is that designers are likely to miss important details, which cannot be modeled completely. The experimental approach will test all the design details but is not likely to subject the prototype to critical design limits. The best approach logically combines a balance of both analysis and testing to verify analytical models. Once a reliable set of design loads are established and the analytical model is refined, experiments can be conducted to subject a component to laboratory and field-test conditions that simulate most of the extreme static and fatigue load conditions.

Figure 1 shows the NREL "Design and Analysis Track" and the "Test and Verification Track" for product development. The combination of these two tracks presents a check-and-balance system of analytic predictions combined with test results. The Design and Analysis Track shows the stages of design starting with conceptual design and ending with verification that the original design specifications have been met. The Test and Verification Track shows how the design process is verified in stages, first component qualification tests and finally prototype reliability tests, which should lead to certification. The results from the Test and Verification Track are used to check the predictions developed in the Design and Analysis Track. As such, the iterations that occur in each of the design stages (vertically) are checked against the results of the testing stage, which are fed back into the design stages.

At the preliminary design stage, design requirements and the initial configuration are established. For all DOE/NREL funded programs, IEC 1400-1 defines the basic design requirements. NREL recommends that manufacturers meet with the certification agents to clearly define all certification requirements before the design effort begins. Preliminary analysis is done to begin to quantify the loads and economics of the wind turbine system.

At the detailed design stage, the preliminary analysis is refined by incorporating qualification test results, such as blade tests and modal tests, into a detailed dynamics analysis. The results of these analyses contribute to a loads document. This is a living document, which is used to define all design loads. It should also include all test data used to verify predicted loads. As the design evolves and changes to the design are made, new design loads should be documented as updates to this document. A document such as this is required by all certification bodies.

At the final design stage, final analysis has occurred and resulted in complete design drawings and specifications for all aspects of the machine. Manufacturing, operation, maintenance and installation manuals should also be complete. This documentation constitutes a complete description of the design, how to build the machine, and how the machine is to be installed and operated. This collection of documentation is what the certification body will use to verify that the design complies with IEC 1400-1.

Prototype loads data collected during field tests are used to verify the predicted design loads and operational characteristics. Blade structural tests are used to verify the fatigue life and extreme load capacity of the blade (21). Performance measurements are made to verify turbine performance. Noise measurements are made to document acoustic emissions. These tests are conducted to IEC standards and constitute Type Testing requirements specified in the draft IEC certification standard. It is very important to select test sites that represent the design wind regime, extreme wind conditions and environmental conditions whenever possible.

This development process satisfies most certification requirements for a Type Certificate.

CERTIFICATION REQUIREMENTS

The proposed IEC Type Certification procedures have four basic components.

1. Design Evaluation
2. Type Testing
3. Manufacturing Quality
4. Turbine Characteristics (optional for basic Type Certificate)

Conformity statements are needed for successfully completing all the requirements of each component. When the first three component conformity statements are issued and the design loads are verified with type test data, a Type Certificate can be issued. The fourth component defines tests that quantify the turbine performance characteristics. These tests are not required to demonstrate the safety of the turbine and are therefore not required to meet basic type certification requirements, but they are usually required by customers to verify performance characteristics, which can affect the economics of their investment. In some cases, noise and power quality tests are required to meet local regulations. Figure 2 lists the requirements in each area.

The specific requirements for each element may change depending on which set of national requirements, and perhaps which certification agent, is used. The descriptions below are intended to describe general requirements for each element.

DESIGN EVALUATION

Component Tests: This optional element can by used to verify the design performance of a machine component such as a blade, gearbox, or pitch system. Component test data are most often used when the analysis of the component is difficult to accomplish with confidence. They can be used instead of an analytical approach if all the component design loads can be accurately simulated in a bench test. Usually this is impossible so the test data are used to verify specific design cases, and computer models are then used to simulate the complete set of design loads. Wind turbine blades are almost always tested for design verification

Loads Verification Document: Most design procedures for wind turbines are based on a structural dynamic model. Structural dynamic simulations are used because they can account for all the steady and unsteady aerodynamic loading, inertial loading, and control-induced loading simultaneously. It is impossible to account for all these factors with simple design calculations. However, these models can be very complicated and often require validation before the designer can use them confidently to predict fatigue and extreme loads. Test data are commonly compared with simulations of the corresponding test conditions. This load verification process also gives the certification body confidence in the process used to develop the rest of the predicted loads. Documentation of the structural dynamic model verification has become an important part of most certification requirements.

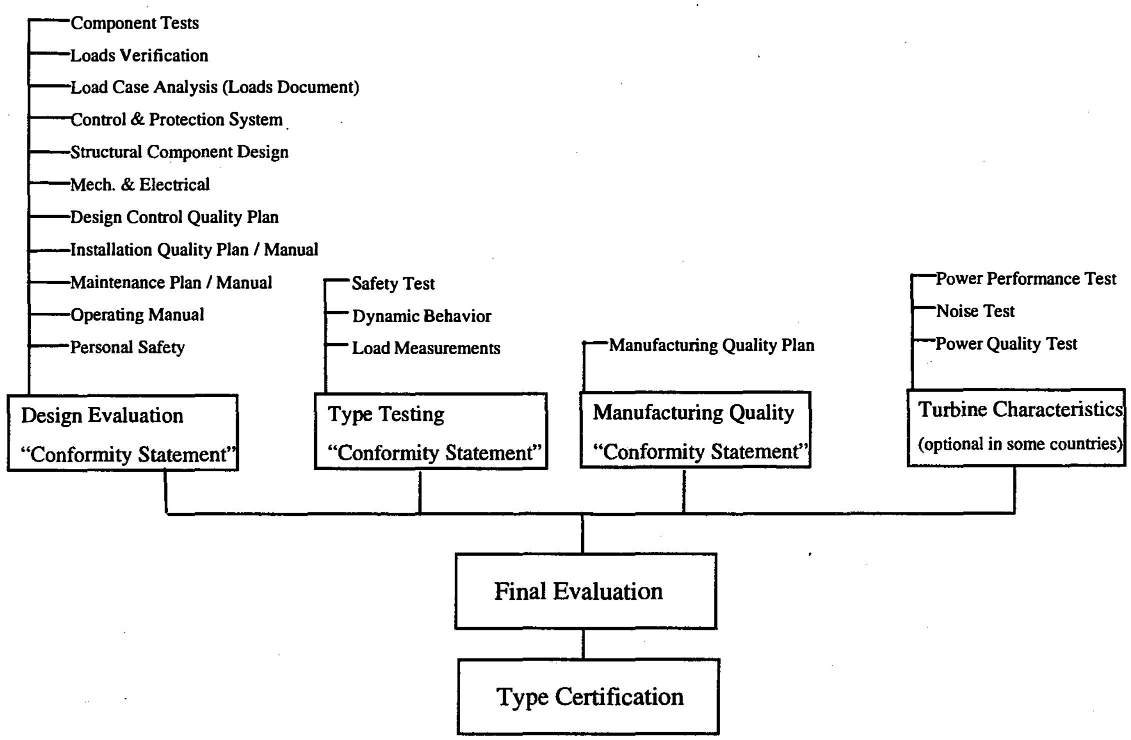

FIGURE 2. TYPICAL TYPE CERTIFICATION REQUIREMENTS

Load Case Analysis (Loads Document): A loads document should contain all the critical static and fatigue loads for plausible combinations of external conditions and operating conditions defined in IEC 1400-1. The load distributions should be determined for the blades and all critical load paths within the structure. The electrical loads, fault loads, and any control-induced loads should also be calculated for all possible operating conditions. This loads document should be a living document. It should include results from field tests that support the predicted loads. As the machine configuration changes, this document should be updated to account for any load changes. The certification body will review this document for accuracy and thoroughness.

Control & Protection System: The control and protection system should be documented in a way that clearly illustrates all possible faults and demonstrates how the protection system functions to prevent catastrophic failures. This might include control logic diagrams, fault trees, failure modes and effects analyses, test results of the control system when subjected to simulated faults, and tests of any mechanical backup systems.

Structural Component Design: The structural design of all components should be documented. Appropriate material properties should be used along with the static and fatigue loads, taken from the loads document, to evaluate structural integrity. Component tests can be used to support design calculations. If the component tests simulate all possible design loads, load distributions, static and fatigue loads throughout the life of the machine, it may be possible to substitute the component tests for analysis.

Mechanical and Electrical Design Document: Mechanical and electrical devices such as gearboxes, actuators, bearings, electrical contactors and controllers must be sized to accommodate the loads they are subjected to throughout their service life. This document must contain a translation of the general turbine loads into component loads for each of the specific devices and document the performance of the device when subjected to these loads. Analysis results or manufacturers specifications can be used to demonstrate component serviceability. For critical components, bench tests simulating the wind turbine application are recommended to demonstrate component performance. Performance and geometrical specifications are a good basis for a quality agreement between the manufacturer and the supplier and are generally required for the manufacturing quality plan. These performance and geometrical specifications should be part of this Mechanical and Electrical Design Document.

Design Control Quality Plan: The design process is the first stage of a product's life. During this stage the wind turbine will constantly change and mature. As the changes occur, design loads will be impacted, manufacturing procedures will change, and operation and maintenance procedures will change. There must be a system of controlling and documenting these changes so that the impact on other parts of the turbine design are accounted for appropriately. Such a Design Control Quality System must include Engineering Change Orders which are approved by the engineering organization, manufacturing organization, and Operation and Maintenance organization before the change is implemented. Documentation of this system is an important part of the certification review since it demonstrates the use of an engineering development process. ISO 9001 (18), section 4.4, defines a quality procedure that will satisfy a certification body's requirements for the Design Control Quality Plan.

Installation Quality Plan/Manual: A turbine is not a complete operating system when it leaves the factory floor. The machine must be installed in the field. The same machine could be installed anywhere in the world by different installation crews. Very often local building requirements may impact the final turbine configuration. To guarantee that the turbine will perform as specified in the design documentation, it must be installed to meet the original design specifications. The Installation Quality Plan/Manual must contain all specifications and procedures needed to properly install the machine.

Maintenance Manual: Many component performance predictions are based on the assumption that maintenance will be performed at specified intervals. If this maintenance is neglected or improperly done, the safety and performance of the turbine can be impacted. This maintenance will be conducted by different crews throughout the world. They will certainly be trained, but they may not be trained by the original designers. To make sure that maintenance is performed properly, a maintenance manual should describe all aspects of the required maintenance. The certification body will review these maintenance specifications to make sure that they are consistent with the design assumptions.

Operations Manual: The designers base their predicted performance on specified operating procedures. Many machines can fail if operated improperly. This manual should contain specifications for safe startup, shutdown, access to critical parts, emergency procedures, and procedures for the general control of the machine. The certification body will review the Operations Manual to assure that the operating procedures are consistent with the design assumptions and that they are clear to intended wind turbine users.

Personnel Safety Manual: The certification agent will review and evaluate the installation, operation, and maintenance manual(s) provided by the wind turbine manufacturer using applicable safety requirements/guidelines contained in the IEC 1400 series of standards.

TYPE TESTING

Safety Test: Safety tests are performed by the certification body or its authorized representative. The test is intended to demonstrate that the control and safety systems specified in the design actually do function as the designer intended. These tests include, for example, normal startup, shutdown, parking, simulated faults, and testing of the overspeed protection system. Generally the certification agent will follow a checklist documenting successful completion of each test, which verifies the design documentation.

Dynamic Behavior: Dynamic characteristics are difficult to predict. Confirmation of stable operation is very important to the safe operation of the turbine. This test can be conducted in many ways. The best way is through a well-planned loads test program that measures vibrations during the full range of operating conditions of the machine. Component and full system modal tests can also provide extremely useful data for validating dynamics models and verifying predicted dynamic characteristics. However, this may not be practical or necessary on the final production turbine if a comprehensive test program has already been conducted on a dynamically similar prototype. Dynamic similarity may be demonstrated through simple measurements on the final production machine. On small turbines, it may be possible to demonstrate dynamic stability through observation and/or long-term reliability testing. IEC standards should be used as a guide for these tests and the certification body should be consulted.

Loads Measurements: Loads measurements are a critical part of confirming the design assumptions and the dynamic load model. Normally, loads tests are conducted on a prototype, which may not match the final production configuration exactly. These loads tests need not be repeated as long as the production configuration is dynamically similar to the prototype configuration. Guidelines which describe appropriate test procedures are being developed by IEC Working Group 11. The certification agent will likely require a test report from an accredited test laboratory, which describes the results of such a test program. They will use this test report to confirm the design loads predictions before a Type Certificate is issued.

MANUFACTURING QUALITY SYSTEM

Manufacturing Quality Plan: The purpose of a manufacturing quality plan is to document a manufacturing process or set of procedures that will produce a wind turbine that meets the design specifications. This plan should include all the quality procedures for monitoring and documenting critical design specifications of components, assembly of the system, and final assembly checkout tests. ISO 9002 (19) is a good model for this plan. IEC certification standards will require that the certification body include this plan before a Type Certificate can be issued.

TURBINE CERTIFICATION

Power Performance Test: Wind turbine performance can be very difficult to predict and is crucial to the economic viability of the turbine. IEC 1400-12 specifies an internationally agreed-upon procedure for accurate methods of power performance measurements for individual grid-connected turbines. It is easier to verify the performance of a single turbine than the performance of a collection of turbines in a wind farm. Performance of small turbines operating with variable loads such as batteries are even more difficult to characterize. Standards for the latter two cases are not available. A power performance test is not required for safety reasons but is generally required to confirm predicted performance for the customer. This procedure is intended to be performed by an accredited laboratory. The certification body will require a test report from such a laboratory as part of the Type Testing documentation.

Noise Test: Noise testing is also part of the performance documentation of the machine. This test is not a safety test and is therefore optional. However, many European countries require an acoustical emissions test and compliance with a national standard for noise emissions. These tests must be conducted by an independent, accredited laboratory. IEC Working Group 5 (WG5) has developed a draft test procedure. This document will be circulated for national vote by September 1997.

Power Quality Test: In many countries, the utilities are asking for a power quality standard for wind turbines. They want a standard that addresses issues that are specific to wind turbines, such as power flicker, inrush currents, harmonic distortion and power factor. IEC WG 10 was formed to develop such a standard. This group is taking advantage of existing standards, such as IEC 1000, as much as possible. This is also considered an optional test since it is a performance-related issue.

PROPOSED PROJECT CERTIFICATION

Some experts believe Project Certification is needed to verify that the turbine is installed according to the turbine design specifications and that the site conditions are consistent with the design conditions. Others feel that Project Certification is not needed. In many cases, all components of project certification are too costly and not economically justified, especially for small turbine installations. In these cases, elements of the project certification may be selected to satisfy the customers needs. The opponents believe that this certification should not be included in the standard because it will routinely and inappropriately be requested by uninformed local governments. The working group is still debating the merits of Project Certification and has tentatively proposed the following procedure which might be appropriate for a large, multiple turbine installation.

Figure 3 describes three basic requirements for project certification: 1) project design conformity, 2) a Type Certificate, and 3) maintenance and performance surveillance.

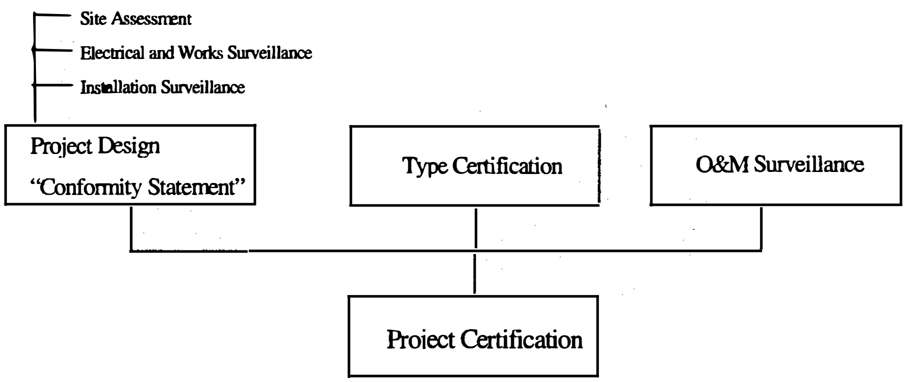

FIGURE 3. PROPOSED PROJECT CERTIFICATION REQUIREMENTS

Project Design Conformity: Much of the installation must be designed to meet local site conditions and local government requirements. Designs for the foundation must meet local soil conditions, electrical systems must interface with an existing electrical grid, and local requirements may dictate a certain tower type. These issues result in installation designs that must be performed correctly if the overall turbine installation is to operate reliably. To assure that the installation is performed according to design specifications, the installation process is reviewed and monitored (Works Surveillance). A Site Assessment is required by IEC 1400-1 to assure that the site conditions are less demanding than the turbine design conditions. This site assessment requires documentation of wind conditions through measurements such as 10-minute mean wind speed, turbulence intensity, maximum gust magnitudes, and maximum instantaneous wind shear. Wind data from wind resource assessments can be used if the data sampling rates and record averaging times are compatible with IEC 1400-12 (Power Performance Measurement Techniques). Once the turbine installation satisfies the site assessment, electrical and works surveillance, and installation surveillance, a Project Design Conformity Statement can be issued.

Type Certificate: A Type Certificate, as previously described, is required before a Project Certificate will be issued.

Operations and Maintenance Surveillance: O&M Surveillance is intended to verify that the turbine is operated within its design conditions according to the operating manual. The maintenance is monitored to assure that the turbine is maintained according to specifications defined in the maintenance manual. In order to maintain a Project Certificate, O&M Surveillance is conducted regularly throughout the life of the project. The certification body conducts unannounced audits (usually annually) to assure these procedures are being faithfully performed.

THE NREL CERTIFICATION PROGRAM

NREL has been asked by AWEA and directed by the DOE to facilitate the development of a U.S. Certification program for wind turbines. This program must result in certifications that are accepted throughout the world. According to its contract with the DOE, NREL is not authorized to issue certification but is able to perform tests and design reviews that would meet certification standards. NREL can supply these reviews to a certification agent who can use them in their certification process.

Underwriters Laboratories Inc. (UL) (22) is an international certification body operating in the United States and throughout the world. They have expressed an interest in coordinating their expertise in electrical equipment certification and manufacturing quality reviews with NREL's wind turbine design expertise to develop a certification program. Figure 4 illustrates the proposed interactions among UL, NREL, and the applicant. This certification program proposes that the applicant contract with UL for certification. UL can perform all electrical equipment reviews and manufacturing quality reviews and subcontract to NREL for design reviews of certification documents and type testing. UL anticipates using NREL reports to support its certification of the applicant's turbine. UL has field representatives located globally who could be used to perform much of the field surveillance during project certification.

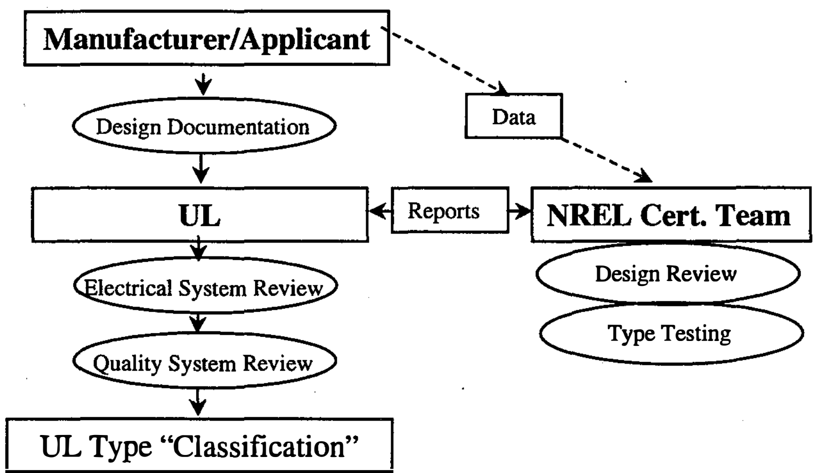

FIGURE 4. CERTIFICATION ORGANIZATION AND ROLES

INTEGRATED DEVELOPMENT/CERTIFICATION

The DOE/NREL Turbine Research program is responsible for assuring that turbines developed in the program are designed according to good engineering practice. Meeting IEC standards simultaneously satisfies both NREL's technical management responsibilities and the certification body's design conformance responsibilities. NREL requires documentation of all the important design steps. By coordinating NREL's contractually required deliverables with IEC documentation requirements, the development process becomes more efficient. NREL's design reviews are scheduled throughout the design process. Design requirements for the Turbine Research program are defined at the beginning of the program. Certification requirements will be defined at the same time. As certification documentation becomes available, NREL can perform certification reviews. If deficiencies exist, the designers will become aware of them early in the development process. This approach reduces the chances that design changes will be mandated by certification requirements that may have been poorly defined at the beginning of the design process.

The Turbine Research program requires testing of components such as the blades and of the whole prototype turbine. Generally, engineering prototypes are tested for loads and proof-of-concept testing. The design is then refined based on the test results. A production prototype is fabricated and tested for final performance, dynamics, and reliability. These tests can satisfy Type Testing requirements if conducted by an accredited laboratory to IEC standards.

SUMMARY

Certification has become a necessity for wind turbine companies competing in the international wind turbine market. Currently, U.S. manufacturers must use European certification agents to get the required certification. NREL has integrated preparation for certification into their Turbine Research program, which facilitates the certification process. UL is interested in establishing a certification program with NREL. This program will offer the U.S. wind industry a U.S.-based alternative with world-wide authority for certification of its wind turbines.

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