Northwind® 100 Wind Turbine
21 Meter Rotor, 37 Meter Tower
Application Requirements

Document A00298
December 2009

Revision History

Revision	Date	Description of Change
A	1/13/09	Release for customer use
B	6/18/2009	Release for customer use, electrical section revisions
C	12/30/09	Release for customer use, certification revisions, ECR-080

Contents

Printed Copies are **Uncontrolled**

1 Introduction

This document presents key application requirements for the installation of a Northwind 100 wind turbine. These requirements include (or reference) site environmental parameters, foundation requirements, remote data connection and electrical interconnect requirements.

The customer shall utilize a qualified engineer to design the installation for their turbine(s) according to site-specific data which meets the requirements provided herein. The installation shall be designed and constructed in accordance with any and all applicable codes and regulations.

This document is applicable for the Northwind 100 wind turbine with 50 or 60 Hz power output, 21 meter rotor and 37 meter tower. Specifications for this turbine are listed in the document A01465, Northwind 100 General Specification.

2 Reference Documents

A01465, General Specifications

1001441, Layout, Conduit, 37m Tower Base

1000152, Bolt Ring, Base, 37m Tower (tower base section flange detail)

A00293 Protective Relay Specifications (Protective Relay Option Equipped Only)

J00295 Protective Relay Overview Schematic (Protective Relay Option Equipped Only)

A01131 SmartView RTU Application Requirements

3 Environmental Requirements

Environment specifications and requirements for the Northwind 100 turbine are published in the Northwind100 General Specification document A01465. Installation at a noncompliant site may result in reduced turbine performance and / or lifetime. It is the customer’s responsibility to assure that the intended installation site meets turbine specifications and requirements.

Printed Copies are **Uncontrolled**

4 Electrical Specifications and Requirements

4.1 Section Overview

This section defines the electrical design requirements for the Northwind 100 wind turbine installation. The customer shall design and install the electrical system using qualified engineers, and in accordance with this requirements document, Northwind100 General Specifications document A01465, site conditions, and all codes and regulations applicable to the site.

The Northwind 100 wind turbine scope of supply includes turbine electrical equipment to and including the fused disconnect and junction box located at the bottom of the tower.

4.2 Electrical Requirements

Permitting and determination of locally applicable installation codes and standards shall be determined by the customer. A Northwind 100 installation has specific requirements for grid, transformer, grounding, and conduit.

4.2.1 Grid Requirements

The Northwind 100 must be connected to a three-phase 60 or 50 HZ grid that is regulated to within +/- 5% voltage and not more than 3% voltage imbalance.

Note that there is no specification for grid voltage because a separate interconnection transformer is specified to provide the proper voltage for connection to the fused disconnect at the tower base.

Northwind 100 turbines are typically connected in two basic configurations:

- To utility medium voltage (MV) distribution feeders, typically at over 1000 volts.
- To the distribution system of a new or existing low voltage facility, typically under 600 volts.

At all times there shall be an isolation transformer. The interconnection must be reviewed by the customer to determine that the grid or facility has the capacity to receive the full power output of the turbine.

4.2.2 Transformer Requirements

Each Northwind 100 must have a dedicated interconnect/isolation transformer with the following specifications. This transformer is required for the turbine to meet IEEE519 and UL1741 standards. This transformer is required even if connecting to a distribution system matching its 480V output voltage. The transformer must have isolated primary and secondary windings. An autotransformer is not acceptable.

Table 1 Interconnection Transformer Requirements

Apparent Power Rating	112.5 kVA
Low-Voltage Winding	480 VAC, Grounded Wye
High-Voltage Winding	(Determined by customer)
Impedance	See 4.2.3

Efficiency	NEMA TP-1 or greater
Voltage Adjustment Taps	+2 -2 each individual tap, approximately 2.5%

4.2.3 Transformer Impedance Requirements

The Northwind 100 operates over a wide range of interconnect impedances (the interconnect impedance being the impedance between the Northwind 100 output contactor and the grid source). In order for the power electronics to function properly, the acceptable range is:

Minimum Impedance = 0.025 + j0.075 ohms

Maximum Impedance = 0.15 + j0.38 ohms

In a medium voltage utility distribution (infinite primary model), the interconnect impedance is dominated by the isolation transformer. If utility grid impedance is neglected, an isolation transformer of 3.5% at 112.5KVA is required to satisfy minimum impedance requirements. In the case of a low voltage interconnect (i.e. high interconnect impedance) one should select an isolation transformer with less than 4% Z (impedance). It is the responsibility of the customer's electrical system designer to verify the interconnect impedance and to specify the appropriate transformer

4.2.4 Transformer Winding Requirements

The turbine-side connection of the isolation transformer is required to be grounded wye. The grid-side connection can be either wye or delta. This grid-side connection is usually determined by utility requirements or facility requirements based on consideration for ground fault protection, potential ferro-resonance, etc.

The Northwind 100 wind turbine only provides balanced three-phase output current, so the transformer does not need to accommodate current imbalance. This means there is no need to run a neutral conductor. The neutral of the grounded Wye should be bonded to ground within the transformer.

4.2.5 Interconnect Feeder

In Northwind 100 applications which connect to substantial medium-voltage utility distribution, line losses and voltage drop considerations are minimal. Typically the step-up transformer is mounted as close to the turbine as possible (< 5 meters) to keep losses in the 480V connection to a minimum.

Northwind 100 applications connecting to low voltage facility distribution systems require more planning to minimize kW losses and voltage rise. Depending upon interconnect feeder distance, a cost comparison is typically made between running larger conductors at 480V or. stepping up to a higher voltage and running smaller wire, but incurring the cost of an additional step-down transformer to connect to the facility. Northern recommends a total line loss in the feeder of less than 1%.

A voltage drop across the entire circuit causes voltage at the output terminals of the turbine to rise as the turbine pushes power into the interconnection. Most utilities require the turbine to trip at 110% voltage (at the utility tie point), so there is a limit to how much voltage rise can be tolerated (typically less than 5% between turbine terminals and the regulated utility source). A voltage rise calculation should be performed at full output and minimal facility consumption to verify that over-voltage tripping will not occur.

Energy (kWh) losses can add up significantly over the lifetime of the installation. The owner of the turbine should make an informed decision on installation cost vs. lifetime cost of the interconnection cables and transformer(s). See Appendix B, Example 1.

Printed Copies are **Uncontrolled**

4.2.6 Disconnect Requirements

A means of disconnecting all power from the turbine and its control circuits is required between the turbine's last down-tower electrical box and the isolation transformer. This disconnecting means must be:

- Readily accessible from the turbine base
- Externally operable
- Lockable
- Service rated, NEMA/IP rating to match environment in which it is installed.
- Where installed, be compliant with all code regulations.

4.2.7 Grounding Requirements

The turbine installation requires an earth-ground electrode system. An earth-ground electrode system typically is comprised of driven ground rods and buried copper wire in the surrounding soil and/or connection to foundation concrete and steel.

The customer is responsible for the design, installation and connection of/to the earth-ground electrode system in compliance with codes mandated by the local authority having jurisdiction and the following Northern requirements:

- The earth-ground electrode system shall have a resistance value of 5 ohms or less.
- In addition to the grounding requirements of a separately derived system for the isolation transformer, it shall be bonded to the tower earth-ground electrode system using #1/0 AWG copper wire minimum. Exothermic weld is the only acceptable means to accomplish this.
- Ground conductors of ancillary structures shall be bonded to the tower earth-ground electrode system with #1/0 AWG copper wire minimum.
- Tower foundation bolts shall not be used as terminations for ground conductors
- The foundation reinforcing steel and foundation piles (if used) shall be electrically bonded together to serve as or supplement the foundation electrode.
- Two conductors shall be attached using an exothermic welding process to the electrically interconnected reinforcing steel in two separate locations that are on opposite sides of the turbine tower. Each conductor shall be connected to the turbine tower bonding bus. Refer to Figure 1 for connection detail.
- The turbine bonding bus is pre-drilled to accept ground conductors with crimp type or compression lugs and is located at the turbine tower base. Anti-oxidation compound shall be used on these connections.
- Ground conductors used for attachment to the earth-ground electrode system shall be protected with a plastic sleeve, conduit, or insulation to provide corrosion/physical protection where conductors enter or exit the concrete floor of the tower interior. All conduit ends above grade shall be terminated with a bushing.
- If ground conductors are to be routed through metallic conduit, the conductors shall be electrically bonded to the conduit at both ends.

Printed Copies are **Uncontrolled**

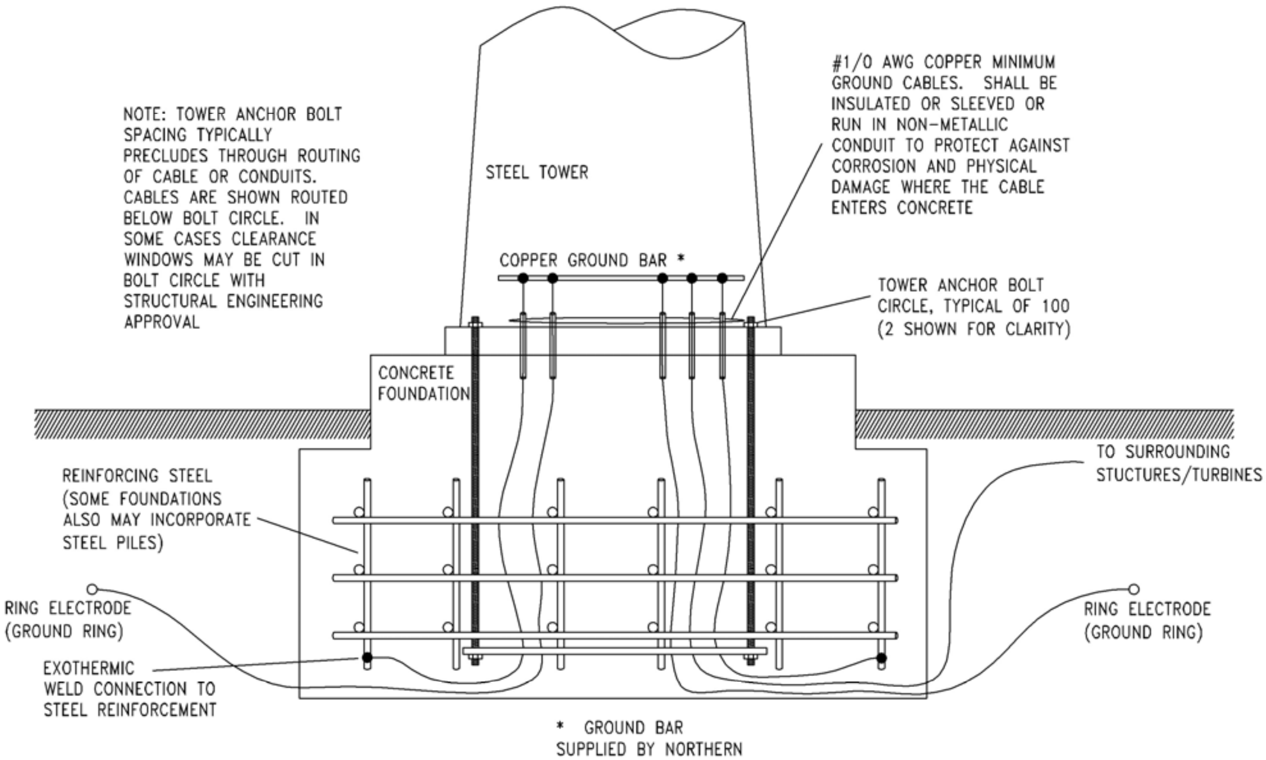

Figure 1 Grounding Detail Example

For low-impedance earth electrode systems, Northern recommends:

- A ring earth electrode encircling the foundation, in addition to the electrode system formed by foundation reinforcing steel.

When designing and installing the earth electrode system, Northern recommends the following references:

- IEC 62305 (Protection Against Lightning)
- Germanischer Lloyd Guideline for the Certification of Wind Turbines
- MIL-HDBK 419, Grounding, Bonding and Shielding for Electronic Equipment and Facilities
- IEEE 141-1993 (Red Book)
- IEEE 142-2007 (Green Book)
- NFPA 780 art 3 (Standard for Installation of Lightning Protection Systems)
- NFPA 70 art 250 (Grounding and Bonding)
- Motorola R-56, “Standards and Guidelines for Communications Sites”

Printed Copies are **Uncontrolled**

4.2.8 Conduit Requirements

Conduit recommendations are summarized in Table 3. When interpreting the location references, note that the tower door is located at 6 o'clock, and the turbine grounding bus is located at 10:30 o'clock (as viewed from above). Locate conduits at least 100mm (4") away from the tower flange to provide clearance for grout and bonding bus. Customer is responsible for all final decisions regarding conduit size, quantity and layout. Refer to drawing 1001441 specific requirements..

Table 2 Recommended Conduit Schedule

Conduit Trade Size	Quantity	Location	Usage
4"	See 1001441	See 1001441 Drawing	Power cables
2"	See 1001441	See 1001441 Drawing	Communications
Customer Spec	Customer Spec	opposite sides	Ground wire protection

5 Control and Monitoring Requirements

5.1 Section Overview

This section defines the control and remote data interconnect requirements for the Northwind 100 wind turbine.

5.2 Control Interface

The Northwind 100 includes a fully automatic control system that safely operates the turbine to maximize energy capture in all operating conditions. The controller is housed in the power controller cabinet in the nacelle, with a communication interface in the junction box at the base of the tower. The customer permissive input requires a customer-supplied dry contact closure for the turbine to operate.

Table 3: Controller Specification

Network Interface	Internal static IP address required* External access shall be blocked by customer firewall
Customer Permissive equivalent circuit	24 Vdc relay coil with 2A fused 24 Vdc power

* A static IP address for the turbine needs to be established as soon after purchase as possible.

5.2.1 Monitoring System

The Northwind 100 comes equipped with Northern's SmartView Monitoring System, which provides a data logging and diagnostic interface required to provide remote support for the Northwind 100. It also provides a web-based human-machine interface (HMI) that can be accessed by any authorized person from anywhere in the Internet. The SmartView Monitoring System includes a computer to be installed at or near the site of the turbine, referred to as the Remote Terminal Unit (RTU).

The customer is responsible for providing a protected environment for the RTU, and for providing an Ethernet communication network. The customer is also responsible for providing Internet access to the RTU throughout the warranty period.

One SmartView Monitoring System will be provided for each site. If a site contains multiple Northwind 100 turbines, only one monitoring system will be provided that will monitor all turbines.

Table 4: Desktop Remote Terminal Unit Specifications

Model	Desktop computer, including LCD monitor, keyboard and mouse
Typical Case Dimensions (H x W x D)	44.7cm x 17.1cm x46.8cm (17.6" x 6.8" x 18.4"
Typical Weight	17.7 kg (39 lbs)
Typical Input Power	120/22/ Vac, 250 Watts, 50 or 60 Hz
Network Interface	100baseT, Ethernet, TCP/IP

	Internal static IP address required External access shall be blocked by firewall except access to RTU port 3307 via static IP address or host name required
Required Environment	Indoor environment, 0°C to 40°C (32°F to 104°F)

Please refer to A01131 SmartView RTU Application Requirements and R01129 SmartView RTU Specifications for details regarding the RTU.

5.2.2 Turbine Network Interface Specifications

The Northwind 100 wind turbine includes as standard an Ethernet network switch in the tower base. Its specifications are provided below in Table 5.

Table 5: RJ45 Copper Port Specifications

Port Type	IEEE 802.3 Compliant
Speed & Duplex	10/100 auto-detecting for speed & duplex (full or half)
MDI/MDIX	Auto-mdi/mdix-crossover automatically supports either straight or crossed cables
Polarity	Auto-polarity for automatic correction of crossed TXD and RXD pairs

Northern recommends:

- Fiber optic connection to turbines. For sites with the following conditions, fiber optic connections are strongly recommended:
  - Frequent lightning activity
  - Multiple turbine installations
  - Long distances between turbine and RTU
- Wireless modems or bridges may be used but the following conditions apply:
  - Antenna cables must not require perforating the tower or grout in any way. All cables exiting the turbine should be run in conduit through the foundation.
  - High level security from unauthorized network access is required.
- If Category 5 or 6 cables must be used (not recommended), place surge suppressors on both ends of all cables that leave the tower.

The number and type of connections and the specifications for the different ports are listed in the SmartView RTU Application Requirements document A01131.

5.2.3 Network Time Service

The turbine requires access to the Internet on UDP port 123 so it can reach a network time server and set it's internal clock using the Simple Network Time Protocol.

Printed Copies are **Uncontrolled**

6 Foundation Specifications and Requirements

6.1 Section Overview

This section defines the foundation design requirements for the Northwind 100 wind turbine. The customer shall design a foundation for their turbine(s) using qualified engineers according to site-specific geotechnical data and the structural requirements in the Appendix which achieve the requirements provided herein. The use of site-specific geotechnical data ensures that the foundation design is optimized for the site's soil conditions. The foundation shall be designed and constructed in accordance with all applicable codes and regulations.

6.2 Foundation Types

There are several types of wind turbine foundations. They include, but are not limited to:

- Concrete spread footing
- Pile footing with concrete pile cap
- Deep concrete/steel mono-pile
- Deep steel freeze-pile

The selection of the right type of foundation for a given site requires knowledge of both soil conditions and the availability of local resources. Concrete spread footings or deep monopiles are typically appropriate and most economical for the majority of sites. Documentation suitable for the purpose of estimating typical spread footings has been assembled in the document W00188 Northwind 100 Logistics and Installation Guidelines.

While not suitable for construction, reference to the Logistics and Installation Guidelines during planning stages should provide the basis for an accurate foundation budget. Final foundation sizes and details shall be derived from the information provided or referenced herein and from geotechnical studies of the project site.

6.3 Structural Design Requirements

In all types of foundations, the base of the tower must be tightly fastened to the top of the foundation. The anchor bolts make this critical connection. The anchor bolts transmit the tower loads into the foundation, and the foundation transmits the loads into the surrounding soil. The foundation must provide adequate resistance to the overturning moment resulting from the lateral loads on the turbine, and in order to prevent settling and subsequent loosening of the foundation, the loads imposed upon the soil by the tower and foundation must not exceed the bearing strength (maximum allowable bearing pressure) of the soil.

The structural design criteria of the foundation are dependent on turbine configuration (e.g. rotor diameter, hub height, tower top mass) and site data (e.g. wind speed, air density). Structural design criteria for available turbine configurations and IEC standard site conditions are provided in Appendix A.

6.3.1 Foundation Design Loads

The foundation loads for the tower may be found in Appendix A. Unless otherwise specified, the loads provided DO NOT include safety factors or load factors. They are the characteristic extreme loads at the base of the tower as calculated during tower design. Appropriate load and/or safety factors are

Printed Copies are **Uncontrolled**

jurisdiction-dependent and shall be applied to the loads by the foundation engineer. The foundation design loads shall be no less than those resulting from the use of the following partial load factors:

- The partial load factor for loads derived from wind and aerodynamics (F_{xy}, M_{xy}, M_z) shall not be less than 1.35.
- The partial load factor for favorable loads (e.g. dead loads, which are favorable because they increase the overturning resistance) shall not be greater than 0.9.

The foundation engineer shall submit a design summary to Northern Power in which the foundation design safety and/or load factors are explicitly identified.

Where permitted by applicable codes, the provided loads may be scaled down if more accurate site data (e.g. from site studies or code-based wind maps) regarding extreme wind speed (3 second gust; 50 year return) and air density is available. Scaling in this manner may reduce foundation cost. If scaling of the provided loads for site-specific data results in foundation loads greater than those provided (e.g. as could happen at a site with high air density and high wind speed), the site conditions may exceed turbine design limits, and Northern Power must be contacted to re-evaluate the suitability of the turbine configuration for the site.

6.3.2 Stiffness/Frequency

In order to prevent resonance of the tower structure, the foundation must be designed to achieve a turbine system fundamental frequency that is sufficiently distant from the operating speed of the turbine. The corresponding requirements for the minimum lateral (horizontal) stiffness K_{xy} and rotational (overturning) stiffness $K_{\theta,xy}$ of the foundation may be found in Appendix A. There is no maximum stiffness requirement. The lateral stiffness and rotational stiffness shall be calculated by the structural and/or geotechnical engineer and shall be noted on the foundation drawings.

6.3.3 Anchor Bolts

The anchor bolts are to be specified by the foundation engineer. The anchor bolts must be capable of bearing loads greater than or equal to those assumed during tower design. This is achieved through an appropriate combination of fastener size and strength (i.e. grade or class). The fasteners and fastener preload assumed during tower design may be found in the appendices.

The anchor bolts and associated hardware shall be stamped by the manufacturer to demonstrate accordance with the governing standard(s) and shall be accompanied by lot traceability records.

6.3.3.1 Anchor Bolt Pattern

The anchor bolt pattern in the foundation must match the bolt pattern in the flange at the base of the tower. The bolt pattern at the base of the tower may be found in the document identified in the appropriate appendix; note that the tower base flange is an internal flange (bolts inside the tower).

6.3.3.2 Anchor Bolt Selection: Required Size & Length; Implications for Stiffness

The bolts must be sized such that adequate clearance is present between the bolts and the holes of the tower base flange to account for tolerance stack-up and bolt misalignment. Northern Power assumed standard (coarse thread) metric sizes (e.g. M24x3.0, M27x3.0) during tower design. In the United States, where imperial specifications are prevalent, inch-specification fasteners of approximately the same size (e.g. M24→1", M27→1 1/8") may be substituted, when approved by the foundation engineer (considering clearance and fastener strength).

The length of the anchor bolt shall be determined by the foundation engineer. The effective grip length of the anchor bolt must be sufficient to result in a bolt aspect ratio (L/d) greater than or equal to that assumed during tower design. The minimum bolt L/d ratio is provided in Appendix A.

In addition to the bolt-specific requirements, the bolted joint at the foundation-tower interface shall be designed to ensure a sufficiently high ratio of joint axial stiffness to bolt axial stiffness. This is required in order to ensure that the bolt preload assumptions and resultant bolt strength calculations performed during tower design remain valid. The minimum joint/bolt stiffness ratio is provided in Appendix A.

6.3.3.3 Anchor Bolt Selection: Strength (Class/Grade) & Corrosion Resistance

High strength structural/construction fasteners shall be used according to the relevant DIN or ASTM specification. Heavy-hex nuts of the corresponding specification shall be used. Washers shall be structural flat or plate washers with a minimum hardness of 30 HRC (~350 HV). The foundation engineer shall specify an appropriate coating on the fasteners to ensure adequate corrosion resistance; mechanical zinc-plating or hot-dip galvanizing is typical. Examples of acceptable fastener standards are summarized as follows:

DIN Standards

- High Strength Threaded Rod & Studs: DIN 975
- Heavy Hex Structural Bolts: DIN 6914 (EN 14399)
- Heavy Hex Nuts: DIN 6915 (EN 14399)
- Structural Washers: DIN 6916 (EN 14399)[1], DIN 7349

ASTM Standards

- High Strength Threaded Rod & Studs:, ASTM A449, ASTM F1554, ASTM A193; ASTM A615 (e.g. Williams-type anchors)
- Heavy Hex Structural Bolts: ASTM A325, ASTM A490
- Heavy Hex Nuts: ASTM A563, ASTM A194
- Structural Washers: ASTM F436

Fastener specifications for low-temperature applications may be substituted as required by the foundation engineer and/or applicable codes.

6.3.3.4 Anchor Bolt Selection: Preload

An appropriate combination of fastener size and strength shall be selected such that the required bolt preload is 75% (± 5%) of the minimum yield strength of the fastener, such that fasteners do not exceed their proof load during bolt tightening.

Regardless of the fastener specification, the bolt preload shall fall within the preload range assumed during tower design (see Appendix A for specific limits). The effects of bolt preload shall be given due consideration during design of other details; see Section 5.4.

6.3.3.5 Anchor Bolt Tightening: Direct Tension Indicator (DTI) Method

Due to the inaccuracy (± 25%) inherent to using torque as a means of controlling bolt tension, the use of load-indicating washers—also known as direct tension indicators, or DTIs—is preferred to the use of conventional methods (such as torque-tightening, turn-of-nut, or nut runners) when tightening the foundation anchor bolts. DTIs are inexpensive, easy to use, and offer a positive go/no-go indication of adequate bolt preload.

[1] The oversized holes in the tower base flange necessitate the use of (2) DIN 6916 structural washers beneath the bolt head or nut. For the other washer specifications (DIN & ASTM) listed here, only (1) washer is required.

Printed Copies are Uncontrolled

If DTIs are used, the load rating of the DTI shall match the required bolt preload, and all DTI calibration and installation instructions shall be followed. Oversized washers may be required for use beneath the DTI.

6.3.3.6 Anchor Bolt Tightening: Torque Control Method

If torque control methods are used for bolt tightening, the target tightening torque shall be determined assuming a nut factor (k) of 0.15 unless more accurate data regarding friction coefficients is available. Lubricant (e.g. nickel-based anti-seize paste) shall be applied to external threads and mating fastener faces (i.e. bottom face of nut and top face of washer) to ensure a relatively consistent coefficient of friction among the fasteners. A calibrated torque wrench shall be used.

6.3.3.7 Anchor Bolt Tightening: Preparation & Tightening Sequence

All fasteners shall be clean, and the threads free from damage or deformation. Previously used bolts, nuts, washers or studs may not be used as anchor bolts or bolt-hardware. The mating surfaces of the flanges are typically galvanized only, and should be free of dirt, paint, rust, or other contaminants. Use a wire brush to clean the surfaces as required.

The foundation engineer shall specify the tightening sequence for the anchor bolts. Numbering of bolts is recommended to facilitate the tightening process. All bolts shall be snug (i.e. tightened to at least 20% of target with a large ratchet or impact wrench) prior to beginning the tightening sequence to achieve full preload (or target torque). Upon completion of the tightening sequence, the sequence shall be repeated to check for appropriate preload (or torque) in the first several bolts tightened in the pattern, as they typically loosen as the adjacent bolts are brought to full preload. Bolts should continue to be checked until the target preload (or torque) is consistently demonstrated.

6.3.4 Seismic Considerations

Seismic loading, though typically non-governing, shall be considered as required by applicable codes and/or the geotechnical report. If seismic load cases govern foundation design, Northern Power shall be contacted to evaluate the suitability of the turbine configuration for the site.

6.4 Construction Requirements

6.4.1 Requirements for All Foundations

All foundation designs must incorporate the following details:

- A means for leveling the foundation prior to tower installation (e.g. use of screw jacks at the base of a steel frame foundation) and/or a means for leveling or plumbing the bottom tower section after installation (e.g. use of leveling nuts on three or more anchor bolts to elevate and level/plumb the bottom tower section, then in-filling the gap with an appropriate grout). This procedure is described in the installation manual, but may also be provided on the foundation drawing. If the procedure is described on the drawing, the foundation drawing shall supersede the installation manual. The bottom tower section must be plumb/level ± 0.2° (0.4” in 10’). If grout is to be used:
    - (i) Grouts shall meet ASTM C1107 and Army Corps of Engineers CRD-C-621.
    - (ii) The grout shall have a one-day strength of at least 45 MPa (6500 psi) so as to allow tightening of the bolts soon after installing the tower base section[2]. Weaker grouts may be used, but cure time may need to be longer in order to develop adequate strength. Adequacy of grout strength shall be confirmed by the foundation engineer, because the

[2] Northern assumes a bolt preload of 249 kN in deriving required grout strength

requirements are dependent on the bolt preload. The area used for the stress calculation shall be the net area of the tower base flange (annular area minus area of holes).

(iii) The grout shall be sufficiently thick so as to effectively distribute the compression load (from the bolts) into the concrete. The compressive stress at the grout/concrete interface shall not exceed the concrete strength. Grout is typically formed at a 45° angle relative to the concrete and flange surfaces. Adequacy of the grout thickness, grout cross-section, and concrete strength shall be confirmed by the foundation engineer because these requirements are affected by the bolt preload.

(iv) The anchor bolts shall be sleeved (e.g. with PVC or foam pipe insulation) to prevent the grout from adhering to the anchor bolts.

- A means for ensuring that the anchor bolt pattern is properly aligned and positioned at the top surface of the foundation. Northern Power offers an anchor bolt template ring as an option.
- A means for liquid water to drain to the outside of the foundation from inside the tower. The foundation shall be designed to prevent the accumulation of water around the base of the tower to minimize corrosion. This drain may be governed by local plumbing codes. It is the responsibility of the foundation engineer to see that the design complies with all applicable codes and standards.
- A means for preventing rotation of the anchor bolts during tightening. If the anchor bolts extend deep into the foundation, anti-rotation is typically accomplished by the use of two nuts at the bottom (lower) end of the anchor bolt. If the bottom end of the anchor bolt is accessible such that a wrench can be placed upon it while the nut at the upper end of the bolt is tightened (e.g. if the entire anchor bolt is above the top surface of the foundation), means for anti-rotation are not required.
- If a pad-mounted transformer is planned, the foundation design should include the transformer's pad located as per Section 4.2.2.
- A grounding system that meets the specifications contained within Section 4, Electrical Specifications and Requirements.
- Power and control conduits as per Section 4.2.8.

6.4.2 Requirements Associated with Long (Deep) Anchor Bolts

In typical non-steel foundations, the anchor bolts extend to approximately the full depth of the foundation. In such cases, the following provisions must be made:

- A means for effectively distributing the bolt loads at the bottom of the foundation. In concrete foundation designs, this is typically accomplished by the use of a thick steel "embedment ring" which is cast into the concrete near the bottom of the foundation. The bolt pattern in the embedment ring must have tolerances sufficiently tight to ensure proper alignment of the anchor bolts. The foundation engineer may design the embedment ring or use Northern Power's embedment ring[3] which is available as an option. In either case, the foundation engineer must approve the ring sizing as adequate. The foundation engineer must perform calculations to verify:

(i) The compressive stress in the concrete directly above the embedment ring (as a result of the tension from all bolts) is acceptable. This stress is dependent on the bolt preload, concrete strength, and the surface area of the embedment ring. The surface area used for the calculation shall be the ring area minus the area of the holes and the nuts.

[3] Northern assumes 5000 psi (34 MPa) concrete and a bolt preload of 249 kN for its embedment ring design. The foundation engineer must confirm the ring designed by Northern Power is adequate for the concrete strength and bolt preload to be used.

Printed Copies are Uncontrolled

(ii) The embedment ring has adequate thickness so as to produce acceptable bending stresses in the ring.

(iii) The embedment ring has an adequate pullout capacity (ultimate limit state; assume loss of clamping force at foundation/tower interface). The pullout capacity is dependent on the projected concrete failure area (a factor of embedment depth, proximity to edges, etc) and the concrete strength.

- A means for developing tension (preload) throughout the entire length of the anchor bolt, and which prevents purchase of the anchor bolts within the foundation except at the intended point of connection at the bottom of the foundation. In concrete foundation designs, this is typically accomplished by the use of sleeves (PVC pipe or similar) through which the anchor bolts are passed, preventing the bolts from being cast into the concrete.
- The engineer must specify a concrete mix that will allow the coarse aggregate to fit within the available space between the anchor bolt sleeves.
- The engineer must specify a concrete mix with an adequate range of slump that will ensure adequate fresh concrete flow through the anchor bolt sleeves.
- For very deep foundations and long anchor bolt lengths, the engineer must consider providing access for electrical and control conduits and the drain pipe through the long anchor bolts.

Printed Copies are **Uncontrolled**

A Appendix: System Design Parameters, Northwind 100/21/37

A.1 Turbine Configuration

Please refer to Northwind100 General Specification document A01465.

A.2 Site Wind Speed Range

Please refer to Northwind100 General Specification document A01465

A.3 Extreme Foundation Loads

50-Year Extreme Load	Magnitude
F_{xy} (Shear)	124.4 kN (28.0 kip)
F_z (Weight)	-194.1 kN (-43.6 kip)
M_{xy} (Overturning Moment)	3352.8 kN-m (2471.0 ft-kip)
M_z (Torsional Moment)	31.5 kN-m (23.2 ft-kip)

- Coordinate system is defined with X and Y as orthogonal axes within the plane of the tower/foundation interface. The positive Z axis points upward; i.e. from the foundation toward the tower top.
- Loads DO NOT include safety factors. Appropriate safety factors for foundation design are jurisdiction-dependent and shall be selected by the foundation engineer. See Section 5.3.1.

A.4 Anchor Bolts

Fastener Specifications	DIN 975 (Stud), DIN 6915 (Nut), 2X DIN 6916 (Washer)
Nominal Fastener Size	M24x3.0
Fastener Strength Class	Class 10.9 (Stud), Class 10 (Nut)
Fastener Preload	185 kN (41.6 kip) MIN, 310 kN (69.7 kip) MAX
Bolt Ratio (L/d)	3.3 MIN
Axial Stiffness Ratio (Joint/Bolt)	9.5 MIN

A.5 Foundation Stiffness

Lateral Foundation Stiffness K_{xy}	$5x10^7$ N/m MIN
Rotational Foundation Stiffness $K_{\theta,xy}$	$2.5x10^9$ Nm/rad MIN

- K_{xy} is the stiffness of the foundation in any lateral (horizontal direction); $K_{\theta,xy}$ is the stiffness about any horizontal axis passing through the origin of the previously defined coordinate system.
- These requirements correspond to a minimum fundamental frequency of 0.7 Hz for the turbine-tower-foundation system. The maximum fundamental frequency for the system is 0.8 Hz, corresponding to the case where the foundation is of infinite stiffness (i.e. base of tower is "fixed"). The foundation cannot be too stiff; thus, no maximum stiffness requirements are given.

A.6 Design References

- **1000152 Bolt Ring, Base, 37m Tower**
- **1001441 Layout, Conduit, 37m Tower Base**

B Appendix: Electrical Specifications Examples

Example 1 - section 4.2.5:

Voltage drop can be translated to power lost: the current heats the wire it is being transmitted on. Power lost as heat is essentially kWh's lost as energy.

If a turbine creates 200,000 kWh/year, and loses 1%, that's 2,000 kWh. Over 20 years that's 40,000 kWh's.

If a turbine creates 200,000 kWh/year, and loses 3%, that's 6,000 kWh. Over 20 years that's 120,000 kWh's.

Using time-averaged cost of electricity at $0.15 over 20 years, that is $6,000 lost for 1% drop and $18,000 lost for 3% drop. This is a significant amount of lost revenue, which could easily be avoided by utilizing proper design.