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Wind Energy Alternative for the Railbelt Region of Alaska

Volume XVI

Ebasco Services Incorporated

August 1982

Prepared for the Office of the Governor
State of Alaska
Division of Policy Development and Planning
and the Governor's Policy Review Committee
under Contract 2311204417

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The major portion of this report was prepared by the Bellevue, Washington, and Newport Beach, California, offices of Ebasco Services Incorporated. Their work includes the Introduction, Technical Description, Environmental and Engineering Siting Constraints, Environmental and Socioeconomic Considerations and Institutional Considerations. Capital cost estimates were prepared by S. J. Groves and Sons of Redmond, Washington, and reviewed by the Ebasco cost estimating department in New York City. Cost of energy calculations were prepared by Battelle, Pacific Northwest Laboratories of Richland, Washington.

PREFACE

The state of Alaska, Office of the Governor, commissioned Battelle, Pacific Northwest Laboratories (Battelle-Northwest) to perform a Railbelt Electric Power Alternatives Study. The primary objective of this study was to develop and analyze long-range plans for electrical energy development for the Railbelt Region (see Volume I). These plans will be used as the basis for recommendations to the Governor and Legislature for Railbelt electric power development, including whether Alaska should concentrate its efforts on development of the hydroelectric potential of the Susitna River or pursue other electric power alternatives.

Large wind energy conversion systems were selected for consideration in Railbelt electric energy plans for several reasons. Several areas of excellent wind resource have been identified in the Railbelt, notably in the Isabel Pass area of the Alaska Range, and in coastal locations. The winds of these areas are strongest during fall, winter and spring months, coinciding with the winter-peaking electric load of the Railbelt. Furthermore, proposed hydroelectric projects in the Railbelt would prove complementary to wind energy systems. Surplus wind-generated electricity could be readily "stored" by reducing hydro generation. Hydro operation could be used to rapidly pick up load during periods of wind insufficiency. Wind machines could provide additional energy, whereas excess installed hydro capacity could provide capacity credit. Finally, with the exception of their visual presence, wind systems have few adverse environmental effects and appear to have widespread public support.

A prototypical large wind energy conversion system was selected for study. The prototype consisted of a wind farm located in the Isabel Pass area and was comprised of ten 2.5-MW-rated capacity, Boeing MOD-2, horizontal axis wind turbines. This report, Volume XVI of a series of seventeen reports, documents the findings of this study.

Other power-generating alternatives selected for in-depth study included pulverized coal-fired power plants, natural gas-fired combined-cycle power plants, the Chakachamna hydroelectric project, the Browne hydroelectric project and coal-gasification combined-cycle power plants. These alternatives are examined in the following reports:

Ebasco Services, Inc. 1982. Coal-Fired Steam-Electric Power Plant Alternatives for the Railbelt Region of Alaska. Prepared by Ebasco Services Incorporated and Battelle, Pacific Northwest Laboratories for the Office of the Governor, State of Alaska, Juneau, Alaska.

Ebasco Services, Inc. 1982. Natural Gas-Fired Combined-Cycle Power Plant Alternative for the Railbelt Region of Alaska. Prepared by Ebasco Services Incorporated and Battelle, Pacific Northwest Laboratories for the Office of the Governor, State of Alaska, Juneau, Alaska.

Ebasco Services, Inc. 1982. Chakachamna Hydroelectric Alternative for the Railbelt Region of Alaska. Prepared by Ebasco Services Incorporated and Battelle, Pacific Northwest Laboratories for the Office of the Governor, State of Alaska, Juneau, Alaska.

Ebasco Services, Inc. 1982. Browne Hydroelectric Alternative for the Railbelt Region of Alaska. Prepared by Ebasco Services Incorporated and Battelle, Pacific Northwest Laboratories for the Office of the Governor, State of Alaska, Juneau, Alaska.

Ebasco Services, Inc. 1982. Coal-Gasification Combined-Cycle Power Plant Alternative for the Railbelt Region of Alaska. Prepared by Ebasco Services Incorporated and Battelle, Pacific Northwest Laboratories for the Office of the Governor, State of Alaska, Juneau, Alaska.

SUMMARY

Several sites showing substantial potential for the development of wind-powered electricity generation have been identified in the Railbelt Region of Alaska. These include sites along the Gulf of Alaska and the Isabel Pass Region in the Alaska Range, south of Big Delta. The seasonality and magnitude of the Isabel Pass wind resource was thought to be sufficiently favorable to warrant an in-depth investigation of the costs and performance characteristics of wind turbine generators in this area.

Accordingly, a suitable site, wind turbine design and cluster configuration were chosen for further study. The site for the proposed project is north of Isabel Pass in the valley of the Delta River, near the Black Rapids Glacier. The wind farm would consist of 10 Boeing MOD-2 (BWT-2560) units rated at a full load capacity of 2.5 MW each, for a total installed capacity of 25 MW. The machines would be installed in two clusters of five machines each, on the west side of the Richardson Highway. Power from the project would be transmitted at 138 kV, approximately 50 miles to intertie with the Golden Valley Electric Association (GVEA) system at Big Delta. The proposed 138-kV line would be of sufficient capacity to transmit up to 80 MW of power, providing additional capacity for future wind turbine clusters. The estimated annual average energy production from the project is 73.3 GWh.

Cost estimates for the proposed project indicate an overnight capital cost of 2490 $/kW, fixed operation and maintenance costs of 3.68 $/kW/yr and variable operation and maintenance costs of 3.3 mills/kWh. Assuming a 1990 in-service date,[a] levelized busbar energy costs were estimated to be 103 mills/kWh. This busbar energy cost should not, however, be used for direct comparison with other generating options, since wind machines operate intermittently and should be evaluated as fuel savers. The cost of energy produced by the machines should be compared to the energy cost of production potentially displaced by wind turbine operation. Given the current suite of generating plants in the Fairbanks Municipal and GVEA systems, it appears

(a) Used for comparative purposes in this series of power plant analyses.

that the winter peaking wind resource would largely displace oil-fired combustion turbine production. Thus, even given the somewhat high forecasted cost of energy from the proposed wind turbine farm, the installation could conceivably be economically competitive. However, if the Anchorage-Fairbanks electrical intertie is completed, the availability of lower-cost natural gas-fired capacity to the Fairbanks-GVEA region may substantially alter the feasibility of the proposed wind system.

A minimum of 3 years would be required for project development, including a minimum of 1 year for wind resource studies and 2 years for construction. The BWT-2560 machines described in this analysis are currently available for order; however, further testing of the prototype machines currently installed at Goodnoe Hills, Washington, and assessment of potential machine performance in cold climate conditions appear to be desirable prior to order.

Environmental effects of the proposed wind turbine farm appear to be minor. Hydrologic and atmospheric effects would be minimal; the principal impact would be aesthetic. No significant engineering constraints appear to be present other than the fairly lengthy transmission link required to intertie with the existing GVEA system. The costs of the transmission link could be shared with several additional wind turbine clusters.

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1.0 INTRODUCTION

The intent of this study is to describe the characteristics and costs of a typical wind farm that can be treated as a modular unit in the development of Railbelt electric energy plans. The typical wind farm consists of 10 horizontal-axis, 2.5-MW MOD-2 wind turbines, with a 25 MW total rated capacity. Because the Railbelt electric energy plans may include several typical wind farms, this study presents an understanding of possible economies of scale resulting from use of joint facilities (e.g., maintenance and control facilities) by adjacent wind farms.

Machine design is based upon technology that is now available and applicable to cold climate regions. The wind farm can be constructed to come on line in the 1985-1986 time frame.

The typical wind farm is assumed to be located in the Isabel Pass wind resource area south of Big Delta. Estimates of the wind resource in this vicinity were obtained from the Alaska Wind Resource Atlas (Arctic Environmental Information and Data Center (AEIDC) 1981). It is assumed that access to the potential wind farm sites will be from the Richardson Highway and that a 138-kV transmission line would have sufficient capacity to deliver the output to the Fairbanks area.

1.1 WIND ENERGY HISTORY

The history of large wind energy conversion systems stretches back to Persia, to as early as 200 B.C. During this period the use of windmills of various types spread throughout the Islamic world. By the 11th century A.D. windmills were in extensive use in the Middle East and were introduced into Europe in the 13th century by returning Crusaders. Windmills were extensively developed and deployed in Holland for draining and reclaiming low lands. Later they were applied to commercial tasks such as grinding grain and operating sawmills. By the middle of the 19th century some 9,000 windmills were in use in the Netherlands for a variety of purposes. With the introduction of the steam engine during the Industrial Revolution, the use of wind power started to decline. However, there are still many windmills operating in Holland today.

In the United States the use of windmills has been widespread. Since the mid-19th century, more than 6 million small windmills of less than 1 horsepower each have been built and operated to pump water, generate electricity, and perform other functions. Over 150,000 windmills are still in operation. Wind energy supplied a significant amount of energy to rural areas of the U.S. until the Rural Electrification Administration (REA) introduced electrical cooperatives in the mid-1930s. With widespread electrical energy availability, there was diminishing use of and interest in wind power, and almost all alternative forms of energy production, until the early 1970s when a sharp increase in the price of imported oil occurred in the U.S.

1.2 U.S. WIND ENERGY PROGRAM

As a result of the increase in energy costs, the U.S. Federal Government undertook an accelerated Wind Energy Conversion System (WECS) program with the objective of stimulating the development of WECS capable of producing a significant amount of the U.S. energy needs by the year 2000. This program originated in the National Science Foundation and was moved to the Energy Research and Development Administration (ERDA) when it was formed. In October 1977 ERDA became part of the Department of Energy (DOE). Major parts of the Federal Wind Energy Program were administered by the Lewis Research Center of the National Aeronautics and Space Administration (NASA) under DOE funding.

The DOE has spent about $200 million on wind turbine research and development. The purpose of the program is to develop small-, intermediate-, and large-scale wind turbines to harness the wind in a cost-effective way. This wind turbine development effort includes construction of several intermediate- and large-scale wind turbines at utility sites and experimental testing of these machines on utility networks.

1.3 CURRENTLY AVAILABLE AND ADVANCED TECHNOLOGIES

The MOD-2 wind turbine, a second-generation machine rated at 2.5 MW in a wind of 27.5 mph, is the latest development in the U.S. wind program. MOD-2, designed, built, and installed by the Boeing Engineering and Construction Company, is the culmination of an effort to design a machine with a high potential for commercial production. It is projected that the MOD-2, when produced in quantities of 100 or more, can generate electrical energy at a cost very close to the current costs of fossil-fuel generated electricity (Linscott et al. 1981). The first cluster of three MOD-2 demonstration wind turbines, located near Goodnoe Hills, Washington, has been producing power for the Bonneville Power Administration.

The Bureau of Reclamation of the Department of the Interior is examining the integration of large clusters of wind-turbine generators with existing hydroelectric power systems. The technical and economic feasibility of this concept will be evaluated by the installation and operation of two different wind turbines. Each wind turbine, called a Systems Verification Unit (SVU), will be installed at the site of a potential cluster of wind turbines. One such site is located approximately 5 miles southwest of Medicine Bow, Wyoming. The SVU wind turbines will be placed about 3000 feet apart and are scheduled to start checkout operations in late-1981. The Bureau of Reclamation awarded a contract to Hamilton Standard to design, fabricate, install, and test a wind turbine called the WTS-4 SVU machine. The WTS-4 has a 265-foot-diameter rotor, supported on a tubular steel tower with a hub height of 262 feet. With a wind speed of 36 mph at hub height, the WTS-4 is designed to produce 4 MW of power. In addition, NASA awarded a contract to the Boeing Engineering and Construction Company to install a MOD-2 SVU machine near Medicine Bow. The MOD-2 machine is described in detail in later sections of this report.

NASA has awarded contracts to General Electric Company and Boeing Engineering and Construction Company to design a MOD-5 wind turbine generator, with 7 MW output. The MOD-5 is to reduce the cost of electricity by 25 percent under that predicted for the MOD-2 machines. Typically, it has taken about 3 years from the start of a program to first rotation, with about another year for testing and commercial acceptance by the purchaser. However, no money has been authorized for construction of a demonstration MOD-5. Thus, the availability of this machine is highly uncertain.

1.4 ADVANTAGES AND DISADVANTAGES OF WIND ENERGY SYSTEMS

As with most of the solar energy alternatives, the advantage of the wind energy conversion system is that the energy, or "fuel," is free and operating costs are low. The major revenue requirements are for repayment of the capital costs associated with the initial construction of the facility. Hence, the revenue requirements are practically "inflation proof."

The disadvantages are that the capital cost is somewhat high relative to other generation capacity in terms of cost per kilowatt, and that power is available only on an intermittent basis, thus depriving wind turbines of significant capacity credit. A third disadvantage is that the power density is low so that the cost of switchgear, tie lines, transmission lines, and other required components needed to consolidate power will add to the already high cost per kilowatt.

Even the largest wind generator now envisioned, the 7.2-MW, MOD-5B, is still very small by contemporary utility standards. New coal-fired power plants have power ratings of 500 to 700 MW. The simplicity of the wind generator compared to such a plant is counterbalanced by the need for two hundred twenty-five 7-MW units operating at a capacity factor of 0.35 over the year to match the annual energy production of one 700-MW coal-fired plant (DeRenzo 1979).

Because of the finite probability that a low wind condition would result in no energy production from the wind farm, the cost of backup capacity must be considered. Backup capacity can be provided by hydroelectric projects with storage capacity, energy storage facilities (i.e., pumped hydro) or thermal units with load-following capability. When operated in parallel with hydroelectric or thermal facilities, wind systems are operated as intermittent baseload capacity, displacing plants of higher variable operating cost. This is so-called "fuel saver" operation. The fuel saved may be coal, gas or oil for displaced thermal capacity, or water (retained in storage) for displaced hydroelectric capacity. Two factors, the amount of high variable cost capacity available for displacement and possible system control difficulties with a high percentage of intermittent generation, may limit the amount of wind energy capacity that should be installed to around 20 percent of total system capacity.

Whether wind energy systems can be economically justified depends upon both the capital costs and the availability of the wind energy compared to the energy value of the power displaced. Evaluation of the economic feasibility of wind energy systems is accomplished by computing the levelized busbar cost of energy over the period of study with and without wind energy systems.

Rather than prejudge whether large-scale wind energy conversion systems can be competitive in Alaska, a conceptual design for a 25-MW wind farm on the Delta River is presented in this report. The potential amount of wind energy available through this system is evaluated, and estimates are prepared for capital and operating costs for this system, which would deliver its energy to Fairbanks. Since energy storage is not available, the economics of wind power must be evaluated in terms of its energy savings in the existing power system.

The basic procedure to be followed is to evaluate the proposed site on the Delta River, north of Isabel Pass, using the site-selection criteria of Hiester and Pennell (1979), considering available wind resource data (AEIDC 1981, Hiester 1980). A conceptual design is prepared using the Boeing MOD-2 system description for wind turbines. A tentative site and configuration are selected. The required supporting facilities and transmission systems are examined in the context of the severe environment. It is concluded that once the support facilities are in place, the resource is of sufficient magnitude that the power output of the site could be increased by an order of magnitude without requiring a substantial increase in the support facilities. The contemplated transmission facilities would be capable of supporting up to 55 MW of additional capacity.

A tentative project schedule is developed. The lead time of the wind turbine equipment is reasonably short. One of the pacing items in the construction schedule is having a wind-free period during the summer months for the installation of the nacelles and rotors on the 200-foot towers. It is expected that these conditions would occur for about 6 to 8 weeks each summer. The entire construction schedule, equipment, and labor force must be keyed around this "window."

In summary, two clusters of five MOD-2, 2.5-MW wind turbines will comprise the proposed 25-MW large wind energy conversion system. A tentative site has been selected on the west side of the Delta River at the foot of Black Rapids Glacier. It is estimated that this installation will produce an annual average of 7773 MWh of electrical energy per year (35.5 percent equivalent capacity factor). The energy will be transmitted by means of a 138-kV line to Fairbanks where it will be incorporated in the local utility grid. The project could be on line in a period of about 36 months from authorization to proceed, providing that the decision-to-proceed date was synchronized with the summer construction cycle.

2.0 TECHNICAL DESCRIPTION

2.1 SITE DESCRIPTION

The site for the proposed project is north of Isabel Pass, in the vicinity of the Black Rapids Glacier on the Delta River in southcentral Alaska (refer to Figure 2.1). While most of the interior of Alaska is characterized by rather calm winds for most of the year, the Isabel Pass Region appears to have an excellent wind energy resource (AEIDC 1981).

The region is characterized by rugged mountainous terrain that is dominated by the Alaskan mountain range. Mount Deborah, 12,540 feet, Mount Hess, 12,030 feet, and Mount Hayes, 13,832 feet are to the west of the Delta River, and numerous peaks such as Mt. Gakona, 9,460 feet, and White Princess, 9,860 feet, are east of the Delta River, which is at about 2,400 feet in elevation in this area. The Alaskan Range presents a high barrier to the flow of air between the Copper River Plateau and the Tanana River Valley. With differences in atmospheric pressure between the two regions, the Delta River Valley forms a natural "funnel" for the air to flow between the two basins.

The Wind Energy Resource Atlas (AEIDC 1981) discusses the wind resources in the region in some detail. The data are based primarily on observations made at Big Delta (64.0°N, 161.8°W), Paxson (63.0°N, 145.5°W), and Rapids (63.5°N, 145.5°W) (refer to Figure 2.2). Paxson is just south of Isabel Pass, on the Richardson Highway. Rapids is in the Delta River Canyon, and Big Delta is about 10 miles southeast of the junction of the Delta and the Tanana Rivers, about 50 miles north of the proposed windfarm site.

The Wind Energy Resource Atlas presents wind resource potential by classes of wind power density at 10 m (33 ft) and at 50 m (164 ft) above ground level. Classes of wind power density are given in Table 2.1.

Isabel Pass is cited as having an annual wind power of class 4 to 7 compared to the annual wind power of class 1 that prevails in the interior regions, such as along the Tanana River (AEIDC 1981).

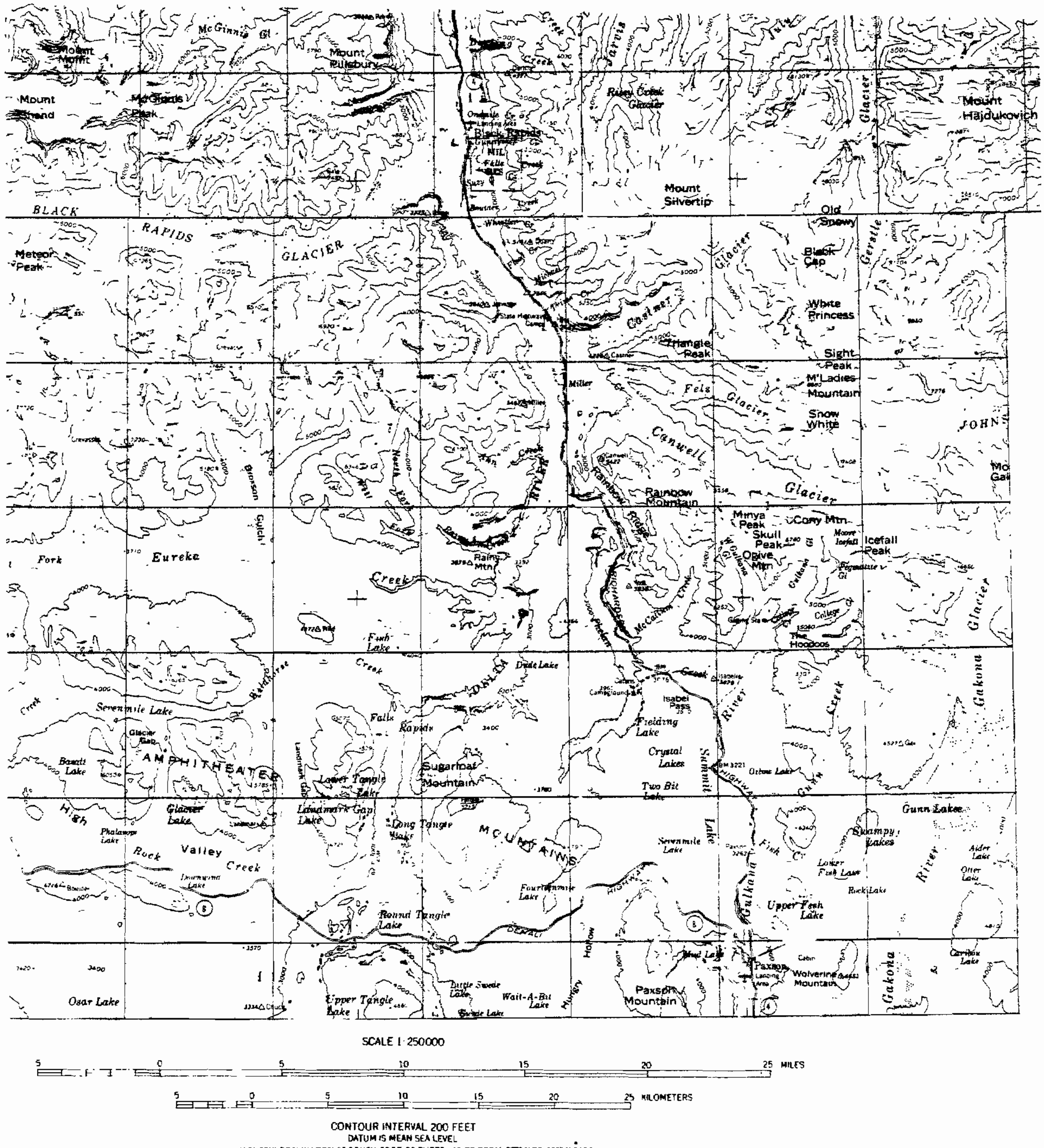


FIGURE 2.1. Area Location Map

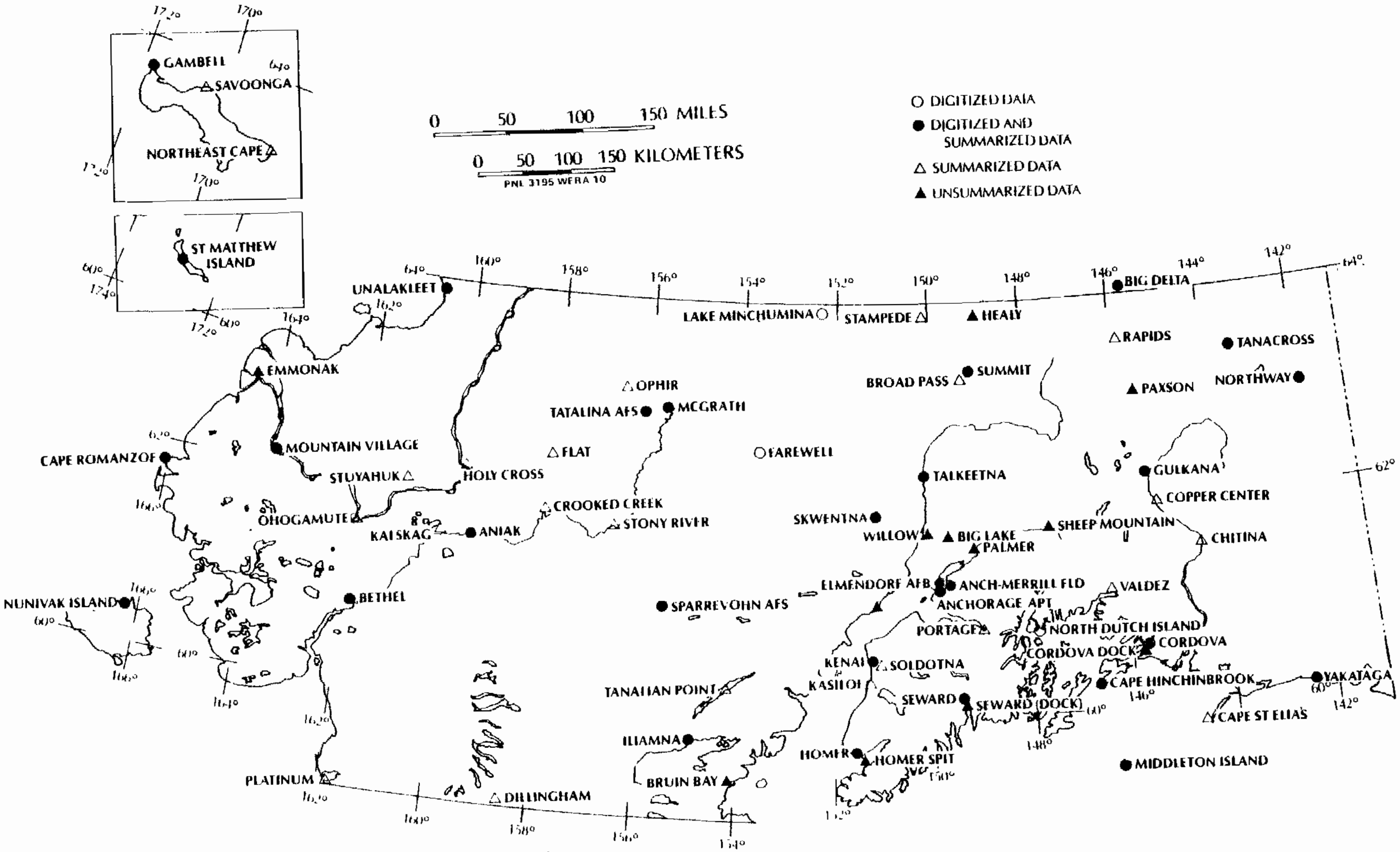


FIGURE 2.2. NCC Station Locations in Southcentral Alaska

TABLE 2.1. Classes of Wind Power Density[a]

Wind Power Class	10 m (33 ft) Wind Power Density, watts/m^2	10 m (33 ft) Mean Wind Speed,[b] m/s (mph)	50 m (164 ft) Wind Power Density, watts/m^2	50 m (164 ft) Mean Wind Speed,[b] m/s (mph)
	0	0	0	0
1	100	4.4(9.8)	200	5.6(12.5)
2	150	5.1(11.5)	300	6.4(14.3)
3	200	5.6(12.5)	400	7.0(15.7)
4	250	6.0(13.4)	500	7.5(16.8)
5	300	6.4(14.3)	600	8.0(17.9)
6	400	7.0(15.7)	800	8.8(19.7)
7	1000	9.4(21.1)	2000	11.9(26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.
(b) Mean wind speed is based on a Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5 percent/5000 ft (3 percent/1000 m) of elevation.

The seasonal wind power for the Isabel Pass Region is shown in a series of maps for the southcentral region that are reproduced here as Figures 2.3 through 2.8. Generally, winter is the season of maximum wind power in the mountain passes because of the high barometric pressure differentials.

In winter, the wind corridor in the Isabel Pass Region has class 7 power for the northern part of its length, as shown in Figure 2.3. In spring the wind corridors at Isabel Pass have class 3 or 4 wind power, as shown in Figure 2.4. In summer, class 1 wind power prevails over most of southcentral Alaska, as shown in Figure 2.5. During autumn the Isabel Pass wind corridor has class 5 and 4 wind powers, as shown in Figure 2.6. The annual average wind power for this region is given in Figure 2.7. A histogram of seasonal wind power classes is shown in Figure 2.8.

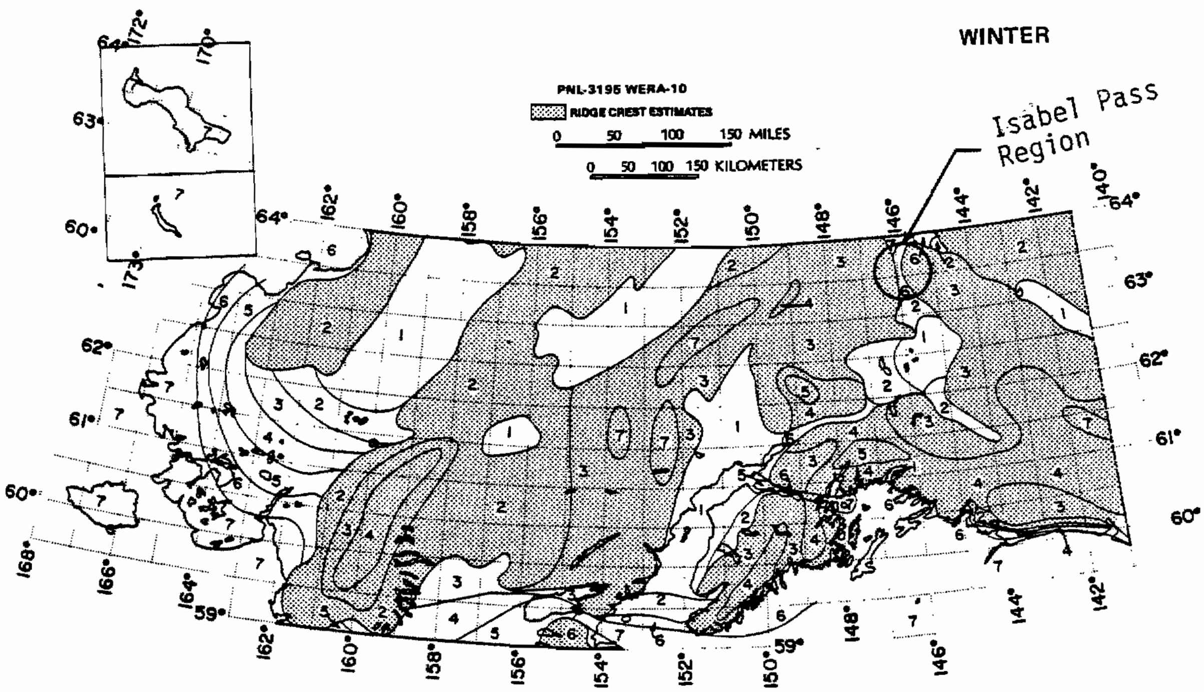


FIGURE 2.3. Seasonal Average Wind Power in Southcentral Alaska - Winter (Source: AEIDC 1981)

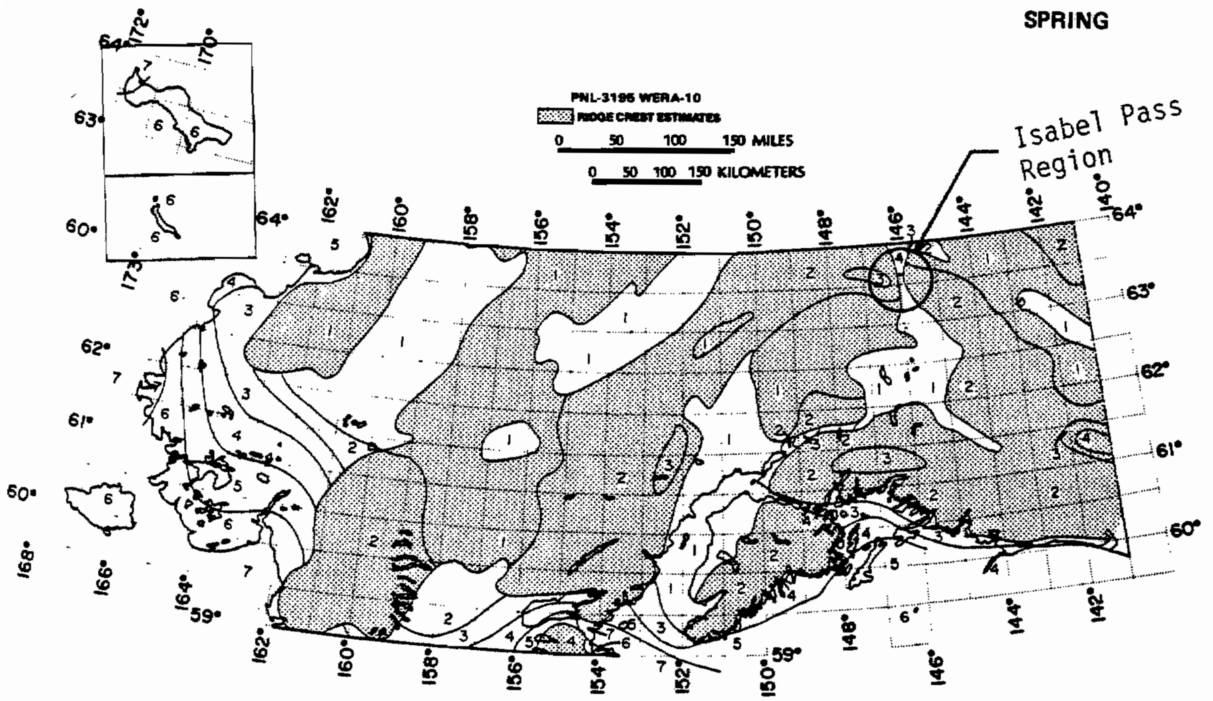


FIGURE 2.4. Seasonal Average Wind Power in Southcentral Alaska - Spring (Source: AEIDC 1981)

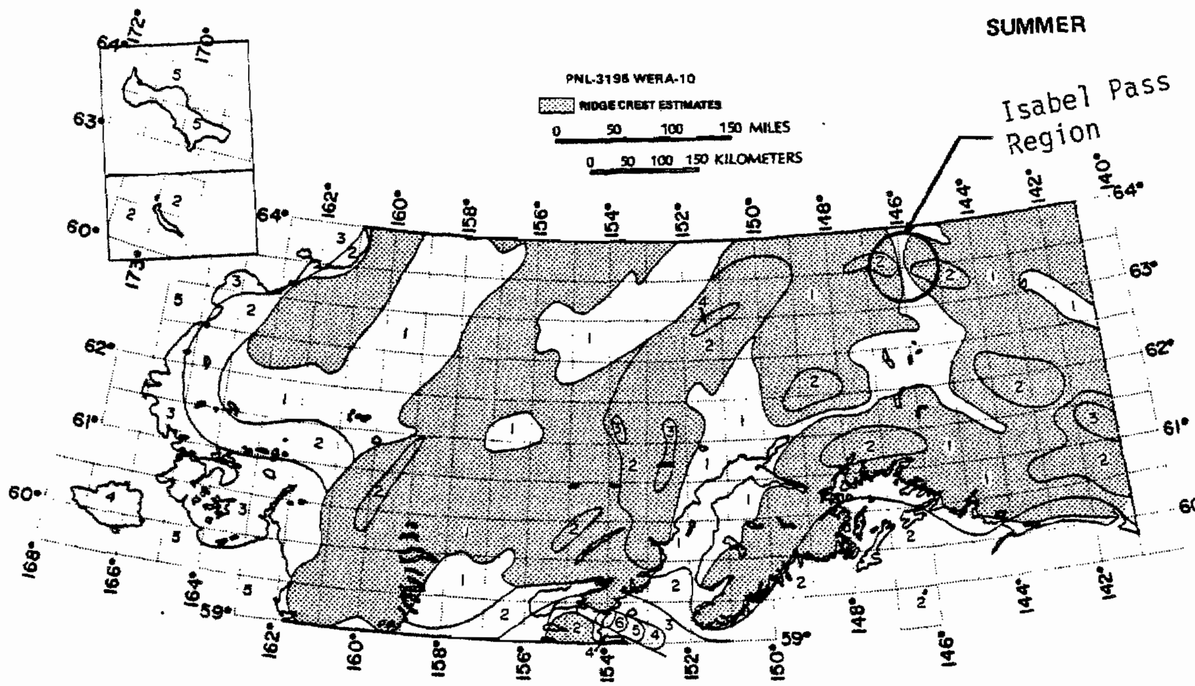


FIGURE 2.5. Seasonal Average Wind Power in Southcentral Alaska - Summer (Source: AEIDC 1981)

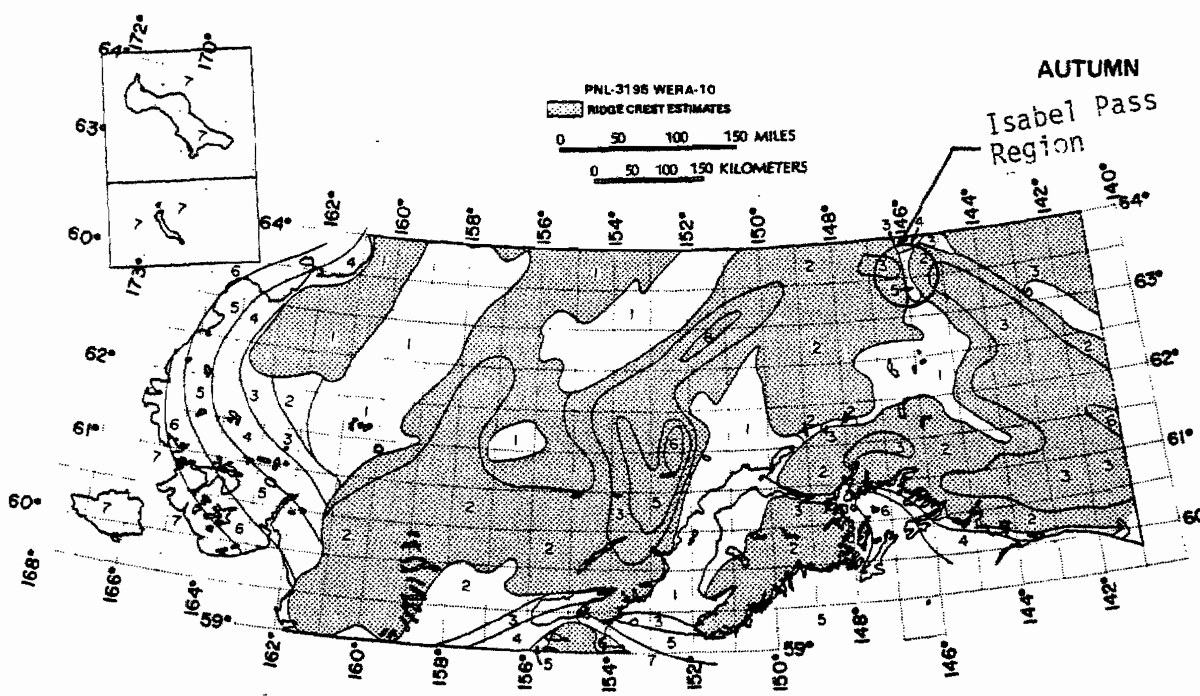


FIGURE 2.6. Seasonal Average Wind Power in Southcentral Alaska - Autumn (Source: AEIDC 1981)

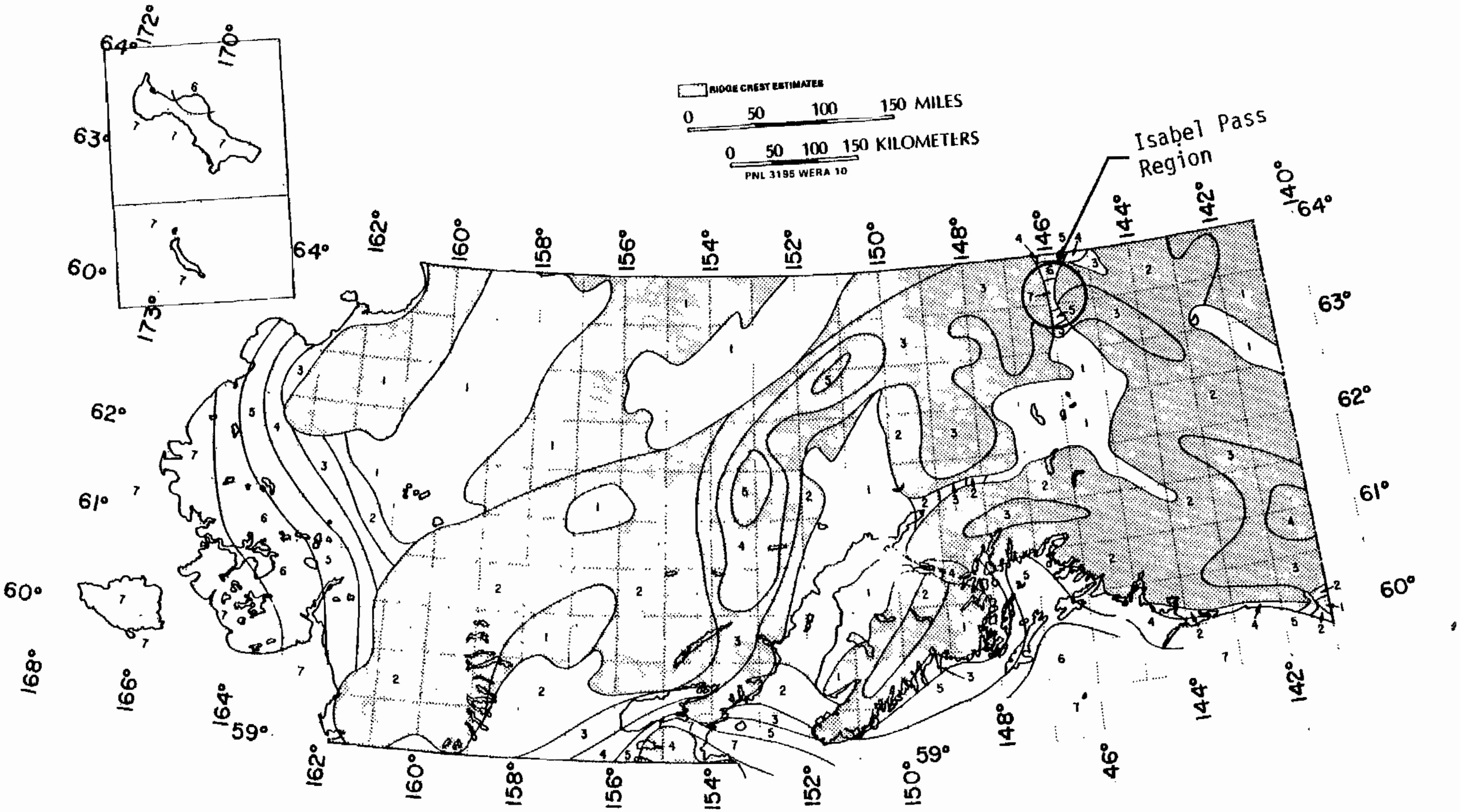


FIGURE 2.7. Annual Average Wind Power in Southcentral Alaska (Source: AEIDC 1981)

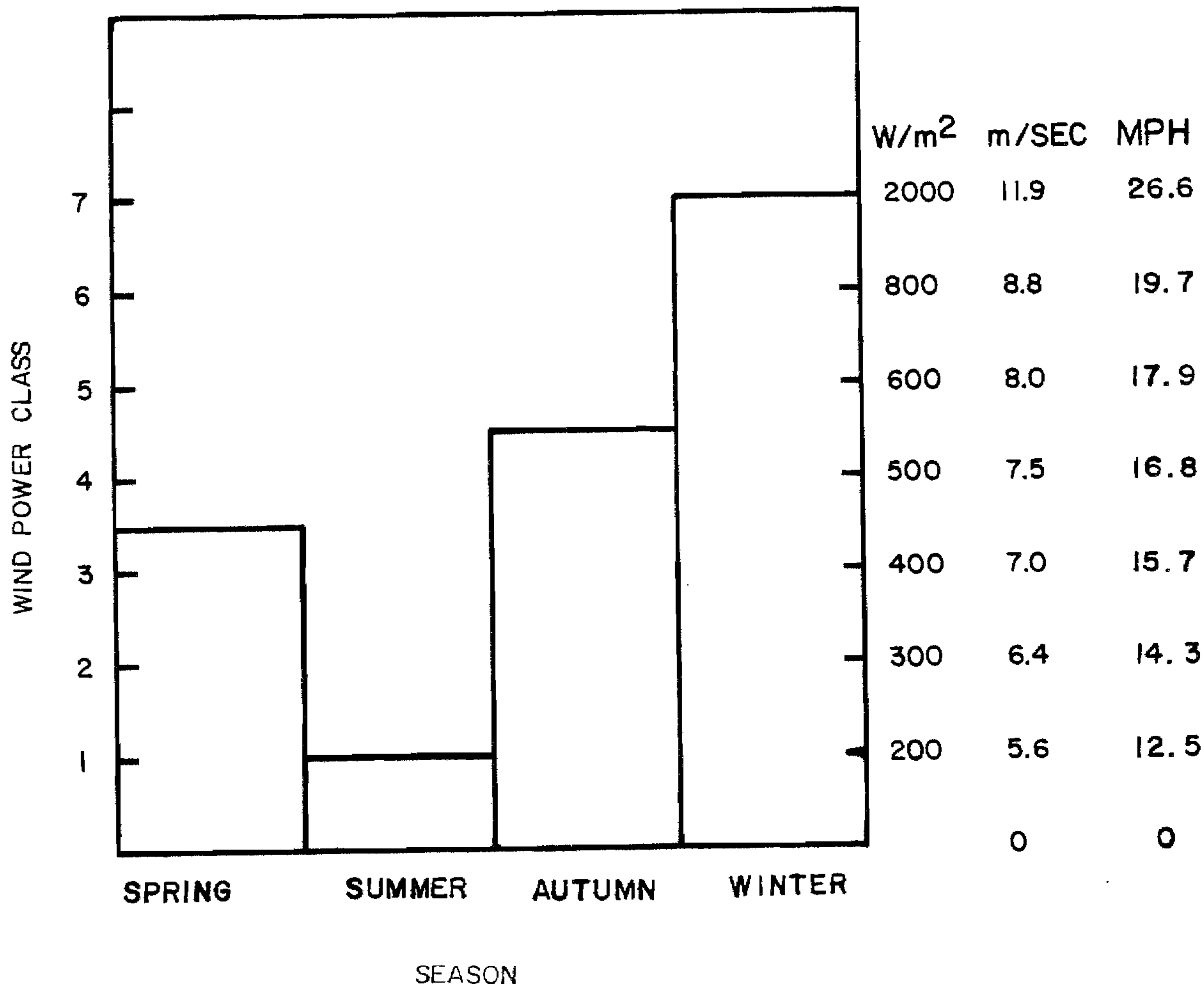
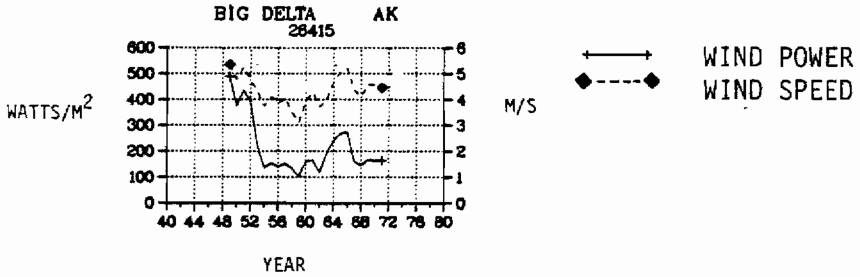


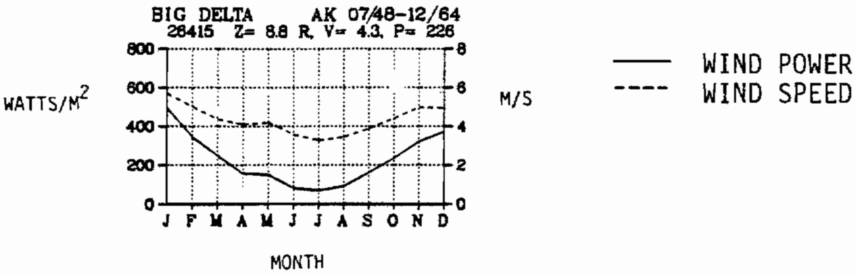
FIGURE 2.8. Histogram of Seasonal Wind Power Density at Delta River Canyon

Data on interannual variations of wind power and speed are presented for Big Delta, which is located on the Delta River about 10 miles southeast of its confluence with the Tanana River. This station is affected by flow through Isabel Pass. The terrain is gently rolling for about 10 to 15 miles in all directions from Big Delta, so that under some conditions air moving through Isabel Pass can have sufficient momentum to produce strong winds at Big Delta. Therefore, Big Delta shows variations from class 1 to class 7 wind power from one year to another, as shown in Figure 2.9A.

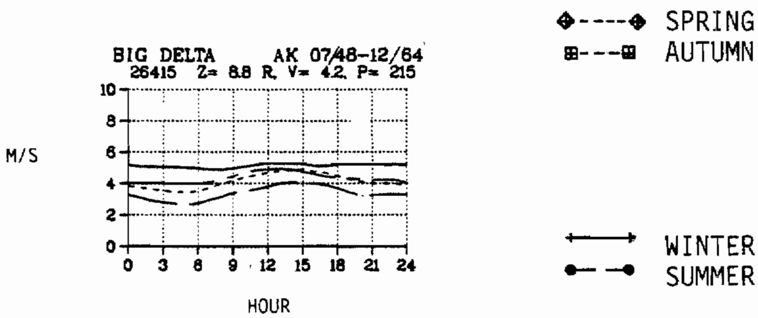
The data for Big Delta, Figure 2.9B, show a winter maximum and a summer minimum with respect to monthly average wind power and speeds. As shown in



A. Big Delta showing variations from Class 1 to Class 7 wind power from one year to another.



B. Big Delta showing a winter maximum and a summer minimum.



C. Big Delta showing some diurnal variation with maximum winds between noon and late afternoon local.

FIGURE 2.9. Wind Variations at Big Delta

Figure 2.9C, there is some diurnal variation, with maximum winds between noon and late afternoon. This variation is largest at Big Delta during the spring and summer, and least during the winter when there is very little warming by the sun.

Strong east-southeast winds exist at Big Delta, with mean wind speeds of 7.9 to 9.2 m/s (17.7 to 20.5 mph). These winds are associated with flow through Isabel Pass.

It should be noted that, for wind energy purposes, the elevation of the Delta River in the region where the wind farm will be located is about 2400 feet above sea level, which implies a reduction in energy density of about 2 percent because of the reduced air density. However, because of the low temperatures generally prevalent in the region, the effect of altitude is approximately compensated by the higher density of cold air.

Siting of the wind farm can be established after determining the magnitude of the wind resource. From Figure 2.1, it can be seen that there is roughly a 30-mile section along the Delta River from Rainbow Ridge to Bear Creek where the river goes through a canyon. The river is relatively flat in this area, with an average elevation of about 2200 feet above sea level. The bottom of the canyon varies from 1 to 2 miles wide, then the canyon wall rises steeply, reaching altitudes of 5000 feet or more about 1 mile from the edge of the canyon flood plain. The walls of the canyon are defined in several areas by large glaciers (i.e. the Black Rapids Glacier, the Canwell Glacier, the Fels Glacier, and the Castner Glacier). From the presence of the glaciers and the braided nature of the river channel it can be assumed that the bottom of the canyon is made up of deposits similar to glacial till so that reasonable foundation conditions can be assumed for the wind turbine towers.

The canyon is traversed by the Richardson Highway, Route 4, and the Alyeska pipeline, which moves crude oil to the Port of Valdez. Aside from these two features, which include the Aladyn pumping station and the military Reservation at Black Rapids, it appears possible to locate the wind farm any place along the canyon, in a roughly 50 square mile area.

As a first approximation, the most logical location for the wind farm will be in the region with the highest wind velocity, which will normally be the part of the canyon with the smallest cross-sectional area. By constructing the wind farm in a canyon, yawing of the wind turbines to track the wind is minimized. From the meteorlogical data (Hiester 1980) it is concluded that the wind in the canyon will be predominantly from the south whenever there is appreciable wind. The turbines will face up the canyon (assuming an upwind rotor design) and will rarely change direction when the wind is blowing with any strength. This can simplify the design and operating strategy for the turbines (Andrews et al. 1981). With more detailed wind data available it will be possible to evaluate whether the wind turbine systems should even include yawing systems. Elimination of yawing controls would allow appreciable savings in capital costs and simplify operations. The wind farm should be placed at the upwind end of the canyon to reduce turbulence on the wind generators, since the turbulent boundary layer thickness increases with distance along the flow channel.

The Isabel Pass Region is characterized by two factors that are unfavorable for the wind-farm project: 1) the long distance from the site to the region where the electricity can be used, and 2) the remoteness of the area when viewed from a maintenance standpoint.

2.2 PLANT DESCRIPTION

2.2.1 Overview

The objective is to examine a large wind energy conversion system (wind turbines) configured as a wind farm. For study purposes, the wind farm rated capacity has been established as 25 MW. Using presently available technology as represented by the 2.5-MW MOD-2 wind turbines, the wind farm will consist of 10 of the MOD-2 wind turbine systems.

Several possible arrangements exist for the wind turbine farm. The general siting relations are specified to avoid aerodynamic interference. This will require that the units be spaced about 3 blade-diameters apart, perpendicular to the prevailing wind direction, and about 10 blade-diameters apart parallel to the prevailing wind direction. For the MOD-2 machines with rotor diameters of approximately 300 feet, the minimum spacing perpendicular to the wind would be 900 feet, while the spacing parallel to the wind would be 3000 feet.

The spacing limitation parallel to the wind arises because as energy is removed from the moving air the velocity is reduced. The mass flow continuity condition requires that the air that has slowed must have a larger flow area, so the streamlines behind the wind turbine disc expand to a larger flow diameter. In the downstream direction, the slowed flow looks like the inverse of a submerged jet, i.e., a region of slow flow rather than a region of high flow. In the submerged jet case, analysis shows that the edges of the jet mix with the surrounding fluid and that within about 10 diameters the original jet has all but disappeared. Since the boundary layer mixing mechanisms are similar between the faster and slower jets, the 10-diameter characteristic length should be applicable to both cases. One of the parameters being investigated at the 7.5-MW, MOD-2 wind turbine cluster located at Goodnoe Hills near Goldendale, Washington, is the interaction between adjacent wind turbines. The spacings between the three Goodnoe Hills wind turbines are approximately 5, 7, and 10 rotor diameters (Axell et al. 1980). These spacings enable evaluation of wake effect of one of the turbines on a downwind turbine. In the absence of data from these tests, it is assumed that the three diameter and ten diameter spacings discussed above are reasonable.

One possible configuration, using these spacing criteria for the wind farm, is to locate the wind turbine generators in a line more or less along the middle of the valley, 3000 feet apart, making the total length 5.1 miles. This configuration may be the lowest-cost alternative if the Richardson Highway can be used for close; i.e., 200 feet, access to all sites. However, this configuration will have the highest costs for consolidating the power at one location for step-up to transmission line voltages.

A second configuration would be to array the ten wind turbines in two rows of five each across the valley, the two rows being about 3000 feet apart. This configuration would probably require one or more bridges across the Delta River to provide access to the units on the western bank if the units were placed in a narrow part of the canyon. In this case the length of electrical connection lines would be reduced from 5.1 to 1.9 miles.

A third potential configuration that may be possible at this location, because the wind is highly undirectional, is to place the wind turbines in a staggered pattern with the turbines in the back row(s) offset by 1.5 blade diameters from the front row, and spaced at about 3 diameters behind the front row. This configuration will provide the shortest interconnecting network, 1.5 miles, and result in the shortest access road.

One important consideration is the question of avoiding wind turbulance because it increases fatigue loading on the turbine blades. There is a gradient in the velocity profile above the surface of the earth. The velocity is zero at the ground/air interface and increases to the free stream velocity at some distance above the earth. This velocity profile is usually characterized by what is called the "1/7 power law," which describes the vertical variation in velocity in the present case. The thickness of the boundary layer is a function of the Reynolds number. The higher the velocity and the longer the distance it has been maintained, the thicker the boundary layer. Figure 2.10 illustrates this effect.

The variation in wind velocity within the boundary layer causes uneven loading on the rotor blades. The blades experience a higher loading when they are at the top of the rotation arc than at the bottom of the arc. This periodic variation in stress, once per rotation, requires that the rotor be designed with stresses below the fatigue limit.

If it were possible to place the wind turbine in a manner such that the wind velocity were more uniform, then more efficient use of the structural properties of the materials of construction could be realized by the reduction in the fatigue factor. This may be possible at the Delta River site if the canyon is viewed as analogous to a wind tunnel. As the air moves southward, the Alaska Range topography is relatively open so that the average air movement velocity will be relatively low as it approaches the Isabel Pass Region, as shown in Figures 2.3 through 2.6. With this low average velocity of approach, a thin boundary layer appropriate to this low velocity will develop

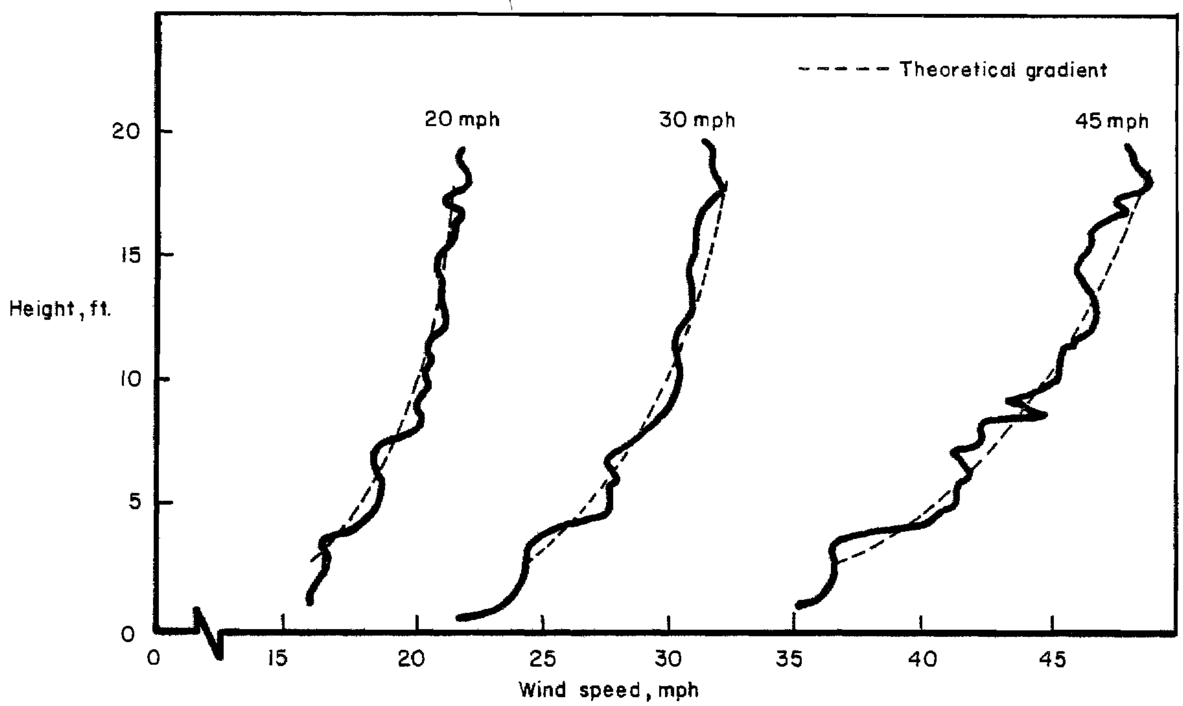


FIGURE 2.10. Examples of Variation of Wind Velocity with Height for Various Wind Speeds (Source: Andrews and Baskin 1981)

in the flow. When the air approaches the narrow part of the canyon and is accelerated to a higher velocity, the boundary layer starts to thicken as the flow proceeds down the canyon. The thickness of the boundary layer is a function of the Reynolds number, which is the product of the velocity times a characteristic distance (in this case the distance down the canyon) divided by the kinematic viscosity of the air. Therefore, if it were possible to locate the wind turbine cluster close to the region where the air is accelerated, then a more uniform velocity profile should be experienced. For the purpose of boundary layer analysis, we can assume that the canyon can be represented as a very high wind tunnel test section.

If we consider a wind of 26 ft/s blowing along a box-like structure 1.2 miles wide, with sidewalls 1.2 miles high and 31 miles long, the turbulent boundary layer will build up to a thickness of about 52 feet (almost to the bottom of the wind turbine blades) in a distance of 1.9 miles. If this "box" was defined as starting with the east sidewall at Darling Creek Ridge and the west sidewall at the prominence called Mt. Pillsbury of Ann Creek, the 52-foot-thick boundary layer thickness would occur at the foot of Black Rapids Glacier.

At this point the canyon widens out and there is a relatively flat spot about 2 miles wide on the west side of the Delta River that might make a suitable site for the wind farm. Access to this site would require the construction of a bridge across the Delta River.

For a project of this magnitude, it appears appropriate to construct and test a physical model of this region in a wind tunnel to evaluate which site would be the most desirable from an energy conversion standpoint. This approach would yield data allowing the alternate sites to be weighed against each other.

It should be noted that there are a variety of sites to choose from along the Delta River. If we look at the wind energy contained in a channel 10,000 feet wide by 500 feet high moving with a velocity of 38 ft/s, and assume a power coefficient of 0.5, we arrive at an available wind power of 250 MW. The suggested wind turbine cluster could be much larger if there was a market for the electricity and suitable backup capacity. Assuming momentum transfer from overlying moving air masses not affected by the wind turbines over distances of the order of 10 to 20 layer thickness (1.1 to 2.1 miles), it should be possible to have about 10 wind turbine clusters along a 15.5-mile length of the Delta River Valley.

For the sites to be examined, the units are arranged in two clusters of five machines each. A main control house gathers the outputs from the clusters (two in this case) and the total site output is elevated to the transmission voltage. This system of two clusters can be easily expanded to include additional clusters. However, the main step-up transformer size must be increased and an additional 13.8-kV air circuit-breaker will be required for each additional cluster.

The proposed 138-kV transmission line can easily transmit 80 MW of power, so that four additional clusters (of five units) can be added either in the Delta River Canyon or enroute to Fairbanks.

A plot plan of the proposed wind farm arrangement is given in Figure 2.11.

2.2.2 Wind Machines

Three government-funded design studies of large-scale (MOD-2) wind turbines were conducted by General Electric Company, Kaman Aerospace Corporation and Boeing Engineering and Construction Company. The designs are very similar, with the major external differences being that the Boeing configuration has the rotor upwind of the pedestal, primarily to relieve the rotor of cyclic stresses caused by passing through the wake of the tower. The G.E. and Kaman designs had the rotor downwind. The Kaman Aerospace design for the control system was based on conventional electromechanical controls, while the G.E. and Boeing designs were predicated on a dedicated microprocessor for a majority of the control decisions. Since the three studies were prepared in response to a NASA specification, the units all have the same output and the designs were based on the same set of wind condition assumptions. Three units of the Boeing MOD-2 design were fabricated and installed near Goldendale, Washington, in 1980, and began producing power for utility customers in May 1981. A fourth unit is being installed at Medicine Bow, Wyoming, while a fifth unit is being installed in northern California.

Boeing Wind Turbine System Description

The Boeing wind turbine (BWT-2560) is a horizontal-axis wind turbine generator (WTG) featuring an upwind 300-foot-diameter teetering rotor with controllable blade tips. The rotor turns at a rated speed of 17.5 rpm. It is attached to the low-speed end of a drive train that is housed in a nacelle, which in turn is supported by a 193-foot-tall cylindrical tower. Rated power output of the machine is 2.5 MW. The system is designed for unattended, remote operation in utility grids. While the main considerations in selecting the configuration were minimum energy cost and reliable operation, attention was also given to minimizing visual and environmental impact. Machine specifications are summarized in Figure 2.12; details of the WTG are described in subsequent sections.

The machine is designed to be fully automatic, with its operation controlled by a microprocessor unit. Low maintenance requirements and a high

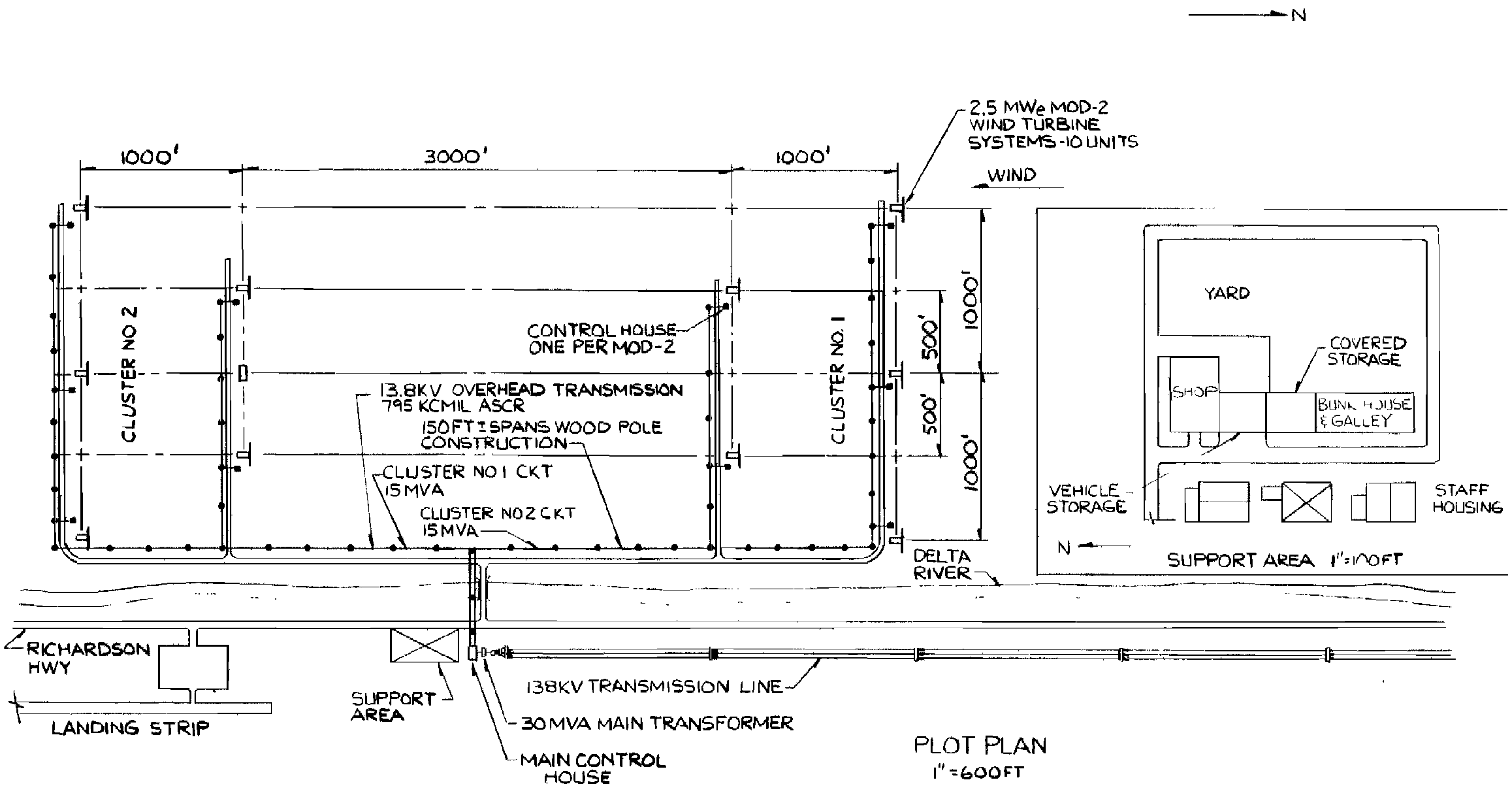
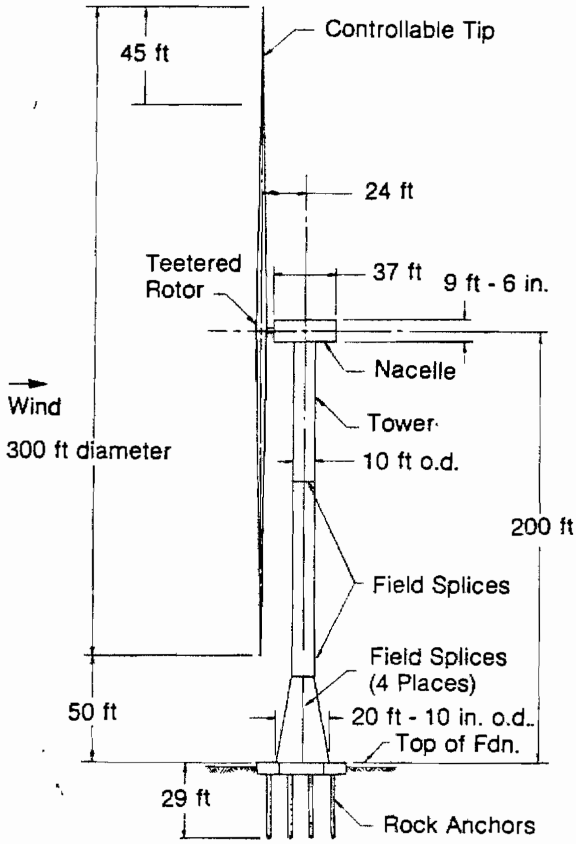


FIGURE 2.11. Large Wind Energy Conversion System Plot Plan



Item	Pounds
Rotor	192,000
Drive train	102,000
Nacelle	82,000
Tower	256,000
Total	632,000

Weight Summary

Rated power	2.5 MW
Capacity	3125 kVA
Rotor diameter	300 ft
Rotor type	Teetered - tip control
Rotor orientation	Upwind
Rotor airfoil	NACA 230XX
Rated wind @ hub	27.3 mph
Cut-in wind speed @ hub	14 mph
Cut-out wind speed @ hub	60 mph
Survivable wind speed @ hub	125 mph
Rotor tip speed	275 ft/sec
Rotor speed	17.5 rpm
Generator type	Synchronous ac
Generator speed	1800 rpm
Generator Voltage	4160V, 3-phase
Generator Frequency	60 Hz
Gearbox	Compact planetary gear
Hub height	200 ft
Tower	Steel-shell type
Pitch control	Hydraulic
Yaw control	Hydraulic
Electronic control	Microprocessor

FIGURE 2.12. BWT-2560 Features and Characteristics (Source: Linscott, Dennett and Gordon 1981; BECC 1980)

on-line availability are facilitated by careful attention to design details. Components are easily accessible, and the system is maintainable by existing utility industry skills. Safety criteria followed throughout the design process assure the absence, and/or proper control, of safety hazards.

BWT-2560 design features resulted from extensive technical trade-off studies accomplished during the MOD-2 program. These studies, conducted under contract with the Department of Energy, had the prime objective of minimizing the cost of energy over the operational life of the WTS. Design work started in 1977 and by mid-1981 five wind turbines had either been completed or were under construction. This development process has resulted in a machine with the following key features:

1. Rotor design employs consistent, well-understood, and thoroughly documented materials (steel) and methods of construction.
2. Upwind rotor orientation maximizes available energy, and reduces rotor fatigue loads and noise.
3. Rotor size and configuration maximize power output during low wind periods and also provides rated power up to 60 mph.
4. Tip controlled rotor signficantly reduces weight and cost through simplification of hub structure and pitch control system.
5. Relatively low rotor tip speed of 275 fps (187 mph) minimizes noise.
6. Teetered hub reduces fatigue loads and minimizes system weight and cost.
7. Pitch control hydraulic system mounted on drive shaft eliminates hydraulic transfer bearings.
8. Driven yaw system controls the rotor heading to maximize energy capture.
9. Soft drive system minimizes torsional fatigue loads and maintains steady electrical power output by isolating the gearbox and generator from torsional oscillations of the rotor.

10. Small, compact, lightweight, high-efficiency gearbox employs advanced technology epicyclic gearing.

11. Steel shell tower configured for minimum cost and weight with fundamental bending frequency below the rotor exciting frequency.

Rotor. The rotor is comprised of two outboard tip sections, two mid-span sections and the hub section, as illustrated in Figure 2.13. The tip sections rotate with hydraulic actuators to control rotor speed or power. The rotor hub incorporates elastomeric radial bearings that allow the rotor to teeter. Mechanical stops are employed to limit teeter excursions to 6 degrees. The hub arrangement is shown in Figure 2.14.

The rotor is a welded steel structure that is fabricated from high-quality low-carbon-alloy steel. Sealed water-tight hatches allow access to the rotor interior.

Power Generation System. The power generation system includes mechanical drive equipment and electrical equipment required for the generation, conditioning and distribution of electric power.

The mechanical drive system includes a low-speed shaft, a step-up gearbox and a high-speed shaft, as shown in Figure 2.15.

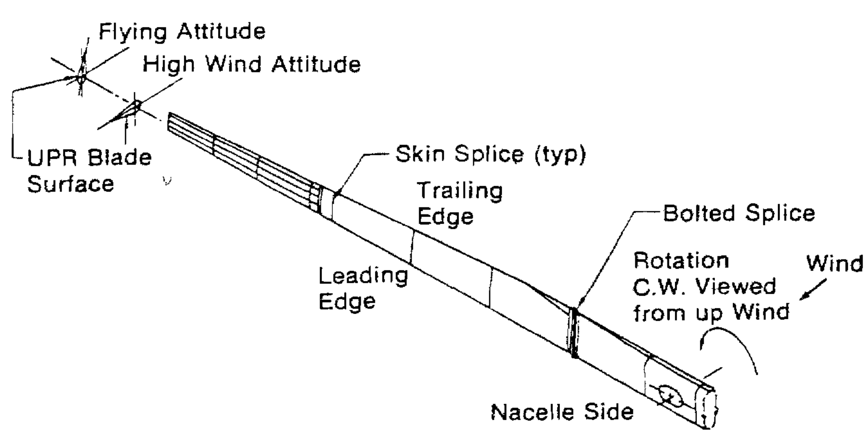


FIGURE 2.13. Rotor Blade Configuration (Source: Linscott, Dennett and Gordon 1981)

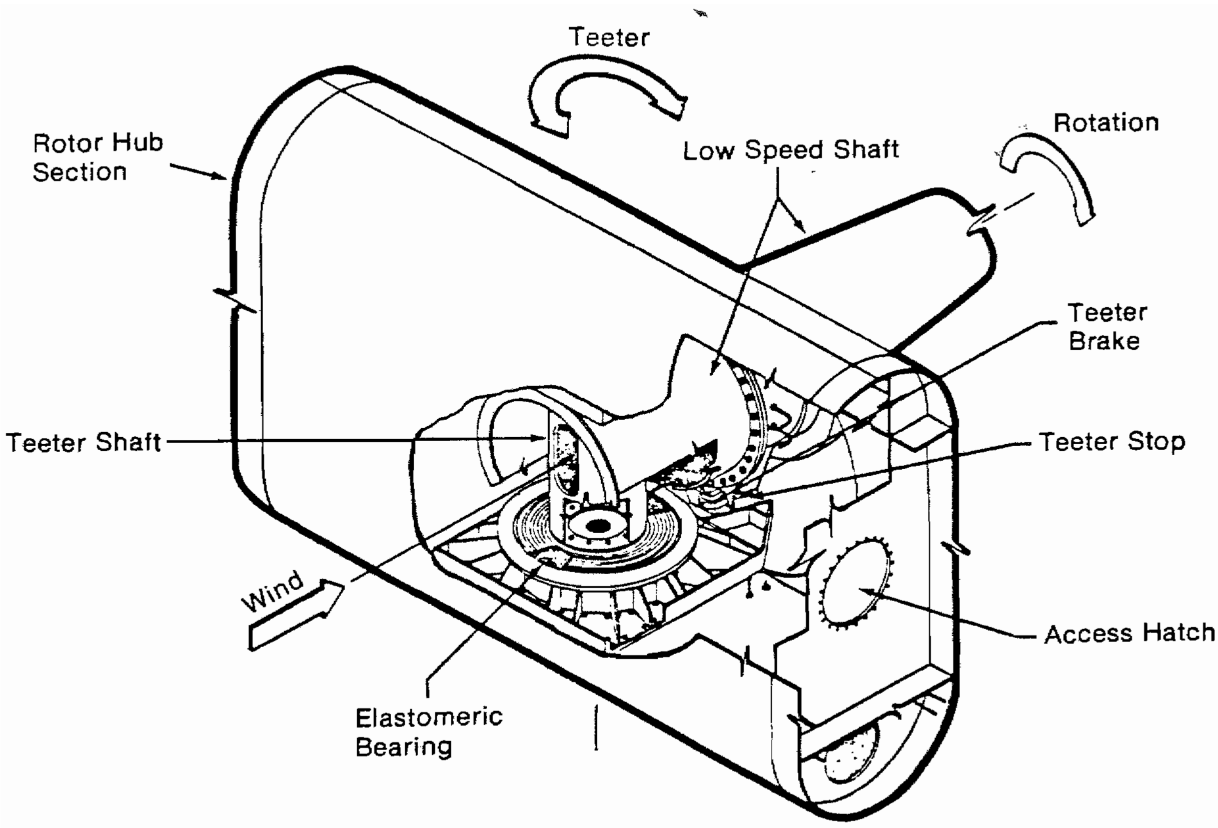


FIGURE 2.14. Rotor Hub Arrangement (Source: Linscott, Dennett and Gordon 1981)

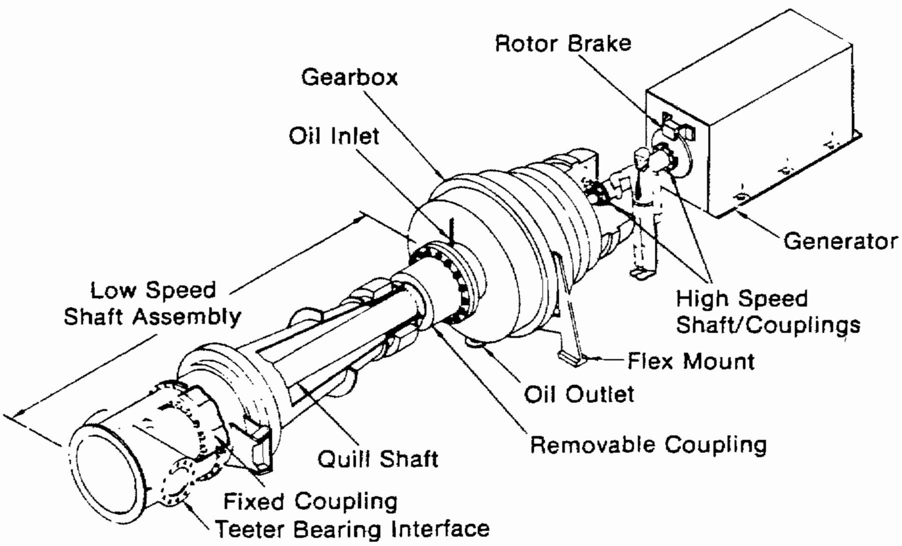


FIGURE 2.15. Drive Train Arrangement (Source: Linscott, Dennett and Gordon 1981)

The low-speed shaft, consisting of a welded steel outer structural assembly with an integral quill shaft, supports the rotor and transmits torque to the gearbox. The alloy steel quill shaft is configured with a torsional stiffness designed to dampen rotor torque fluctuations. Mounted on the outer assembly are the hydraulic power system for the pitch control actuators, and electric slip rings to conduct electrical power and control signals across the rotating interface. The low-speed shaft is supported by both a forward and an aft bearing.

The gearbox is a three-stage epicyclic planetary-type with a 103:1 step-up ratio. The gearbox is equipped with a conditioned recirculation lubricating oil system. The gearbox installation is designed to permit disassembly within the nacelle for overhaul.

A high-speed shaft connects the gearbox to the generator. Bolted couplings on either end of the high-speed shaft, as well as on the aft end of the low-speed shaft, allow removal and replacement of drive-line components. A chain-driven gear on the high-speed shaft facilitates positioning of the rotor with an auxiliary motor for maintenance. Also located on the high-speed shaft is the drive system brake.

The electrical system employs a four-pole synchronous generator containing an integral brushless exciter. It is a three-phase, 60-Hz, 4160-volt generator with a 3125-kVA capacity at 0.8 power factor. The generator accessory unit houses an excitation control, voltage regulator, power factor controls, electrical fault protective relays, current-limiting devices and a backup generator circuit-breaker. Power from the generator is transmitted via a slip ring from the nacelle down the tower and then underground to a bus-tie contactor. Near the bus-tie contactor unit is the main transformer that increases the generator output voltage to the customer tie line voltage. Electrical interface is at the utility side of the fused manual disconnect switch on the utility side of the main transformer. Additional transformers near the bus-tie contactor and in the nacelle provide auxiliary equipment load voltages of 480, 208 and 120. A battery, floating across a charger, provides an uninterruptible power supply for operation of protective devices and critical loads.

The bus-tie contactor operation is controlled by automatic synchronization equipment. Once the WTG and the utility are electrically connected, the generator voltage and frequency will be automatically controlled.

Nacelle. The nacelle, shown in Figure 2.16, houses the drive train, the generator, the yaw drive mechanism, the hydraulic power supply systems and the control unit. Its overall length is 41 feet, its height is 10 feet, and its width is 11.5 feet.

The nacelle has a welded steel structural frame fabricated from rolled structural shapes. The top and sides are sheathed with trapezoidally corrugated steel sheets. The bottom is enclosed with safety plate walkways. Roof

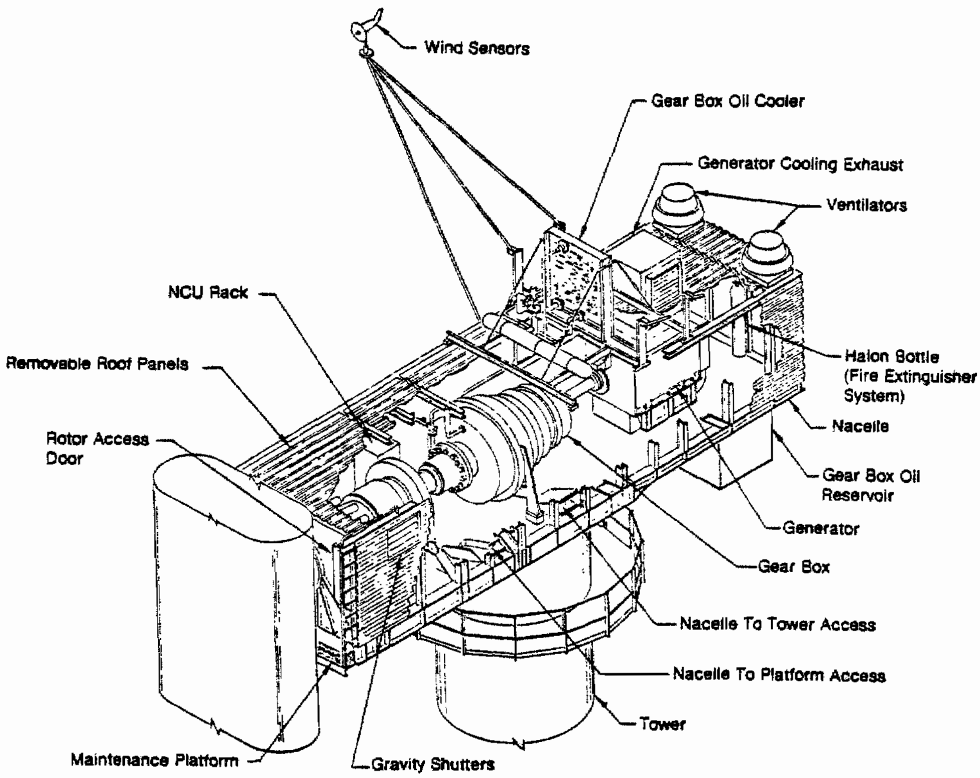


FIGURE 2.16. Nacelle Arrangement (Source: Linscott, Dennett and Gordon 1981)

panels are removable for major equipment access. Hinged doors for personnel and equipment access are located in the aft (downwind) and forward (upwind) walls and in the floor.

The nacelle is connected to the tower through the yaw bearing, which provides full-circle rotation capability. The yaw bearing is of a crossed roller configuration with an integral ring gear. The nacelle is yawed by advancing a hydraulic motor-driven pinion gear along the ring gear.

Tower, Foundation and Facility Layout. The nacelle assembly is supported by a 193-foot-tall, cylindrical, welded steel tower. The tower is 10 feet in diameter with a base section flaring to 21 feet in diameter. It is bolted to a reinforced concrete foundation that is designed on the basis of site soil conditions. The tower contains an internal lift to provide transportation from the ground to the nacelle. The lift ends at a platform near the top of the tower, where final nacelle access is by means of a ladder. A ladder with safety cable runs the entire height of the tower to allow access or egress in the event of a lift failure. The electrical power output cable runs from the slip ring at the top of the tower down the tower side. The tower base interior contains an enclosure for electrical and control equipment. A hinged key-locked access hatch is located near the ground level.

A separate concrete pad, external to the tower, supports both the bus-tie contactor and the step-up transformer. The power output cable from the tower to this pad is buried.

A conceptual site layout is shown in Figure 2.17. The ground area disturbed during construction is about 1-1/2 acres. The permanent installation occupies less than one-quarter acre.

Auxiliary Systems. Personnel access stairways, ladders, and walkways suitable for equipment maintenance purposes are provided in the nacelle. A two-person-capacity lift, including emergency escape provisions, is provided from the tower floor to the top of the tower. A monorail and hoist for equipment transfer between the nacelle and the ground is also provided. Fixed exterior maintenance platforms are located at the forward (rotor) end of the nacelle and at the top of the tower. The nacelle is ventilated with

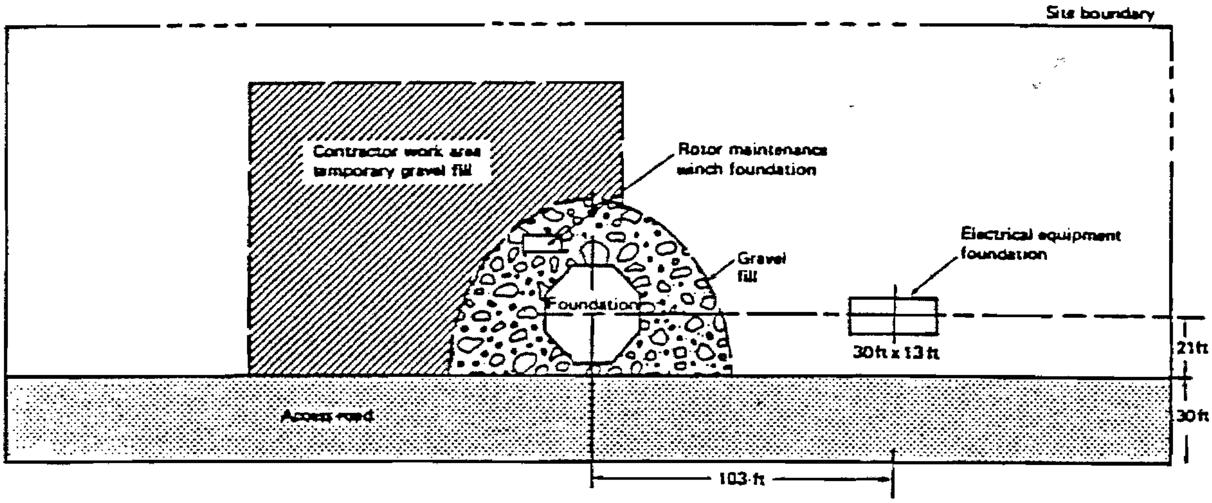


FIGURE 2.17. Wind Turbine System Conceptual Site Plan (Source: BECC 1980)

unconditioned air and convenience electrical outlets are provided for maintenance requirements. A polyurethane paint, which provides a nominal 10-year coating life, is applied to all exterior structural surfaces and equipment. All interior structural surfaces subject to corrosion are treated with a protective coating.

Safety systems are provided to shut down the wind turbine during hazardous conditions. Rotor crack detection is provided by an electro-pneumatic system which distributes conditioned air into the rotor and measures proportional flow rates. Detection of a crack will shut down the WTG. Ice accumulation is detected by rotor-mounted sensors that are included in the control system. Deicing systems are not standard equipment, but may be required due to the potential for freezing precipitation conditions at the proposed site.

2.2.3 Operation and Performance

Control Systems

WTG control systems principally include those associated with the positioning of blade tips, yaw orientation of the nacelle, control of brakes, and scheduling of electrical functions. Commands originate from either the main or the emergency backup control unit.

Control of the blade tip position (pitch) is provided by an electrohydraulic power supply and servo valve-controlled actuators that allow up to 100° angular pitch movement of the tips. The power supply, including the pump, filter, oil reservoir, and redundant supply accumulators, is installed on the low-speed shaft. All hydraulic tubing is of stainless steel. The rate of pitch change is variable up to a maximum capability of 15°/second. The rates are 1°/second and 4°/second for normal pitch operation and emergency shutdown, respectively. Integrated with the pitch system is an electrohydraulic brake system that engages at low rotor speeds.

The nacelle yaw control is provided by an electrohydraulic power supply and servo valve-controlled drive motor. The turning rate is 15°/minute. Failsafe, hydraulically actuated brakes maintain position of the nacelle when not commanded to yaw.

As shown in Figure 2.18, an electronic control system provides the sensing, computation, and commands necessary for unattended operation of the WTG. The controller is a microprocessor that is located in the nacelle control unit. It initiates startup when the wind speed is within prescribed limits. After start-up, the microprocessor computes blade pitch and nacelle yaw commands to maximize the power output for varying wind conditions. Continuous monitoring of wind conditions, rpm, power and equipment status is also provided to the microprocessor, which shuts down the WTG for out-of-tolerance conditions.

A control panel and CRT terminal are located in the tower base to provide operating and fault data displays as well as manual control for maintenance. A remote CRT terminal at the utility control center also provides display of key operating data and fault information as well as shutdown control.

An independent failsafe emergency shutdown system provides sensor redundancy on critical components, and initiates shutdown, when necessary, independent of the primary control system.

Performance

The wind turbine system will produce electricity whenever the wind speed at hub height (200 ft) is between 14 and 60 mph. Below the rated wind speed

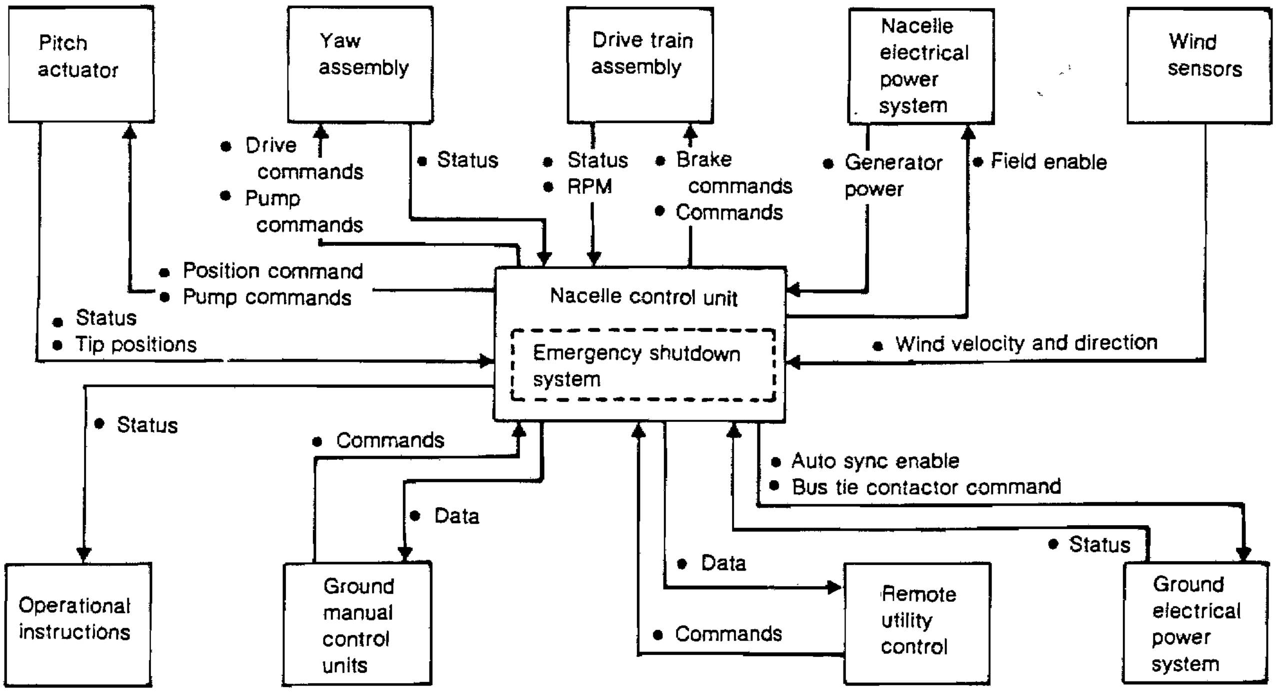


FIGURE 2.18. Control System Interface Diagram (Source: Linscott, Dennett and Gordon 1981)

(27.3 mph), power output is a function of wind speed. Above rated wind speed, the control system positions the blade pitch angle to maintain a constant power output at the rated level of 2.5 MW. This power level can be maintained on hot-day conditions up to an altitude of 7000 feet. The system can also operate to a minimum temperature of -45°F. At wind speeds exceeding 60 mph, the wind turbine is automatically shut down to avoid excessive loads on rotor blades. The system power output profile is shown in Figure 2.19 for sea level, standard-day conditions.

The design specifications for the wind turbine systems will have to be reviewed in a number of areas. The first is that there is very little likelihood of the wind turbine being exposed to 120-mph storm wind conditions. However, there is a high probability that the system will experience high seismic stress. The proposed site on the Delta River appears to be on the border

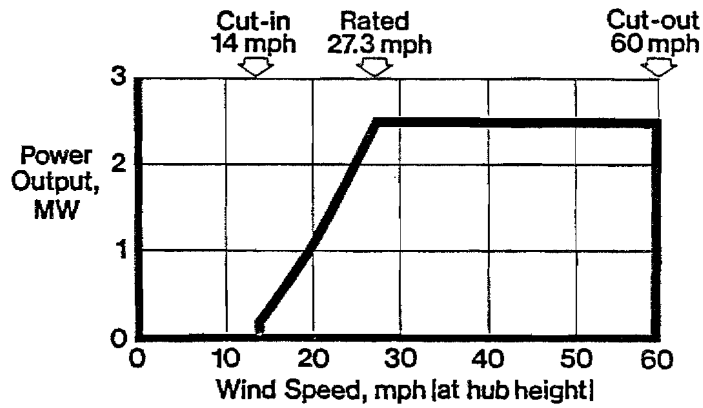


FIGURE 2.19. BWT-2560 System Power Output Profile (Sea Level, Standard Day); Source: BECC 1980

between the zone of moderate and major probability of structural damage (events between 6.0 and 8.8 on the Richter scale) (Hart et al. 1978).

Another factor that must be considered is the possibility of encountering permafrost. While buildings can be put on piles, and utilities can be placed above ground in utilidors to mitigate against permafrost, the tower foundations must be in intimate contact with the soil. Data from Hart (1978) shows that permafrost coverage in the region being considered is generally about 50 percent. Since there is flexibility in the location of the cluster and the individual towers, movement of the site to an area free of permafrost would be the preferred alternative. If that is not possible, the foundation methods outlined by Anderson (1978) will provide acceptable solutions.

It should also be noted that if temperatures in the Isabel Pass area prove to be consistently lower than the present MOD-2 design minimum, -45°F, design modifications can be accomplished to change the fatigue stress of the steel components. The oil system has heaters and will not be affected by cold-region operation.

2.2.4 Auxiliary Facilities

It is contemplated that the WTG would be supplied as complete units and that the supplier would be responsible for all equipment to the main transformer that raises the generator output voltage to the tie-line voltage. The electrical interface is defined as the utility side of a fused manual disconnect switch on the utility side of the main transformer. The other interface is through the control system. A data line is provided for a remote CRT terminal to provide remote display of key operating data, fault information, and startup and shutdown control.

Auxiliary facilities are therefore required to consolidate the power output from the individual wind turbine systems, to raise the voltage to transmission line levels, to consolidate the data channels to a common long-distance data carrier, and to provide onsite maintenance shops and operating supply storage.

In describing the auxiliary facilities, it is assumed that there are two wind turbine clusters of five 2.5-MW MOD-2 wind turbines. Each cluster is comprised of two rows, with a cross-wind spacing of about 3 blade-diameters for the three front-row turbines, and a downwind spacing of about 3 blade-diameters for the back two turbines in the gaps behind the front row, as shown in Figure 2.11. The entire wind farm is supported by a main control house and transformer yard where the voltage is stepped-up to transmission line voltage.

Switchyard and Electrical Onsite Arrangement

A one-line electrical diagram of the site is shown in Figure 2.20. Each machine generator is rated 2.5 MW, 0.8 PF, 4160 volts (the standard voltage supplied by Boeing). A transformer supplied as part of each wind turbine system boosts the output to 13.8 kV. The five generators that comprise one cluster are paralleled at 13.8 kV on a 13.8-kV, 500-MVA bus located in a cluster-control house. The power is transmitted at 13.8 kV to the main control house 13.8-kV, 500-MVA bus, where the outputs of each cluster are gathered. The total site output (two clusters) of 30 MVA is then elevated to 138 kV through a 30-MVA transformer for transmission to the Golden Valley Electric Association System.

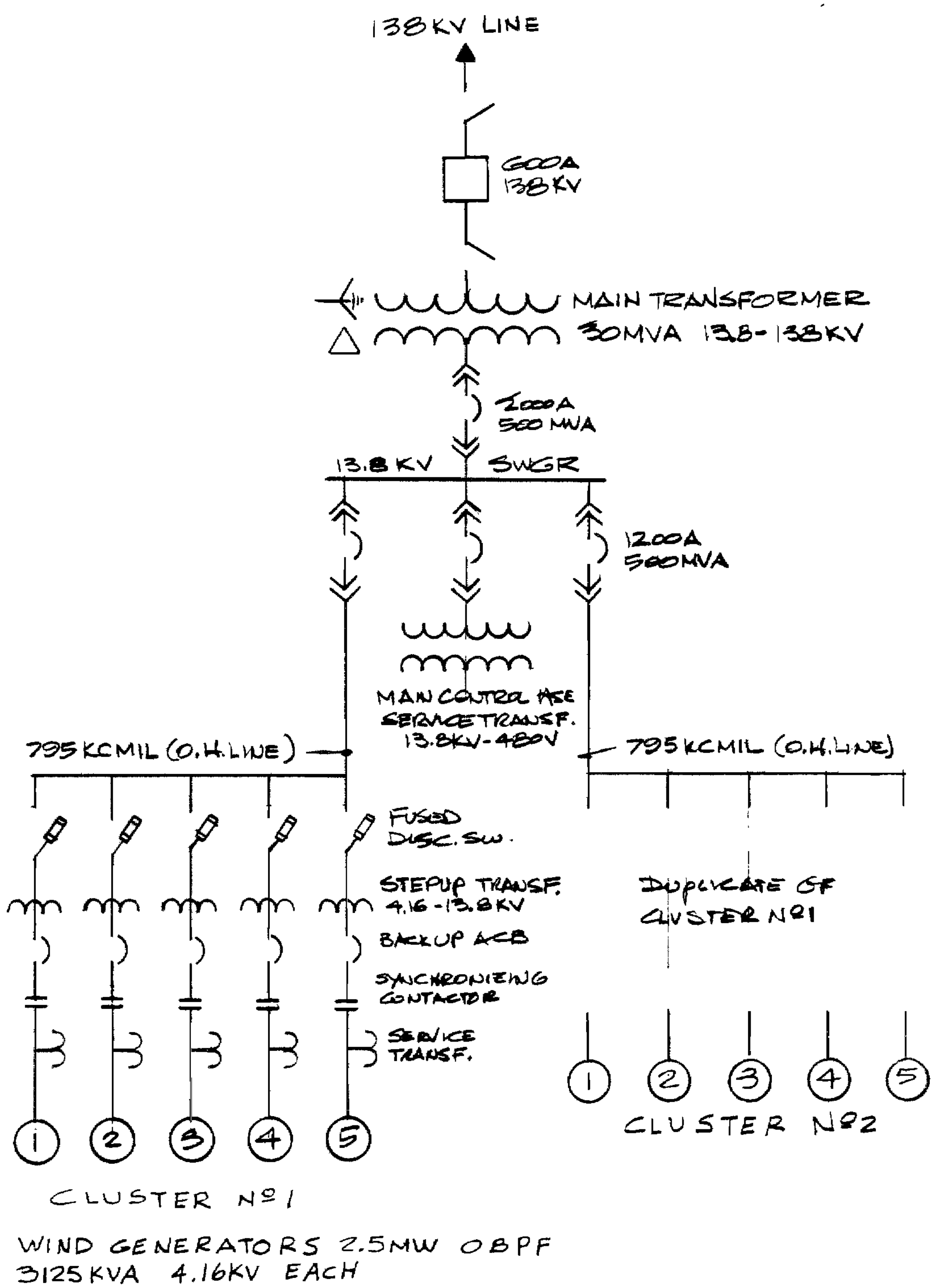


FIGURE 2.20. One-Line Diagram

The basic equipment per cluster will consist of five MOD-2 wind machines and one control house with 13.8-kV, 500-MVA switchgear, including six 400-amp air circuit-breakers (five for generators, one for cluster common power supply, control, heating, lighting, etc.), and one 48-V dc battery and charger for control.

The basic equipment for the main control house will consist of 13.8-kV, 500-MVA switchgear, including three 1200-amp air current-breakers (two for clusters, one for cluster common power supply, control, heating, lighting, etc.), one 2000-amp air circuit-breaker for site output to the main transformer, and one 125-V dc battery and charger for control (13.8-kV switchgear and 13.8-kV oil circuit-breaker).

A small diesel generator of approximately 300 kW is recommended to provide power for house loads in the event of a complete breakdown or freezeup of all generation facilities. This unit, generating at 480 volts can feed into the "house load" panel. One three-phase, 1600-amp, 15-kV bus duct to the main transformers in the switchyard will also be included.

The basic equipment for the switchyard will include one main step-up transformer, 30 MVA, 13.8/138 kV; two 3-pole, 138-kV, 600-amp group-operated disconnect switches and towers; one 138-kV, 200-amp, 50-kiloamperes, symmetrical, interrupting-capacity, pneumatically operated, 125-V dc close-and-trip SF_6 circuit-breaker, and one 138-kV transmission tower.

2.3 TRANSMISSION SYSTEM

The transmission voltage recommended is 138 kV, with phase conductors of 300 MCM ACSR. The conductor size and voltage level were chosen based on the length of the line and on the minimum conductor size required to avoid the corona effect. Approximately three to four steel towers per mile will be required. This line can transmit 80 MW from the proposed site to Big Delta and thence to Fairbanks. The line losses for transmitting 25 MW from Isabel Pass to Fairbanks would be 1.6 MW, or roughly 1.05 kW per mile. A complete system analysis (not within the scope of this study) will be required to ascertain if line compensation is required.

Since the proposed line will pass close to Fort Greeley, a connection to the existing system at this point may be advantageous. Should this prove feasible, the existing transmission line from Fort Greeley to Big Delta should be upgraded to the proposed 138-kV level.

2.4 SITE SERVICES

The Boeing MOD-2 wind turbine is designed for unattended operation, with remote dispatch through a data link. Because of the costs of supporting onsite personnel in the Alaskan interior, unattended operation will be assumed. The wind turbines are designed so that most of the maintenance required by the moving power train components can be performed in the cab or in the nacelle. However, because of the severe climatic conditions at this location, for a major part of the year it will probably be necessary to provide a heated maintenance shop for repair work when needed. Spare parts and operating supplies such as lubricating oils, bearings, and seals would normally be stored at this facility, along with the disassembled 100-ton gin pole and hoisting engines used for rotor and major component replacement. Special equipment or fixtures required to transport the rotor and other components will also be stored at this location.

Because of the value of the equipment and the remoteness of the area, it will be prudent to have quarters for at least one full-time resident at the site. It is contemplated that electronic intrusion detection equipment would be incorporated in all WTG components and support buildings, so the resident's role would be primarily supervisory.

The support facility will house the onsite data recording instrumentation system for the WTGs, an automatic meterological recording station, and the base station equipment for a microwave data link to the dispatch station, assumed to be in Fairbanks. The only periodic attention required for these activities is the occasional changing of data recording media. It is anticipated that the data link will incorporate video channels that could be used with controlled scan cameras for physical surveillance of the site and equipment for transmission in one direction, and used in the other direction for maintenance and repair supervision or instruction.

The support facility will also encompass the voltage step-up station, isolation switches, and oil circuit-breaker for the 138-kV transmission line. The size of the maintenance support facilities will be determined by the preventative maintenance and scheduled maintenance required by the 10 WTGs, and the limited time during the year that outside maintenance can be performed. For example, the WTG specifications cite a nominal 10-year coating life for all exterior structural surfaces and equipment. This leads to a requirement to be able to renew the exterior coatings on at least one of the 10 WTGs each summer work season.

It is contemplated that complicated, infrequent repairs such as replacement of bearing surfaces and gear-tooth restoration, which would require specialized shop equipment, would be performed by removing the defective component and sending it to specialized shops for repair. The primary shop capabilities implemented in the maintenance support activity would be hydraulic and electrical system replacement and repair, with the primary emphasis on replacement. All electronic system repairs will be on a replacement basis only. Major maintenance activities would be scheduled during the summer months when the winds are light and the electrical demand is low. (The support facility could support many more than the two wind turbine clusters previously discussed without a significant enlargement in size or a duplication of facilities.)

The wind turbine clusters will be served by the Richardson Highway. In some areas, it may be necessary to build bridges across the Delta River to provide access to the West bank of the river if some of the WTGs are placed on that bank.

While there is no operational requirement for an airfield to serve the wind farm, the novelty of an installation of this magnitude would probably bring a stream of worldwide visitors. It may be more cost effective to provide a landing strip adjacent to the area to ferry visitors in and out than it would be to maintain facilities at the site to handle visitors for extended periods.

The only utilities required at the site would be for the support of the maintenance shop and the caretakers' living quarters. These would include the usual amenities for cold-region living such as an all-weather water supply, sanitary waste disposal system, fuel oil storage, diesel oil storage, gasoline storage, and an emergency diesel generator to support the living quarters, data recording, and microwave data link in case of an outage on the 138-kV line or lack of wind.

It may be more cost effective to provide temporary living quarters and recreational facilities onsite for the workers doing scheduled maintenance in the summer than to transport these workers each day the some 50 miles each way from Big Delta or Delta Junction. These facilities would also be of value during the construction stage, but will probably be supplemented with temporary portable facilities during that stage.

2.5 CONSTRUCTION

2.5.1 General Construction Methods

Since three MOD-2 wind turbine systems have been constructed and installed, and two are under construction, the procedures to be followed are straightforward (Axell and Woody 1981, Axell and Helms 1980). Under the assumption that the sites have been selected, borings will be made to determine the soil conditions for the foundations and access roads.

Initial construction tasks cover site preparation activities such as grubbing, grading access roads, preparation of storage or laydown areas, and placing of temporary support facilities. The next step covers foundation excavation, form placement, placement of reinforcing steel or rock anchors, concrete batch plant erection, and then pouring concrete for the tower, erection systems, transformer pads, and building foundations. A typical tower foundation may comprise 400 cubic yards of concrete in an octagonal pad. Care will have to be taken to preserve the permafrost when making a pour of this magnitude. Seventy-two anchor bolts set into the foundation are used to bolt the four tower base sections to the foundation. The four base sections are then welded together along field splices. The remainder of the tower is then erected by vertically stacking each of the tower sections and welding to the lower tower section along field splices.

In parallel with tower erection, site electrical installation would take place. The switchgear, transformer and a grounding grid are installed at each site. Electrical power panels are installed inside the tower bases and power and signal wiring are connected from the tower base up the tower raceway to yaw slip rings at the top of the tower in preparation for installation of the nacelle.

Previous MOD-2 installations had the nacelle assembled onsite. This included installation of the gearbox, generator, lubrication module, and roof-mounted equipment. The nacelle units were then subjected to an integrated test at ground level to verify proper operation of all significant functions before committing them to installation at a 200-foot elevation. Because of the remoteness of the proposed site in the interior of Alaska, it is suggested that the nacelle be completely assembled and tested prior to shipping. These tests would include: 1) continuity testing of all electrical wiring, 2) operational and failure mode control system tests, and 3) operational tests of the gearbox, lubrication system, pitch system, and yaw system.

Once the nacelle equipment has been functionally tested on the ground, it would then be installed on its tower by means of a gin pole. Because the gin pole is used for placing the nacelle and rotor and for removing major components for repair, a permanent pod and anchors for the gin pole would be placed at each wind turbine. A light mobile crane would be provided to assist in assembling or removing the gin pole and the hoisting engines. The gin pole used for the MOD-2 cluster is a 240-foot truss boom with a 100-ton capacity, secured and manipulated by steel cables. After the initial construction phase, only one gin pole would be required onsite to service several clusters of wind turbines.

Because it is so large, the rotor would be assembled onsite. The hub and two midspan sections would be bolted together at field splices and the wooden controllable tips would be assembled on the pitch-control actuators. The rotor would be integration tested on the ground prior to installation. Tests would include electrical wiring continuity, operation and setting of the pitch system blade position potentiometers, tests of the ice detection and blade crack detector system, operation of the pitch system actuators and hydraulic system, and verification of all the engineering instrumentation system sensors and wiring. Once the rotor integration tests are completed, the rotor would be installed using the gin pole or a heavy-duty high-lift crane. Activities of this nature are best conducted during calm wind periods, which would restrict this type of operation to the summer months. The large "sail" area of the central span would cause very large, fluctuating horizontal loads, which would be difficult to handle if placement or removal of the rotor were attempted during windy weather.

Once the rotor is installed, pre-free rotation tests would be conducted to measure drive-train alignment and rotor strain gauge calibration. Integration testing of the complete machine would then be accomplished. These tests would include the same tests that were run on the ground, but with all systems completed and all operational sensors installed. Upon completion of these tests, the rotor would be allowed to rotate.

Wind-powered checkout and acceptance tests would follow to demonstrate that the machine is fully operable and ready for acceptance. These tests would include wind-powered operation for a specified number of hours, operation through various operating regimes, specified numbers of start/stop cycles, demonstration of failsafe system operations, and operability demonstrations of all systems.

Once all of the turbines in a cluster are operational, they would be operated in parallel on the cluster 13.8-kV bus, and the integrated control systems would be tested. When both clusters are operational, the entire system would be operationally tested using the 138-kV transmission line tie to the load, and the various systems would be tested in response to commands over the microwave data link from central dispatch in Fairbanks. At this time, the acceptance test on the various units would be completed and the system would be turned over to the utility system.

2.5.2 Construction Schedule

Figure 2.21 shows the estimated schedule for the wind farm project. There are two key features or assumptions inherent in this schedule. First, field construction work is scheduled for the five summer months, May through September. Second, it is assumed that the wind turbine supplier could manufacture 10-wind turbine systems at one time within a 16- to 20-month period. Nominally 16 months are allowed from receipt of order to shipment from the plant, and present production capacity is about one unit per month. With an increase in production resources, the potential supplier could meet the schedule shown. If this is not possible, placement of the wind turbine order earlier in the program would allow the 3-year schedule to be met.

The schedule provides for the first activities to be the compilation of wind measurements, an analytical analysis, and wind tunnel testing to select the best site for the wind farm. From available macrodata, the logical area has been selected, so the microclimatological effects will have to be examined to select the appropriate site. Once potential sites have been selected, geotechnical studies would be conducted during the summer months to determine the foundation conditions at each potential site. The wind farm configuration is extremely flexible, so the site choice will be based primarily on the best foundation conditions available. Solid rock, close to the surface, allowing tower foundation bolts to be anchored firmly in the rock, would provide the most desirable condition.

Site selection could be made at the end of the first year, at which time the firm order for the wind turbine systems could be placed. The time requirement for obtaining permits and licenses should be rather short, the major activities being the obtaining of land use and construction permits for the various facilities. Federal Aviation Administration notification is required because the towers will be higher than 199 feet above ground level.

As previosly cited, a wind turbine system manufacturer has quoted a time of 16 months from receipt of order to having the equipment ready for shipment. The wind turbine equipment would probably be moved by rail from the U.S. and offloaded from the Alaska Railroad at Delta Junction, then trucked to the

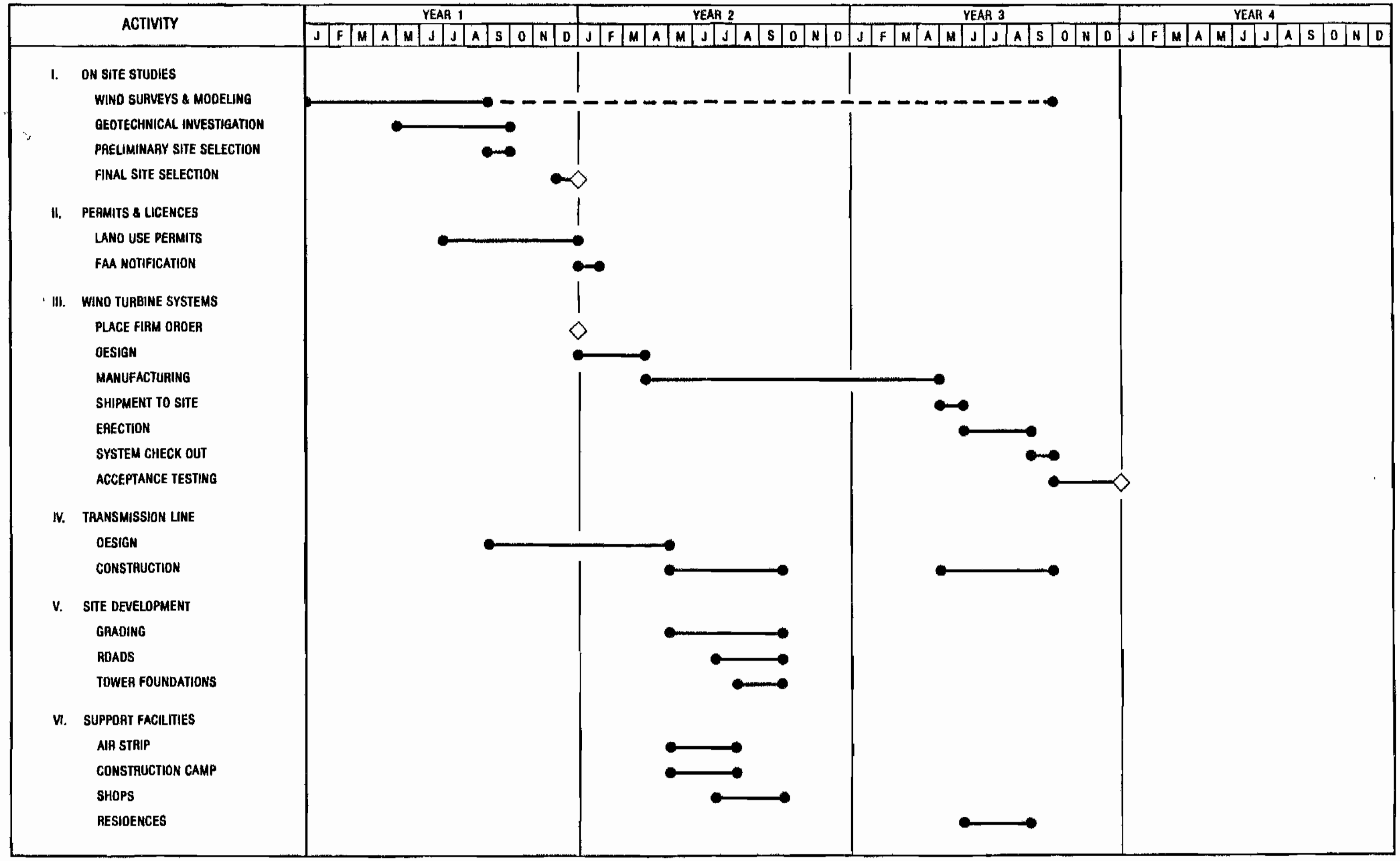


FIGURE 2.21. Project Schedule

wind farm site. The schedule provides for erecting one turbine system per week on the foundations that were placed the previous summer. System checkout and acceptance testing would take place in the fall of the third year when the winds increase after the summer lull.

Design of the transmission line can start once a preliminary site has been selected. The summer of the first year is spent selecting the right-of-way and collecting the necessary topographic data. Activities in the summer of the second year cover construction of the transmission line tower and other foundations, particularly those in permafrost areas. Activities in the third summer cover placement of the towers, stringing the wiring, and erecting substations. The transmission line must be in place for the system check out and acceptance testing of the wind turbine system.

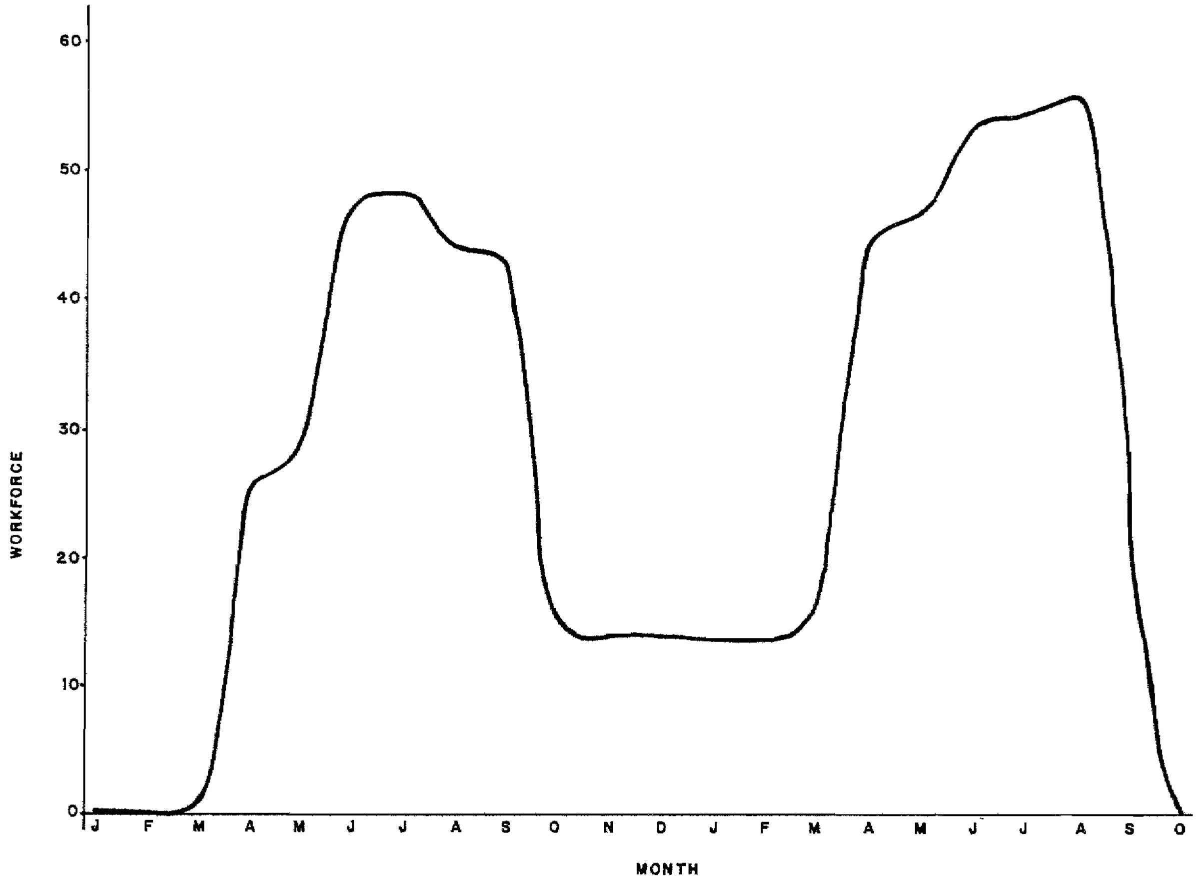
Development of the site and the supporting facilities would follow a normal schedule, with roads, airstrip, construction camp, and shops built during the second summer. Maintenance personnel residences could be built the third summer or sooner, if desired. For the foundation and site development work during the second summer, it is probable that a portable concrete batch plant would be set up onsite and then moved at the end of the construction season.

2.5.3 Construction Work Force

Since most of the wind turbine equipment will be preassembled at the factory, the size of the construction work force at the site will be reasonably small. During the first summer season the number of people at the site performing wind and geotechnical measurements will be of the order of 20 to 25.

A peak construction force of about 100 people would be employed during the second construction season, with about 80 personnel developing the site, permanent structures, and tower foundations for the wind turbines and the transmission line (refer to Figure 2.22).

During the third construction season there would be a peak of about 140 people on the project installing the wind turbine equipment and the 138-kV transmission line. The crew assembling the wind turbines would number about 55 people at the peak activity period.



NOTE: Does not include vendor personnel, owner personnel, A-E engineers, or transmission line construction personnel located at site.

Peak workforce requirements including transmission line construction personnel would be 100 in year 1 and 140 in year 2.

FIGURE 2.22. Construction Work Force Requirements

2.6 OPERATION AND MAINTENANCE

2.6.1 General Operating Procedures

Following system acceptance, it is planned that operational control of the wind turbine systems would be through a central dispatch in Fairbanks. The central dispatcher can start the wind turbines individually if the wind velocity is higher than the "cut-in" speed (see Figure 2.19). Power level control would be maintained by remotely starting or shutting off various wind turbines in the cluster. Controls would be provided so that personnel at the site can start or stop the individual turbines in case the data link is lost, or for maintenance purposes.

It is anticipated that the wind turbine systems would be operated to offset base load insofar as is possible. System maintenance would be scheduled for the summer months when the winds are light and the system load is small.

2.6.2 Operating Parameters

Estimates of forced outage rates for wind turbines are as follows (Electric Power Research Institute 1979):

Unscheduled Outage Rate	6%
Planned Outage Rate	5%
Equivalent Annual Availability	89%

There will probably be several unscheduled outages as the project is started up and initial problems are worked out of the system. The unscheduled outage rate will probably decrease to the level cited above; then in 15 to 20 years start to increase as major system components begin to exceed their normal tolerances. From a utility standpoint, utilization of the wind energy will also depend upon the availability of the step-up transformers, the collection system, and the transmission line. All of these units have very high availabilities and low forced outage rates.

There should not be any variation of forced outage rate with facility (machine and/or cluster) size. Increasing the facility size will not change the annual plant factor, since operation of the individual machines is statistically independent and the machines are essentially drawing on the same wind resource. However, as the number of identical machines is increased, the reliability of the system increases as the square root of the number of machines.

Capacity factor (annual plant factor) is dependent upon the availability of the wind resource and machine availability. Wind resource availability for the proposed site is summarized in the cumulative distribution of Figure 2.8. Equivalent annual machine availability is estimated to be 89 percent.

Capacity factor was calculated using the method described by Cliff (1977). Average turbine power output is estimated using a set of curves relating the ratio of annual mean wind speed to rated wind speed to the ratio of average power output to rated power, as shown in Figure 2.23. The choice of appropriate curve is based on the ratio of cut-out speed to rated speed (1.95 for the BWT-2560). The Cliff method assumes a Rayleigh wind speed distribution, corresponding to the wind speed data of the Alaska wind resource atlas (AEIDC 1981) from which the data of Figure 2.2 are taken; and a simplified machine performance curve having a linear ramp, as in Figure 2.19.

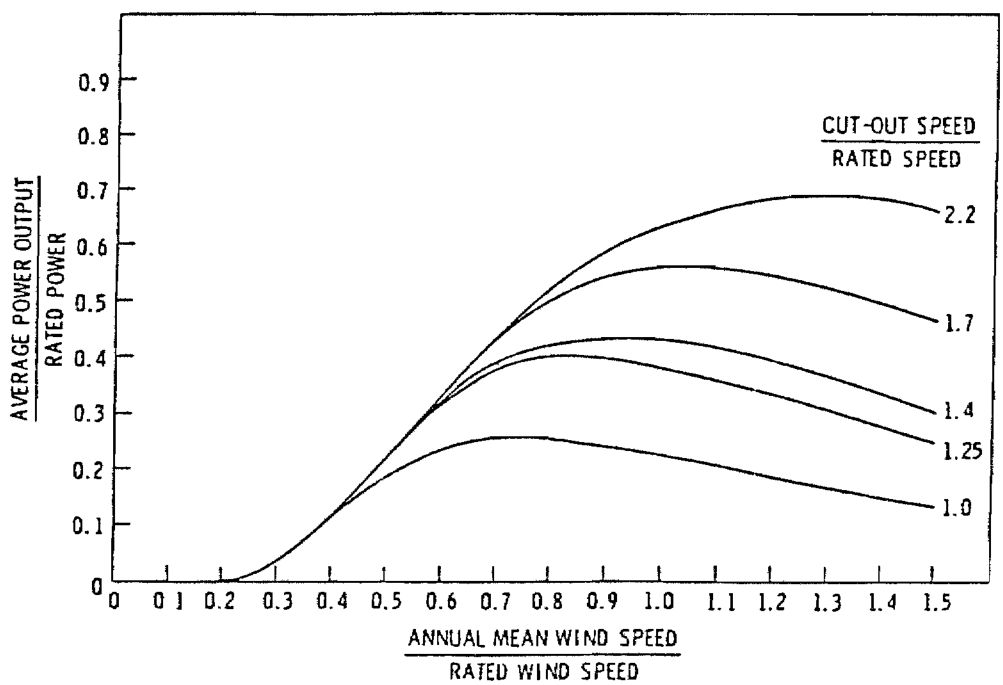


FIGURE 2.23. Estimate of Expected Average Power Output for Wind Turbines as a Function of Cutout, Rated and Mean Wind Speeds and Rated Power Output (Heister and Pennell 1980)

Ratios of the seasonal average wind speeds (Figure 2.8) to the rated wind speed of the BWT-2560 (27.3 mph, Figure 2.19) were taken (Table 2.2). These ratios were transformed through the curves of Figure 2.23 to obtain ratios of seasonal average power output to rated power (not shown in Table 2.2). Potential seasonal energy production was then readily determined (Table 2.2). Potential spring, winter and autumn energy production was then reduced by 6 percent corresponding to the unscheduled outage rate. Potential summer production was reduced by a seasonal average availability factor computed as (1-FOR) (1-SOR), where FOR is the annual forced outage rate of 6 percent, and SOR is a "summer season" planned outage rate taken as 20 percent (four times the annual planned outage rate, since maintenance would normally be scheduled in summer). The resulting energy production for the four seasons was summed to obtain an annual average energy production of 7328 MWh (Table 2.2). This is equivalent to a capacity factor of 33.5 percent.

Wind data from the Rapids weather observation station, unavailable for this study, would help provide a better estimate of average annual energy production. Review of the Rapids weather data would be one of the first tasks if a decision were made for further investigation of the wind energy alternative.

TABLE 2.2. Computation of Average Annual Energy Production

Season	Seasonal Average Wind Speed (mph)	Ratio of Mean Wind Speed to Rated Wind Speed	Potential Seasonal Average Power (MW)	Potential Seasonal Average Energy (MWh)	Machine Availability Factor (%)	Estimated Seasonal Energy Production (MWh)
Spring	16.2	0.59	0.85	1862	94	1750
Summer	12.5	0.46	0.45	986	75	740
Autumn	17.5	0.63	0.90	1971	94	1853
Winter	26.6	0.97	1.45	3176	94	2985
					Annual Average	7328

2.6.3 Plant Life

The wind turbine systems are designed for a plant life of 30 years. Since there are no high temperatures, rapidly moving parts or corrosive atmospheres, the projected units should be capable of achieving these goals. Accelerated testing of many of the critical components reinforces the original design assumptions (Andrews and Baskin 1981).

2.6.4 Operating Work Force

Operation will be controlled by remote dispatch over a microwave data link to Fairbanks. It is anticipated that routine maintenance can be handled by three people who will be in full time residence at the site.

2.6.5 General Maintenance Requirements

Some background on projected wind turbine maintenance requirements have been presented by A. D. Little, Inc. (1980). NASA Lewis Research Center contractors have carried out a detailed analysis of operating and maintenance times and costs for intermediate-range WTS in the 100 to 500 kW size range. Data for the 2.5-MW wind turbine should be similar. These analyses, which have not as yet been published, were developed from a data base derived over many years, and are based primarily on experience with utility and aircraft component operation and maintenance experience. Estimates of component reliability were derived using a computer modeling technique.

For a fully mature, 500-kW machine similar to a MOD-2, but without a teetering rotor, annual maintenance time was estimated to be 205 man-hours (40 scheduled and 165 unscheduled). Added to this sum are 61 hours per year for status checking, 32 hours per year for recording failure histories and reordering spare parts, and 26 hours per year for data recording, resulting in a total of 324 man-hours per year per turbine. For 10 turbines this would total 3,240 hours per year, or 1.84 people. Because of the lower productivity due to the cold weather and maintenance required by the support facilities, three people are provided.

Table 2.3 presents a preventative maintenance list and estimated times required for a MOD-6-sized wind turbine. The functions and times should be similar for the MOD-2.

TABLE 2.3. Preliminary Preventative Maintenance List for MOD-6-Sized Wind Turbine

Item	Typical Maintenance Action	Interval (Months)	Estimated Time Required (Hours)	Annual Time Required (Hours)
Rotor	Inspect for Damage	12	4	4
Rotor, Tower, and Nacelle	Paint	120	90	9
Low Speed Shaft Bearings, Seals	Inspect for Damage, Leaks	12	0.5	0.5
Nacelle Structure	Inspect for Cracks	12	0.5	0.5
Pitch Change Hydraulics	Visual Check for Leaks, Accumulator Pressure, Fluid Level, Fluid Condition, and Filters	12	2	2
Pitch Change Mechanism	Calibrate and Check for Wear	12	1	1
Gear Box	Check Oil and Sensor	12	6	6
Generator, Electrical Switches, and Brushes	Check Condition	12	2	2
Slip Rings (for Power and Signals)	Check Condition	12	2	2
Rotor Brake	Change Disc	12	1	1
Yaw Brake	Check Disc Wear	12	1	1
Wind Sensors	Calibrate	12	2	2
Yaw Drive Mechanism	Clean, Check Condition	12	4	4
Yaw Drive Hydraulics	Visual Check for Leaks, Fluid Level, Fluid Condition, and Change Filters	12	2	2
Aircraft Warning Lights	Change Lamps	12	1	1
TOTAL				38

3.0 COST ESTIMATES

3.1 CAPITAL COSTS

3.1.1 Construction Costs

Construction costs have been developed for the major bid line items common to wind energy conversion systems. These line item costs have been broken down into the following categories: labor and insurance, construction supplies, equipment repair labor, equipment rental, and permanent materials. Results of this analysis are presented in Table 3.1. Total overnight construction costs for the 25-MW wind farm is estimated to be $62.3 million.[a] The equivalent unit capital cost is $2490 per kilowatt.

3.1.2 Payout Schedule

A payout schedule has been developed for the entire project and is presented in Table 3.2. The payout schedule for the project was based on an 18-month basis from start of project construction to commercial operation.

3.1.3 Capital Cost Escalation

Estimates of real escalation in capital costs for the plant are presented below. These estimates were developed from projected total escalation rates

Year	Materials and Equipment (Percent)	Construction Labor (Percent)
1981	1.0	0.5
1982	1.2	1.7
1983	1.2	1.7
1984	0.7	1.3
1985	-0-	-0-
1986	-0.1	-0.1
1987	0.3	0.3
1988	0.8	0.8
1989	1.0	1.0
1990	1.1	1.1
1991	1.6	1.6
1992 - on	2.0	2.0

(a) January 1982 dollars, not including land or land rights, owner's costs or transmission costs beyond the main wind farm switchyard.

TABLE 3.1. Bid Line Item Costs for Wind Energy Conversion System[a] (January 1982 dollars)

Bid Line Item	Construction Labor and Insurance	Construction Supplies	Equipment Repair and Labor	Equipment Rental	Permanent Materials	Total Direct Cost
1. Improvements to Site	97,700		159,000	85,800	112,500	457,000
2. Earthwork and Piling	3,200		4,000	2,500		9,700
3. Concrete	497,700	81,500	73,700	33,300	595,100	1,281,300
4. Structural Steel and Lift Equipment	564,800	1,900	105,100	99,000	10,100,000	10,870,800
5. Buildings	19,000				82,000	101,000
6. Turbine-Generator	195,600				25,000,000	25,195,600
7. Other Mechanical Equipment	3,800	600			83,200	87,600
8. Instrumentation	158,100	500			250,000	408,600
9. Electrical Equipment	569,300	15,000		8,000	1,622,800	2,215,100
10. Painting	22,100	2,300		300	75,000	99,700
11. Off-Site Facilities	12,400		19,700	10,600	272,500	315,200
12. Substation	221,400	11,500		5,000	742,100	980,000
13. Construction Camp Expenses	182,700	765,700				948,400
14. Indirect Construction Costs and Architect/Engineering Services[b]	668,600	5,212,400	154,400	46,800		6,082,200
SUBTOTAL	3,218,400	6,091,400	515,900	291,300	38,935,200	49,052,200
Contractors Overhead and Profit						4,400,000
Contingencies						8,800,000
TOTAL PROJECT COST						62,252,200

(a) The project cost estimate was developed by S. J. Groves and Sons Company. No allowance has been made for land and land rights, client charges (owner's administration), taxes, interest during construction, or transmission costs beyond the substation and switchyard.

(b) Includes $4,400,000 for engineering services and $1,682,200 for other indirect costs including construction equipment and tools, construction related buildings and services, nonmanual staff salaries, and craft payroll related costs.

TABLE 3.2. Payout Schedule for Wind Energy Conversion System (January 1982 dollars)

Month	Cost Per Month, Dollars	Cumulative Cost, Dollars
1.	1,528,900	1,528,900
2.	1,528,900	3,057,800
3.	1,853,000	4,910,800
4.	1,853,000	6,763,800
5.	1,733,500	8,497,300
6.	1,733,500	10,230,800
7.	1,104,700	11,335,500
8.	1,104,700	12,440,200
9.	1,104,700	13,544,900
10.	1,104,700	14,649,600
11.	1,104,700	15,754,300
12.	1,104,700	16,859,000
13.	8,714,700	25,573,700
14.	8,714,700	34,288,400
15.	8,847,700	43,136,100
16.	8,847,700	51,983,800
17.	8,898,500	60,882,300
18.	1,369,900	62,252,200

(including inflation) and subtracting a Gross National Product deflator series which is a measure of inflation. Materials and equipment represent about 93.4 percent of capital costs; labor about 6.6 percent.

3.1.4 Economics of Scale

At the present time, wind turbine systems reflect unitized costs for the major pieces of mechanical equipment and therefore these components would not reflect any economies of scale. However, with power plant capacities up to 80 MW (the maximum capacity of the recommended 138-kV transmission lines;

refer to Section 2.3), transmission line costs would show a substantial savings on a dollar-per-megawatt basis with increased plant capacity. Economies of scale could also be expected for many site development costs, including costs for temporary facilities, construction equipment, and construction labor. These savings could be brought about through more efficient scheduling of construction activities for a larger-sized system.

3.2 OPERATION AND MAINTENANCE COSTS

3.2.1 Operation and Maintenance Costs

The operation and maintenance costs for the 25-MW wind energy conversion system, expressed in January 1982 dollars, are as follows:

Fixed Costs	
Staff (3 Persons)	$92,000 (3.68 $/kW/yr)
Variable Costs	
Operating Supplies and Expenses	Nil
Maintenance Supplies and Expenses	3.3 mills/kWh

3.2.2 Operation and Maintenance Cost Escalation

Real escalation of fixed and variable operation and maintenance costs over the planning period is zero.

3.2.3 Economies of Scale

Costs associated with personnel salaries are generally the major economic item of operation and maintenance costs for energy-generating facilities. In light of this fact, economies of scale would result from larger-capacity wind farms because the personnel requirements would not increase in direct proportion to additional capacity, but rather at a slower rate.

3.3 COST OF ENERGY

Estimated busbar energy cost for the 25-MW wind farm is 103 mills per kilowatt-hour. This is a levelized lifetime cost, in January 1982 dollars, assuming a 1990 first year of commercial operation, and full utilization of the estimated annual power output of the facility. Estimated busbar energy costs for lower capacity factors and later startup dates are shown in Figures 3.1 and 3.2. Because the real escalation rate for O&M costs is zero, levelized costs will be the same as first (and subsequent) year costs. First year cost components are as follows:

Capital	98.5	mills/kWh
O&M	4.6	mills/kWh
Total	103.1	mills/kWh

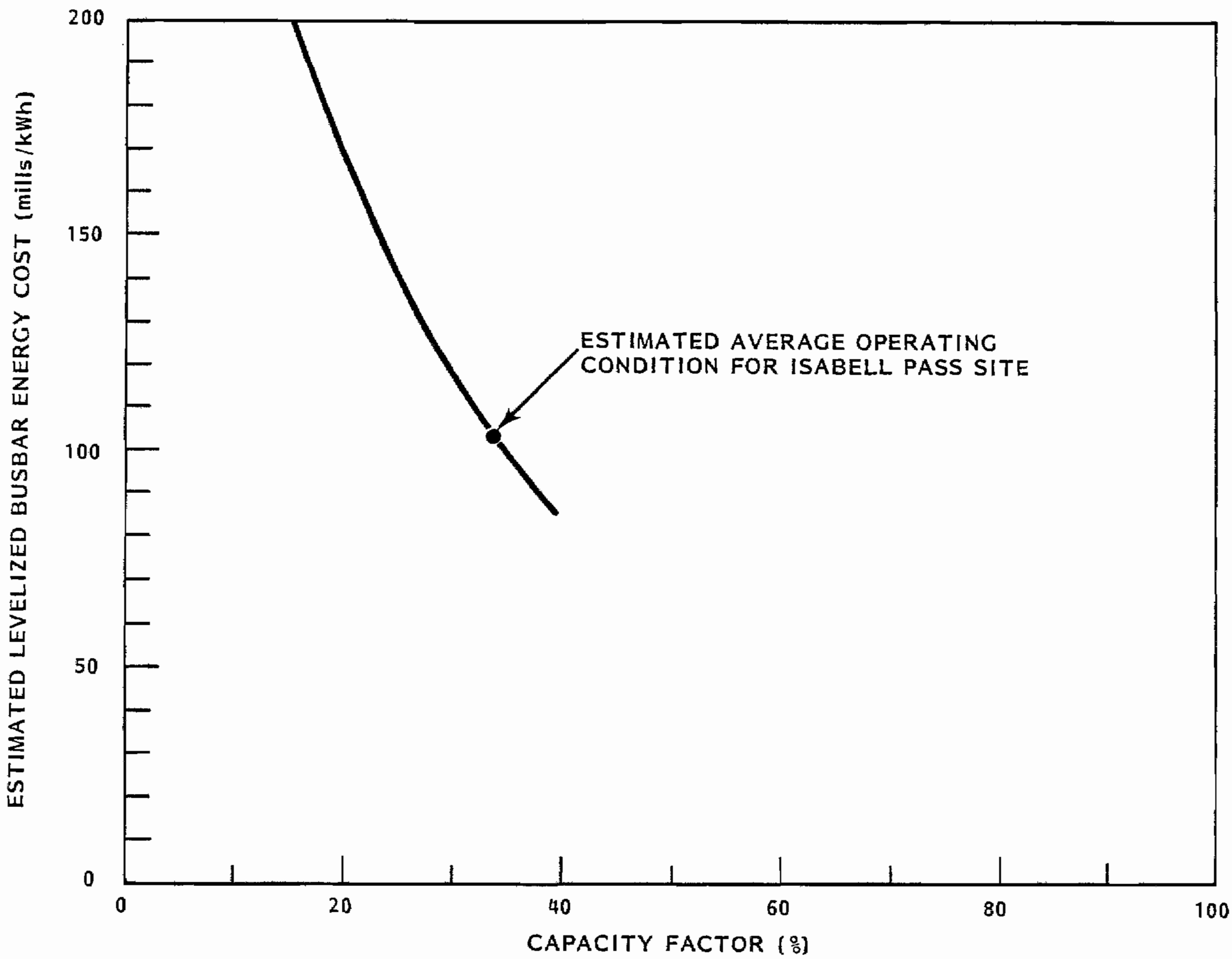


FIGURE 3.1. Cost of Energy Versus Capacity Factor (January 1982 dollars)

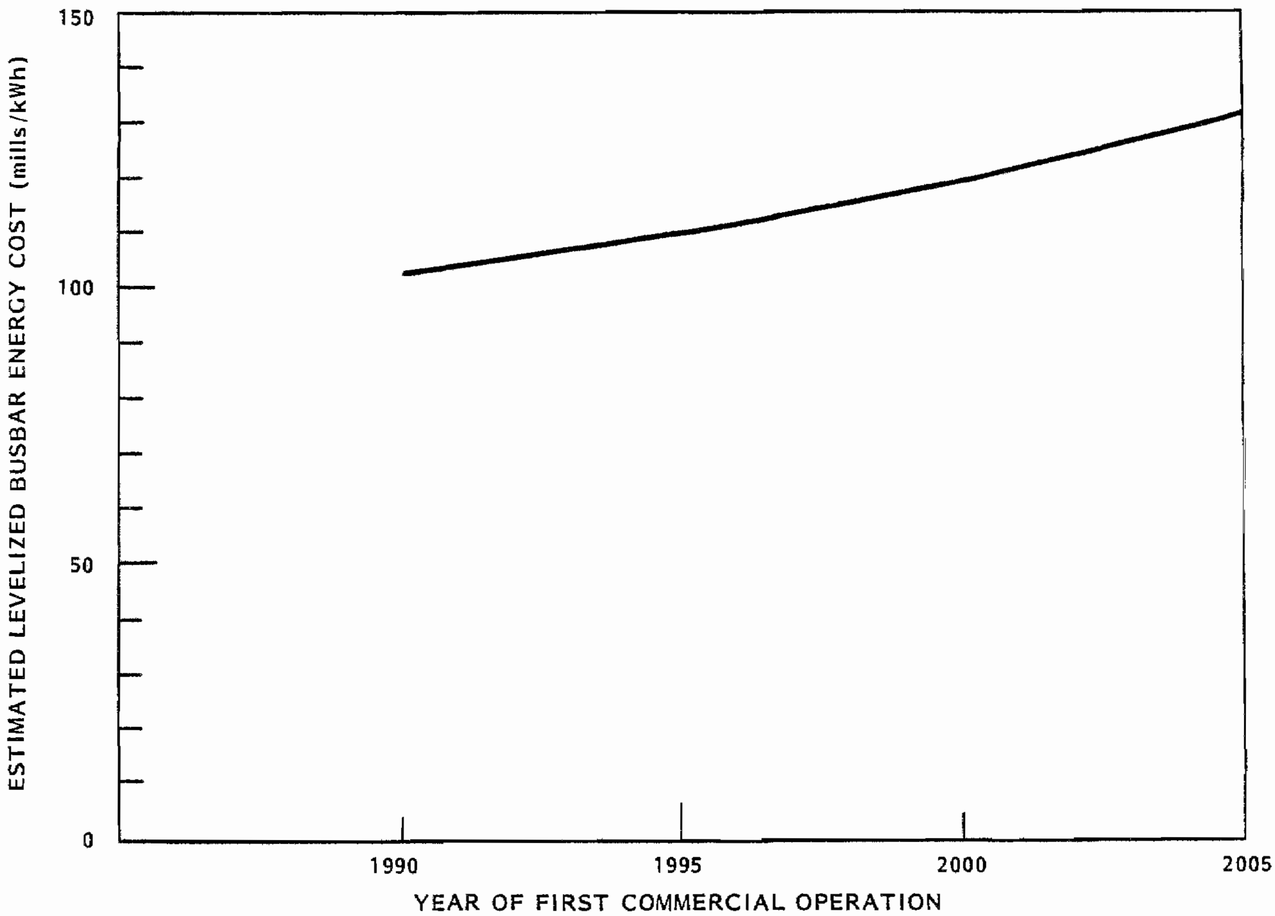


FIGURE 3.2. Cost of Energy Versus Year of First Commercial Operation (January 1982 dollars)

These costs are based on the following financial parameters:

Debt Financing	100%
Equity Financing	0%
Interest on Debt	3%
Federal Taxes	None
State Taxes	None
Bond Life	30 years
General Inflation	0%

The capital cost escalation factors given in Section 3.1 were employed. Weighted average capital cost escalation factors were derived using a labor/material ratio of 7 percent/93 percent.

Because wind turbine generators operate intermittently, they normally cannot receive capacity credit. Thus, the cost of energy estimates presented above should not be used in comparing this project with other generating projects considered in this study. The wind turbine generators discussed in this study should be evaluated as fuel-saver devices. The decision to build should be predicated on the cost of energy potentially displaced by operation of the wind machines, compared with the cost of energy produced by the wind machines. Thus, direct comparison of this project with alternative sources of generation is not properly done on the basis of busbar cost of energy alone, but instead should be done in the context of a system analysis. Such a system analysis has been done in Volume I of the Railbelt Electric Power Alternatives Study (Jacobsen et al. 1982).

4.0 ENVIRONMENTAL AND ENGINEERING SITING CONSTRAINTS

This section presents many of the constraints that would be evaluated during an engineering siting study. Special attention is given to the applicability of these constraints to the Railbelt Region, especially to the location considered in this study. The purpose of such an engineering study is to identify a preferred site and possibly viable alternative sites for the construction and operation of the wind farm. Through this optimization process, environmental and engineering considerations are minimized, which subsequently minimizes project costs. It should be realized that there may be a few constraints placed upon the development of a wind turbine power plant that are regulatory in nature and therefore the discussion presented in this section is complemented by the discussion in Section 6.0.

4.1 ENVIRONMENTAL SITING CONSTRAINTS

4.1.1 Water Resources

Water resource siting constraints generally center about two topics: water availability and water quality. The wind turbine has no significant water requirements or discharges. Hence, there are no major water-siting constraints anticipated. Problems with changes in runoff quality during site construction can be mitigated using proper engineering techniques.

4.1.2 Air Resources

There are no significant atmospheric discharges associated with a wind turbine generating facility. However, due to potential radio frequency interference, the plant should not be located in close proximity to important radio, television, or microwave transmission stations. This should not prove to be a significant constraint in the Isabel Pass Region. In addition, due to the vertical size of the structures, an attempt should be made to position the facility in a manner that does not hinder air traffic and is aesthetically pleasing.

4.1.3 Aquatic Ecology

The facility has no water intake or discharge requirements. Construction runoff would be mitigated through proper engineering. Engineering constraints would prevent location of the facility in a marshy area. Therefore, no aquatic ecology constraints are anticipated.

4.1.4 Terrestrial Ecology

Since habitat loss is generally considered to represent the most significant impact on wildlife, the prime terrestrial ecology siting activity will be an identification of important wildlife areas, especially critical habitat or threatened or endangered species. Based upon this inventory, exclusion, avoidance, and preference areas will be delineated and factored into the overall plant siting process. This identification would include location of any major flyways or areas frequented by birds, due to the collision potential with the rotating blades. As a number of important and sensitive species inhabit the potential site area (including moose, black bear, and perigrine falcons), appropriate consideration of these species and their habitat will be required during the plant siting process.

4.1.5 Socioeconomic Constraints

Major socioeconomic constraints center about potential land use conflicts, and community and regional socioeconomic impacts associated with project activities. Potential exclusionary land uses will include land set aside for public purposes, areas protected and preserved by legislation (federal, state, or local laws), areas related to national defense, areas in which a wind turbine installation or transmission line might preclude or not be compatible with local activities (e.g., urban areas or Indian reservations), or those areas presenting safety considerations (e.g., aircraft facilities). Avoidance areas will generally include areas of proven archaeological or historical importance not under legislative protection, and prime agricultural areas.

Regarding other socioeconomic concerns, minimization of the boom/bust cycle will be a prime criterion. Through the application of criteria pertaining to community housing, population, infrastructure and labor force, this important consideration will be evaluated and preferred locations identified. Due to the fact that the potential wind farm site is somewhat remote some boom/bust-related impacts on small population communities may occur. These should be relatively minor, however, as the peak work force requirement is only 140 and the site location is easily accessible to a number of moderate-sized communities such as Delta Junction.

4.2 ENGINEERING SITING CONSTRAINTS

The development of engineering criteria for use during the site evaluation process is necessary to minimize engineering and construction problems and, thereby, minimizing facility investment and operating costs. The development of the proposed wind farm could be constrained by a number of factors bearing upon the engineering aspects of the project. These factors, which are discussed below, include meteorological aspects, site topography and geotechnical characteristics, and access road distance.

4.2.1 Meteorological Aspects

Site selection of a wind turbine generating facility on a meteorological basis is critical to the successful operation of the facility. Clearly, a suitable site should have steady and strong winds, based on annual, seasonal, monthly and diurnal wind patterns. Locations with excessive periods of calm or gusts of wind exceeding the shutdown point must be avoided. The wind power density, a function of location, should be matched for the maximum efficiency point of the wind turbine. These considerations should be used to plot the specific site within a general area, and should be given prime consideration in the site-selection study.

Very good wind power (400 to 500 W/m^2) exists along exposed coastal and offshore areas of the Railbelt Region of Alaska. The wind power throughout interior Alaska and sheltered coastal regions (e.g., bays, inlets, and sounds in rugged terrain) appears quite low, except for mountains and isolated ridges. A few interior places show greater than 200 W/m^2; these are primarily canyons and valleys where the winds are enhanced by topography, such as the Isabel Pass Region considered in this study.

In general, potential wind power sites should be initially chosen based on large-scale wind power inventories that have already been performed over the State (AEIDC 1981). Further examination of potential sites should include site reconnaissance, qualitative topographic considerations, local inquiry, examination of aeolian features and selected qualitative observations during certain weather conditions. Ultimately, a wind monitoring system should be installed at each of the more favorable sites chosen from the above procedures. The monitoring program should include at least 1 year's data and the installation of wind sensors at a level of 60 feet or more above the surface. Other equipment, including recording devices, electric power, and the installation of a tower, may be required. An extensive intercomparison of all data monitored and a comparison with long-term data must be carried out. Selective relocation of monitoring systems and extended monitoring at some sites may also be required before a siting decision can be reached.

4.2.2 Site Topography and Geotechnical Characteristics

In general, the WTGs should be sited on relatively flat terrain. Rough terrain should be avoided. This will minimize the amount of required access grading and excavation and associated cost. It will also minimize the potential for adverse environmental impacts due to rainfall runoff transport of suspended solids to nearby waterways. The WTGs should also be sited above the 100-year floodplain of any major streams to avoid flooding incidents.

Another criterion is the avoidance of areas with unstable or poor soil conditions, as the towers will require a substantial foundation. Seismic activity can also be an important site-differentiating factor, with sites away from fault lines or in a region of low seismic activity preferred. The availability of suitable foundations for the wind turbine towers is a secondary constraint, which can usually be overcome by available engineering technology, but at higher costs than the cost estimates provided.

4.2.3 Access Road and Transmission Line Considerations

Due to the relatively small size (25 MW) of the project, construction of a long, major access road is not feasible from an economic point of view. However, the weight and size of components of the wind turbine precludes a conventional type of air-lift construction. Hence, the site should be constructed near the existing highway system so that access roads construction is minimized. Route selection will also be affected by soil and meteorological conditions; as permafrost, potential frost heave problems, and other soil-related characteristics can significantly add to the cost of road facilities.

In addition, consideration will need to be given to wind temperature and ice loading in design of the transmission line. This may further reduce feasible transmission distance due to line loss and economic reasons. One of the advantages of wind applications for Alaska is that very few production people are required on the site, and the electrical product can be economically delivered from the remote sites to the consumption points by means of high-voltage transmission lines or underwater cables. An important consideration in a feasibility study of a proposed wind farm in the area investigated in this study is the cost of the transmission link.

5.0 ENVIRONMENTAL AND SOCIOECONOMIC CONSIDERATIONS

5.1 SUMMARY OF FIRST ORDER ENVIRONMENTAL IMPACTS

The construction and operation of a 25-MW large wind turbine generating facility will impact the land, water, air, and socioeconomic environments in which it is located. These impacts are directly related to various power plant characteristics. A summary of these characteristics is presented in Table 5.1. These primary effects are then analyzed and evaluated in light of existing environmental conditions to determine the significance of the impact and the need for additional mitigative measures.

TABLE 5.1. Environment-Related Power Plant Characteristics

Air Environment	
Noise	Estimated less than 10 db above background at site boundary
RF Interference	Significant within 0.6 miles of the facility
Water Environment	No first order impacts
Land Environment	
Land Requirements	Approximately 60-125 acres, depending on final configuration
Socioeconomic Environment	
Construction Work Force	140 personnel (peak requirement)
Operating Work Force	1-3 maintenance personnel

5.2 ENVIRONMENTAL AND SOCIOECONOMIC EFFECTS

5.2.1 Water Resource Effects

Wind-driven turbine generators do not require water for operation, and therefore no first order water resource impacts are anticipated. Secondary impacts from rainfall runoff during plant construction can be mitigated by implementing proper construction practices.

5.2.2 Air Resource Effects

Wind turbine generators have small impacts on the atmospheric or meteorological conditions around the site. No effects on air quality are generated. The impacts relate to small microclimatic changes and interference with electromagnetic wave transmission through the atmosphere.

Wind turbines extract energy from the atmosphere and therefore have the potential of causing slight modifications to the surrounding climate. Wind speeds will be slightly reduced from surface levels up to a distance equivalent to approximately 5 rotor-diameters. Small modifications in precipitation patterns may be expected, but total rainfall over a wide area will not be impacted. Nearby temperatures, evaporation, snowfall, and snow drift patterns will be affected only slightly. The microclimatic impacts will be qualitatively similar to those noted around large isolated trees or tall structures.

The rotation of the turbine blades may interfere with television, radio, and microwave transmission. Interference has been noted witnin 0.6 miles of relatively small wind turbines. The nature of the interference depends on signal frequencies, blade rotation rate, number of blades, and wind turbine design. Due to the project location, this phenomenon is not anticipated to have a significant impact.

5.2.3 Aquatic Ecosystem Effects

Stream siltation effects from site and road construction are the only potential impacts associated with this technology due to the lack of operational process water requirements. Silt in streams may adversely affect feeding and spawning of fish. These potential problems can be avoided by proper construction techniques and should not be significant.

5.2.4 Terrestrial Ecosystem Effects

The greatest impact resulting from wind energy projects on terrestrial biota would be loss or disturbance of habitat that in the general site area is probably predominantly moist tundra with limited areas of spruce and hardwood forests. Wind-generating structures can furthermore impact migratory birds by increasing the risk of collision-related injury or death. One endangered species, the peregrine falcon, is known to exist in the region. However, it has been estimated that the chance of a bird being struck by a large two-blade machine, assuming no evasive action by the bird, is less than 15 percent. Hence, this collision risk is not very large.

Another potential impact is low-frequency noise emanating from the generators. However, from reports on existing facilities, this noise is minimal, barely perceptible at any distance above ambient wind noise. Sound generation outside the human audible range, however, remains to be investigated, and impacts are therefore possible.

5.2.5 Socioeconomic Effects

Construction of a 25-MW wind turbine system and associated transmission lines would require a relatively small work force with a peak requirement of approximately 140 personnel. This would create some minor impacts on the small surrounding communities, but would not significantly alter the communities infrastructures as long as the work force was not concentrated solely in one community. The wind turbine facility requires a very small operating work force, and has minimal maintenance requirements. Therefore, once the facility is operational, impacts to the surrounding communities are not anticipated.

The cost breakdown for a wind turbine investment is based on the assumption that the monitoring field work, site preparation, and installation would be performed by Alaskan labor and that all components would be imported from outside manufacturers. Therefore, approximately 80 percent of the capital expenditures would be spent outside the region, while 20 percent would remain within Alaska. The allocation of operating and maintenance expenditures would be 15 percent spent outside the Railbelt Region and 85 percent within the Railbelt. The high percentage of costs allocated to outside maintenance would be offset to some extent by the small requirements for supplies.

6.0 INSTITUTIONAL CONSIDERATIONS

The technology of a large wind turbine system is still in the developmental stage, with experimentation being performed in both the public and private sectors. The diverse technologies being developed could be subject to distinct sets of institutional considerations in the future. Currently, however, governmental control of wind turbines as sources of energy is limited, as evidenced in the discussion below.

6.1 FEDERAL REQUIREMENTS

On the federal level, construction of a wind power system would not be subject to the requirements of the major environmental regulatory programs traditionally associated with new energy production facility projects. As the system would not produce air or water pollutants, it would not require PSD or NPDES permits issued by the EPA. (Note: an NPDES permit may be required for construction runoff). Unless excavation during construction would uncover hazardous wastes in the soil that must then be disposed of, the project will also fail to produce hazardous wastes that would require compliance with EPA's hazardous waste management program under RCRA. Since the project would not require construction in navigable waterways or the discharge of dredged or fill material, it would be free from compliance with the environmental regulatory programs implemented by the Army Corps of Engineers. The system would also not be covered by any environmental controls imposed upon energy generators, as no federal agencies license the construction of wind power generating systems (i.e., there is no permit equivalent to that issued by FERC for hydroelectric power operations).

As a result of the fact that none of the major federal regulatory programs apply to the construction of a wind turbine system, the activity will probably not be subject to the requirements of NEPA. The requirement in NEPA that an environmental impact statement be prepared for a project is placed upon federal agencies to insure that they consider the environmental impacts of any action they may take. Based upon the information currently available, it does not appear that any federal agency will be performing a major action of the sort that invokes NEPA responsibility with respect to this project.

It should be noted, however, that federal agencies could have some impact upon project siting. For example, the Federal Aviation Administration (FAA) controls the location of structures within navigable airspace. To protect aircraft, the FAA imposes marking requirements on structures that are either 200 feet or more in height or located in the vicinity of an airport. The 200-foot towers currently proposed for construction at Isabel Pass would be subject to FAA requirements.

Federal regulatory authorities may also become involved in reviewing a wind turbine project if it is located on federal land. A large percentage of Alaska's 375 million acres is owned by the federal government. Permission will have to be obtained for use of or access to that land. For example, a special permit is required for persons wishing to gain access to or through federal lands under the jurisdiction of the Bureau of Land Management (BLM). In addition, the site could be located on part of the 103,866,899 acres in Alaska that have been set aside as national parks, monuments, preserves, forests, or wild and scenic rivers, in which case development of the land may be restricted depending upon the land use classification. Limited access can be obtained to those areas from the Department of Interior or the Department of Agriculture.

As the construction and operation of a wind turbine system are not subject to any major environmental regulatory programs, owners and operators of the system may not be involved in a licensing process for the system. The review and approval of the project by federal agencies and the processing of state permits can probably be completed in less than 1 year. A summary of potentially applicable federal regulatory requirements appears in Table 6.1.

6.2 STATE REQUIREMENTS

The primary regulatory requirements that will be imposed upon a wind turbine system at the state level are those imposed upon the control of use of state lands such as the 182,800,000 acres the State of Alaska was given the

TABLE 6.1. Federal Regulatory Requirements

Agency	Requirement	Scope	Statute or Authority
Environmental Protection Agency	Hazardous Waste Management Permit Facility Operation	Hazardous Waste	42 USC 6901 *et seq.*; section 6925
Forest Service	Special Use Permit	National Forests	36 CFR 251
Bureau of Land Management	Rights-of-Way for BLM Lands	Access to Federal Lands	43 USC 1701 *et seq.*;
Fish and Wildlife Service	National Wildlife Refuge	Access to Federal Lands	50 CFR 26
	Threatened or Endangered Species Review	Air, Water, Land	16 USC 1531 *et seq.*
Advisory Council on Historic Preservation	Determination that Site is not Archeologically Significant	Land Use	16 USC 402 aa *et seq.*
	Determination that Site does not Infringe on Federal Landmarks	Land Use	16 USC 416 *et seq.*
Federal Aviation Administration	Air Navigation Approval	Air Space	49 USC 1304, 1348, 1345, 1431, 1501

opportunity to acquire under the Alaska Statehood Act. Examples include an access route permit to gain an easement across state lands or waters, or the special land use permit needed to construct structures on state lands or waters.

State regulatory authorities may have some impact on the location of the wind turbine project even if the site is on private lands. These permits are presented in the list given in Table 6.2. Examples include the permit for development of areas that are critical habitats of fish and wildlife, and the solid waste disposal permit issued by the Alaska Department of Environmental Conservation in the event that hazardous wastes are generated during construction.

TABLE 6.2. State Regulatory Requirements

Agency	Requirement	Scope	Statute or Authority
Alaska Department of Environmental Conservation	Solid Waste Management Facility Operation	Solid Waste	Alaska Statute 46.03.100
Alaska Department of Fish and Game	Critical Habitat Area Permit	Land Use	Alaska Statute 16.20.230
State Game Refuge Land Use Permit	Land Use Permit	Land Use	Alaska Statute 16.20.010
Alaska Department Natural Resources	Leasing of State-owned Lands for Other then Natural Resource Extraction	Land Use	Alaska Statute 38.05.070-107
	Access Route Permit to State Lands or Waters	Land Use	Alaska Statute 41.20.020 and 040
	Special Land Use Permit for State Lands of Waters	Land Use	Alaska Statute 41.20.020 and 040
	State Park Non-Compatible Land Use	Land Use	Alaska Statute 41.20.020 and 040

6.3 LOCAL REQUIREMENTS

The most intensive controls could be those imposed on the local level where zoning ordinances may strictly control land use in the community. Some communities in the United States have even enacted ordinances specifically controlling the location of wind turbine systems. Discussions with municipal officials of Delta, Alaska, revealed that apparently no zoning ordinances exist for the area in the vicinity of Isabel Pass, north of Paxson. In the event that this technology is selected, further investigation can be conducted to determine whether controls may be imposed on a borough level from Glennallen. The likelihood that such controls exist, however, is not great.

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