PN-ABA-436

RENEWABLE ENERGY RESOURCES
FIELD TESTING

CONCEPTUAL DESIGN FOR FIELD TEST #11

WIND FARM AT RAS GHAREB

JUNE 1986

FINAL

Prepared for

Egyptian Electricity Authority
Cairo, Egypt

U.S. Agency for International Development
USAID Mission: Cairo, Egypt

Submitted to

Louis Berger International, Inc.
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FOREWORD

The Egyptian Electricity Authority (EEA), United States Agency for International Development (USAID/Cairo), and a group of U.S. consultants form a team responsible for conducting field test demonstration projects for eleven renewable energy applications in Egypt. These demonstration projects include the use of photovoltaic, wind and solar thermal systems for water pumping, ice making, desalination, industrial process heat and grid connected electricity generation. The specific objectives of the 4-year program are: (1) to demonstrate the viability of renewable energy technologies in Egypt, (2) to comprehensively strengthen Egyptian techaical and institutional capabilities in the full spectrum of renewable energy planning and decision making, and (3) to establish the infrastructure necessary to ensure that renewable energy technologies, which have proven successful, are available for widespread use in Egypt.

Three of the eleven potential field test demonstration projects are wind energy system applications. Each of the field tests contains seven generic tasks: Technology Review, Application Review, Conceptual Design, Preparation of a Statement-of-Work for a Tender Document, Proposal Evaluation, Supervision of Hardware Installation and Performance Evaluation. The Conceptual Design for one of these three field tests, a grid-connected wind farm, is presented in this document. The proposed wind farm is sited near Ras Ghareb on the Red Sea and will consist of multiple, interconnected turbines with a total peak power of approximately 250 kW. The system is designed to operate in a fuel-saver mode for an existing power station and provide electricity to an existing transmission grid. This document is Subtask 3.11.3 of the field test requirements under Contract AID 263-123C-00-4069-00, Task Area 3.

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LIST OF EXHIBITS

1.0 EXECUTIVE SUMMARY

This document presents the conceptual design for Field Test #11, a 250 kilowatt wind farm at Ras Ghareb on the Red Sea coast. The general concept of the wind farm is to generate electricity that will be fed into the existing 6.6 KV grid at Ras Ghareb. In this manner, the wind farm is essentially being used in a "fuel-saver" mode, i.e. the oil and gasfired turbines currently used to generate electricity will have their run-time reduced because the wind-generated electricity will meet part of the Ras Ghareb demand.

The results of this conceptual design study to size the wind farm and to provide specifications for a tender document and a system acceptance test are:

- Maximum size of approximately 400 kilowatts rated power
- Minimum size of approximately 250 kilowatts rated power
- Turbine availability of 90 percent
- Minimum annual energy production of 625,000 kilowatt-hours

It should be noted that the specification for a minimum annual energy production will be revised for the release of a statement-of-work in a tender document based on an updated wind resource assessment provided by Battelle Pacific Northwest Laboratories.

The candidate wind farm conceptualized in this document consists of five 50 kW wind turbines interconnected through a single control box that generates 250 kilowatts of power at a rated wind speed of approximately 15 meters/second. One possible turbine uses a 6.7 meter (22-foot) fixed pitch rotor, the simplest and most reliable rotor design option. To work effectively, the fixed pitch rotor must operate at a relatively constant speed. This can be achieved by coupling the rotor to a 3-phase induction generator tied directly into the utility line power (after necessary protection switchgear are used).

The wind turbine in this example employs two separate braking systems to greatly reduce the possibility for a single failure to cause a hazardous situation. Tip speed brakes are employed that automatically limit rotor speed to negate an overspeed condition. The speed brakes are deployed mechanically by centrifugal force associated with an overspeed condition. The primary braking system, however, is a two-stage electrodynamic brake.

The five turbines can be mounted on 80 foot (24.4 meter) galvanized, self-supporting, steel lattice towers, however, care must be taken to insure that the tower can withstand the apparently corrosive environment at Ras Ghareb. This type of tower is a reasonable compromise between ease of maintenance, cost, and potential for local fabrication in future installations throughout Egypt.

An engineering cost estimate for this possible wind farm is presented in Appendix A.

2.0 OBJECTIVES AND BACKGROUND

2.1 Project Objectives

The Egyptian Electricity Authority (EEA), USAID/Cairo, and a group of U.S. consultants form a team responsible for conducting field test demonstration projects of eleven renewable energy applications in Egypt. These include the use of photovoltaic, wind and solar thermal systems for water pumping, ice making, desalination, industrial process heat and grid connected electricity.

Three tasks are planned:

(1) Field Tests - Assess some selected renewable energy systems/applications which could be suitable for commercial use in Egypt; develop detailed engineering design hardware specifications and system performance requirements; prepare RFP packages for procurring equipment; supervise the work of hardware contractors; and collect and evaluate data generated from the field tests.

(2) Supporting Analysis - Conduct technical, social, financial, economic, and market analyses of renewable systems related to the field tests. Develop a computer based Renewable Energy Information System (REIS).

(3) Training - Improve the skills of the GOE and the private sector in evaluating renewable technologies, applications, economics and markets and provide technical asistance in system design, installation, operation and maintenance.

This project, the Renewable Energy Resource Field Testing Project, provides an opportunity to:

1. Comprehensively strengthen Egyptian technical and institutional capabilities in the full spectrum of renewable energy, planning decision-making technologies and applications;

2. Develop and sustain an Egyptian renewable energy infrastructure through establishment of data bases, information systems and organizations that effectively serve both the public and private sectors;

3. Design, install, operate and evaluate the performance of a series of field tests which utilize commercially available technologies in applications having potential for widespread use in Egypt.

4. Conduct a formal management and technical training program, both on-the-job and specialized, and establish an intensive information dissemination program.

2.2 Project Background

Each of the 11 field tests contains seven general tasks which include site visits to obtain user requirements and site-specific operational data, the gathering and analysis of hardware/manufacturer data, and the development of conceptual designs and system performance specifications. Supporting field test activities include preparation of RFP packages, evaluation of responses, coordination and oversight of the system installation by field test project subcontractors and check-out and monitoring of system performance.

Three of the eleven potential field test demonstration projects are wind energy system applications:

- Village Power - A number of small wind turbines (4 kWp to 25 kWp) and/or wind turbine/diesel/battery hybrid systems will be designed as stand-alone systems or interconnected with existing power distribution systems.
- Desalination - A cluster of wind turbines will be interconnected to supply power for a desalination system near the Hurghada Marine Institute on the Red Sea.
- Grid Electricity - A 250 kWp wind farm will be built near Ras Ghareb on the Red Sea. The system will operate in a fuel-saver mode for an existing power station and provide electricity to an existing transmission grid.

The proposed grid electricity application at Ras Ghareb (Field Test #11) is based on (1) the significant growth in the wind system industry and in particular the success of wind farms in the U.S., (2) the belief that the growing energy demand of settlements along the Red Sea coast, a windy region of Egypt, should consider wind energy systems as a possible renewable energy supply component in a mix of power systems for the generation of electricity, and (3) the historic base, supplemented by recent measurements, that indicates a significant wind resource in many parts of Egypt.

2.3 Description of Field Test #11

This field test is to demonstrate the feasibility of multiple wind turbines (wind farm) interconnected with a local electrical grid distribution system. The Egyptian Electricity Authority (EEA) and USAID/Cairo established that the peak capacity of the wind farm should be approximately 250 kilowatts. The proposed location for the wind farm was the village of Ras Ghareb on the Gulf of Suez across from the southern tip of the Sinai, approximately 320 kilometers from Cairo (Appendix B). The system sizing and specific location for this field test were based on a preliminary analysis of regions in Egypt where stable local grids and an historically good wind resource co-existed. These factors were investigated in detail during a site visit by personnel from the EEA and the the U.S. Project Team on May 14-15, 1985.[1] An analysis of the application based on data obtained during the site visit is presented in the Field Test #11 Application Review submitted on February 5, 1986.

2.4 Intent of the Conceptual Design

The Conceptual Design subtask evolves from activities in support of the Application Review, the Technology Review and the identification and quantification of system performance specifications, and hardware specifications where appropriate, which will become a major portion of the Statement-of-Work. The Annual Operating Plan (AOP) for the REFT Project, dated May 1985, specifies that the conceptual design activities "establish technical objectives, develop a system design data base, and screen candidate system designs to establish a system sizing and operating baseline that satisfies site-specific operational, environmental and user requirements."

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[1] In attendance for the U.S. Project Team were Peter Borgo of Meridian Corporation and Seyoum Solomon and David Tyler of Louis Berger International, Inc. In attendance for the EEA were Eng. Mohamed Mitwally El-Sayed and Eng. Nagi Gowli. Discussions were held with Eng. Ibrahim Aly, the Area General Manager for the General Petroleum Company (GPC), Eng. Wahid Madbouli, a manager in the Electrical Engineering Department for GPC and various members of their staffs.

Specific subtask statements in the AOP specify that the conceptual design shall:

- o Develop site specific energy source profile and application specific load demand profile
- o Define hardware performance and environmental specifications
- o Conduct system sizing and performance trade-off analyses
- o Specify monitoring instrumentation requirements.

These tasks were completed as part of the Application Review and Technology Review activities, in conjunction with visits to the U.S. of Egyptian engineers from the EEA and the General Petroleum Company, the future operator of the wind farm. Elements of the conceptual design described in this document appear in the Application Review and the Technology Review submitted in February 1986 as follows. Appropriate data from these documents will be included in the Statement-of-Work (SOW) for this field test.

- o A site specific energy source profile and an application specific load demand profile are included in the FT #11 Application Review
- o Hardware performance and environmental specifications are included in the FT #11 Application and Technology Reviews
- o System sizing and trade-off analyses are summarized in the Application Review for FT #11 from data published as a separate document in August 1985
- o Field test monitoring instrumentation requirements are included in the Technology Review for FT #11 and Appendix C of this document.

3.0 APPLICATION REVIEW SUMMARY

3.1 Field Test Criteria

An assessment of the contribution of this specific field test to the REFT Project objectives must consider the criteria necessary for a successful demonstration of any grid-connected wind farm. These criteria are comprehensively listed below, although not necessarily in the order of importance.

1. Current and future user needs
2. Size and stability of the local electrical grid
3. Evidence of a viable wind resource
4. Availability of proven and reliable commercial systems
5. Appropriate site characteristics and infrastructure for installation
6. Capability of the host organization for successful operation and maintenance of the systems
7. Potential for widespread use including social, economic and institutional aspects

3.2 Current and Future User Requirements

The village of Ras Ghareb is supplied with electrical power from two power plants, one operated and maintained by the General Petroleum Company (GPC) and one by the Egyptian Electricity Authority (EEA). The GPC power plant has two 3-MW Sulzer gas turbines to meet an average 2.7 MW load demand. The EEA power plant consists of two new Sulzer 5-MW gas turbine. This power generation mix provides a stable, reliable source of electricity for the Ras Ghareb region.

The GPC is planning for a significant growth in the next few years in the industrial load demand in the Ras Ghareb region as new oil fields are developed and interconnected with the existing grid. This growth will increase the baseline demand to more than 3 MW and require the installation of a 5-MW Japanese gas-fired turbine which is currently undergoing check-out tests.

The EEA is cognizant of the expected growth in electrical demand projected for the Red Sea coast. EEA intends to monitor the performance of this wind farm demonstration project to assess the potential for additional wind farms in the region. If wind power is a viable alternative energy source, the EEA would re-allocate existing gas turbine generators to balance regional electricity generating capacity as wind generated power comes on-line.

3.3 Size and Stability of the Local Grid

A large, stable power generation/distribution grid exists at Ras Ghareb which should be able to interface with a 250 kilowatt wind farm. There also appears to be sufficient flexibility in the existing power generation mix to incorporate wind systems as they come on-line.

3.4 The Wind Resource at Ras Ghareb

There are two major historical sources of wind characteristics data for the Ras Ghareb area which indicate an average wind velocity of 6.4 (4 month average) to 7.3 (annual average) meters/ second. This is a sufficient wind velocity for the generation of electricity using wind turbines.

In general, a wind resource is very site dependent, both spatially and temporally. Therefore, it is very important that wind velocity data be validated and collected as near to the actual turbine site as possible and for an extended period of time. In support of Field Test #11, USAID/Cairo has contracted with Battelle Pacific Northwest Laboratories to conduct a wind resource assessment of Egypt. Measurements have been recorded at the proposed wind farm site since March 1985. These data will be analyzed for a period of one year.

For the period April - September 1985, these data indicate an average wind speed of 9.2 meters/second at 10 meters above ground level and 9.6 meters/ second at 20 meters above ground level. This is an excellent wind resource and is comparible to areas in California where commercial installations of wind turbines are found.

3.5 Availability of Proven and Reliable Commercial Systems

Due to the intermittent nature of the wind, the generation of electricity from the wind will vary considerably with time. As a result, wind generated electricity should supply only a small percentage of a given load. In general, the size of a wind farm is usually limited to between 10 and 15 percent of a user's load demand. For the Ras Ghareb application, this results in a wind farm with a peak power of approximately 250 to 400 kilowatts.

A preliminary wind farm conceptual design sizing study was completed in August 1985. Based on the results of this study and consideration of the overall REFT Project objectives, it is proposed that the first wind farm field test demonstration in Egypt be an installation of a reasonable number of inter-connected and commonly controlled turbines connected to an existing electrical grid. Therefore, the Ras Ghareb wind farm should consist of between 5 and 15 wind turbines each producing between 20 and 65 kilowatts peak power for a total of between 250 and 400 kilowatts.

All of the hardware systems required to complete a grid-connected wind farm application are technologically mature, of proven operation and commercially available.

3.6 Salient Issues and Needs

The proposed wind farm site at Ras Ghareb is located along a ridge line at an elevation of approximately 42 meters above sea level. The site is in a treeless coastal desert region and presents an unobstructed view to the prevailing northwest winds. Site preparation in the form of civil work to level the site will be required. An access road capable of transporting heavy equipment (turbines, towers, cement trucks, cranes) will also be required. A soil analysis should be completed as soon as possible to provide data on soil strength so that an assessment on the specifications and cost of the road can be made.

Also soil strength data will be required prior to the preparation of the statement-of work so that bidding contractors can accurately cost the turbine/tower foundations.

A key factor in the success of a wind farm field test demonstration is the ability of the host organization to successfully operate and maintain the system. The GPC engineers and technicians are accustomed to maintaining large rotating machinery, both megawatt size gas turbines and numerous diesel engines. They also have installed and continue to maintain their own electrical transmissio grid, including transformers and switch gear. With sufficient training, which is a part of this field test, it is expected that GPC personnel could operate and maintain a wind farm.

3.7 Status of Agreements and Responsible Agencies

An agreement has been signed by EEA and GPC regarding responsibilities and approval for the wind farm at Ras Ghareb. A review of these agreements between USAID, the EEA and the GPC should be undertaken to insure that the decision to proceed or not with this field test is based on an accurate appraisal of the existing situation as specified in this Conceptual Design document. This includes concurrence by all parties that the field test as specified in the Field Test #11 Application Review is acceptable, that all responsibilities of participant are clearly specified and understood, and that required site preparation and civil works can be completed in a timely fashion.

3.8 Conclusions and Recommendation

The findings in the Field Test #11 Application Review support a strong recommendation to proceed with this field test demonstration. All the necessary criteria for a successful wind farm installation appear to be satisfied at the Ras Ghareb location as follows:

1. The current and future electricity needs of the Ras Ghareb region are supplied by a stable grid that should be able to accept a 250 kilowatt wind farm.

2. The wind resource is excellent, averaging 9.6 meters per second at a 20-meter height from April through September 1985

3. System hardware that is proven and reliable is available from numerous sources

4. There does not appear to be any difficulty in siting and installing the wind system hardware at Ras Ghareb.

5. There appears to be a cadre of engineers and technicians employed by the local GPC operations that can be trained to operate and maintain the windfarm.

Recommendation

1. A grid-connected windfarm of approximately 250 kilowatts should be designed, purchased and installed at Ras Ghareb.

4.0 TECHNOLOGY REVIEW SUMMARY

Wind system hardware performance is rapidly improving after a generally poor showing by early turbine installations in the late 1970's. Measured energy production data from U.S. wind farm applications indicates availability factors (the percent of time that the wind turbine is able to operate when the wind velocity is above the turbine cut-in velocity) in 1984-1985 of 95 to 97 percent with capacity factors (ratio of energy production to total estimated production at rated power output) in 1984-1985 of 8 to 35 percent.

A separate Technology Review document for this field test and a more general Wind Energy Technology Reference Notebook were published in January 1986 and June 1985, respectively. The Technology Review details system component technology, vendor experience and issues concerning specific applications in Egypt. The following summarizes the major findings.

<u>Rotor</u> - Major performance variations in turbine output generally involves rotor design. Popular materials for blade construction are wood, fiberglass and aluminum. Numerous manufacturers make rotors that are proven in operation over the past 5-years. Wooden or fiberglass blades appear to be most suitable for Ras Ghareb because of apparent corrosion problems with metals.

<u>Transmission</u> - Almost all currently operating wind farm machines contain a step-up gearbox between the rotor and the generator. Most wind turbines use helical or planetary gearboxes, with gear ratios ranging from 14:1 to 25:1. Gearbox technology is well understood and used in operational wind farms. Both helical and planetary gearboxes are appropriate for the proposed wind farm at Ras Ghareb.

<u>Generators</u> - Generators used in wind farm turbines are one of three standard types - synchronous, induction or direct current generators. The majority of turbines currently in operation in the U.S. wind farms use induction generators. Generators are standard systems in use throughout the world in wind farm and other applications for the generation of electricity. Any of the three types could be used at Ras Ghareb, although induction generators seem most suitable since they interconnect directly with the grid, require grid power for operation (safety feature) and are used in the majority of successful wind farms worldwide.

<u>Controls</u> - Turbine controls are an important component for optimizing system performance. Turbine control prevents rotor overspeed in high winds and allows turbine operation during cut-in and cut-out wind speeds. Control methods currently used are blade pitch angle control, turbine

yaw control and rotor braking. Many different control systems exist from numerous manufacturers. Rotor braking appears to be the simplest and most practical for application at Ras Ghareb.

Monitoring - Wind farm monitoring systems are essential for providing information on such critical wind farm performance variables as output, energy production, availability, machine status, and wind speed and direction. Systems include a data collection unit to collect information from one or more turbines and a computer to process the data. A number of types are commercially available. Detailed specifications for this equipment appear in Appendix C.

Interconnection - Equipment required for safe connection of a wind farm to a utility grid includes transformers, switchgear, relays and suppressors. This equipment is standard in the electric utility industry. What distinguishes the application of this equipment in grid-connected wind farms is the fact that the power flow is extremely transient. Some of the major concerns with such applications are: Safety for operating and service personnel, and equipment; transient and dynamic stability behavior; the effect of power variability on system dispatch and unit commitment; optimum bus configuration and voltages for array interconnection; and array control. Ras Ghareb appears to have no unusual interconnection problems.

Requirements for utility interconnect are resulting in significant hardware development of power conditioning equipment. Stringent requirements for phase control, voltage regulation and safety have resulted in improvements in inverters, generators and control systems.

The growth of wind farms is the most encouraging indicator of industry progress and technology maturity. At least 50 developers have installed wind farms in the U.S. to sell electricity to more than 15 utilities; approximately 8800 machines totalling almost 1,000 megawatts of capacity were installed at the end of 1985. This is an increase from about 1700 machines and 70 megawatts at the end of 1982. As a result of the industry's growing experience, the cost of energy production from wind farms has declined from about U.S. $0.25/kWh in 1977 to about U.S. $0.10/kWh to $0.12/kWh in 1985.

5.0 CANDIDATE CONCEPTUAL DESIGN

5.1 Design Approach

In August 1985, engineers from Meridian Corporation, the EEA and the GPC conducted a joint analysis to investigate the desired size and estimated energy production of a wind farm at Ras Ghareb that would satisfy the objectives of this field test.[2] The study methodology was to evaluate the performance of wind turbines manufactured by different U.S. companies in the wind resource measured at the Harbor Station at Ras Ghareb in 1983. The evaluation was performed using a wind system performance computer model developed by Meridian Corporation.[3]

A wind farm sizing limitation of between 10 and 15 percent of a base-line load demand suggests a maximum wind farm size of approximately 400 kilowatts for Ras Ghareb. A more conservative size would be 10 percent of the average expected minimum power demand or approximately 250-275 kilowatts peak. This limitation will be investigated for the Ras Ghareb application by careful monitoring of the voltage and frequency stability of the grid during this field test as wind generated power is introduced.

Using the singular measure of peak kilowatts of wind generated power is not always sufficient to determine the effect of a wind farm on a particular grid distribution system. An equally important parameter is the level of energy in kilowatt-hours that is introduced into the distribution system at any given time. For example, a 10 percent wind energy component of a power generation mix (based

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2 Estimated Power Production From a Wind Farm at Ras Ghareb, Egypt, August 1985, Egyptian Electricity Authority, General Petroleum Co. and Meridian Corporation.

3 "Wind Energy System Performance Model-Users Manual," March 1983, Meridian Corporation.

on peak kilowatts) can have a large impact on total energy produced (in kilowatt-hours) during periods when there is a low load demand and the wind velocity is high. Consideration must be given to the level and variability of a relatively continuous baseline load demand for a specific application when the wind system component is being sized.

In summary the results of this conceptual design study are:

- o Maximum size of approximately 400 kilowatts rated power
- o Minimum size of approximately 250 kilowatts rated power
- o Turbine availability of 90 percent
- o Minimum annual energy production of 625,000 kilowatt-hours

It should be noted that the specification for a minimum annual energy production will be revised for the release of a statement-of-work (SOW) in a tender document based on an updated wind resource assessment provided by Battelle Pacific Northwest Laboratories.

Additional factors in the conceptual design approach are the consideration of the performance and environmental specifications that the system hardware must meet and the method to be used for a system acceptance test. The following are specifications that influence the conceptual design. They will appear in the Draft-For-Comment copy of the SOW.

Energy Production and System Acceptance Test

Energy production from the wind farm must be demonstrated by operation of the wind farm with on-site contractor personnel for an acceptance testing period of 30-days after it is designated operational by EEA/USAID. This designation will be based on the contractor's certification that the wind turbines and control system are operational and the EEA's certification that the interconnect with the existing grid is completed. The wind farm must achieve a 90 percent availability during the system acceptance test.

In addition, daily energy production for each turbine during the continuous 14-day period must be no less than 90% of the manufacturers performance estimate provided in the proposal. The performance comparison will be based on measured average daily wind speed for each applicable day during the 30-day performance period. A curve such as that shown in Exhibit 5.1 will be used to compare the manufacturer's performance specification for each turbine with the measured power production.

Control System

The wind turbines shall employ fail-safe controls to protect the rotor from overspeeding in winds greater than its rated speed. The control system shall provide for automatic starting when the wind speed reaches cut-in velocity. The control system shall also provide for automatic restarting when the wind speed drops below the cut-out value. A manual control for shutting the machine down to allow for system maintenance and repair shall be a part of the control system.

Electrical Tolerances

The following tolerances must be met to be deliver power of acceptable quality:

Frequency	50 Hertz $\pm$ 0.5%
Voltage	380 volts $\pm$ 0.5%
Power Factor	Minimum of .80 lagging (approximately the existing average power factor at Ras Ghareb)
Harmonics	Maximum of 3% of the fundamental

Electrical Interface

All electrical connectors and terminals including slip rings must have high resistance to temperature, dust, and corrosion. Other factors such as lightning arrestors, and safety features (breakers, fuses, etc.) must be compatible with EEA electrical codes and be located at ground level for easy operation and maintenance.

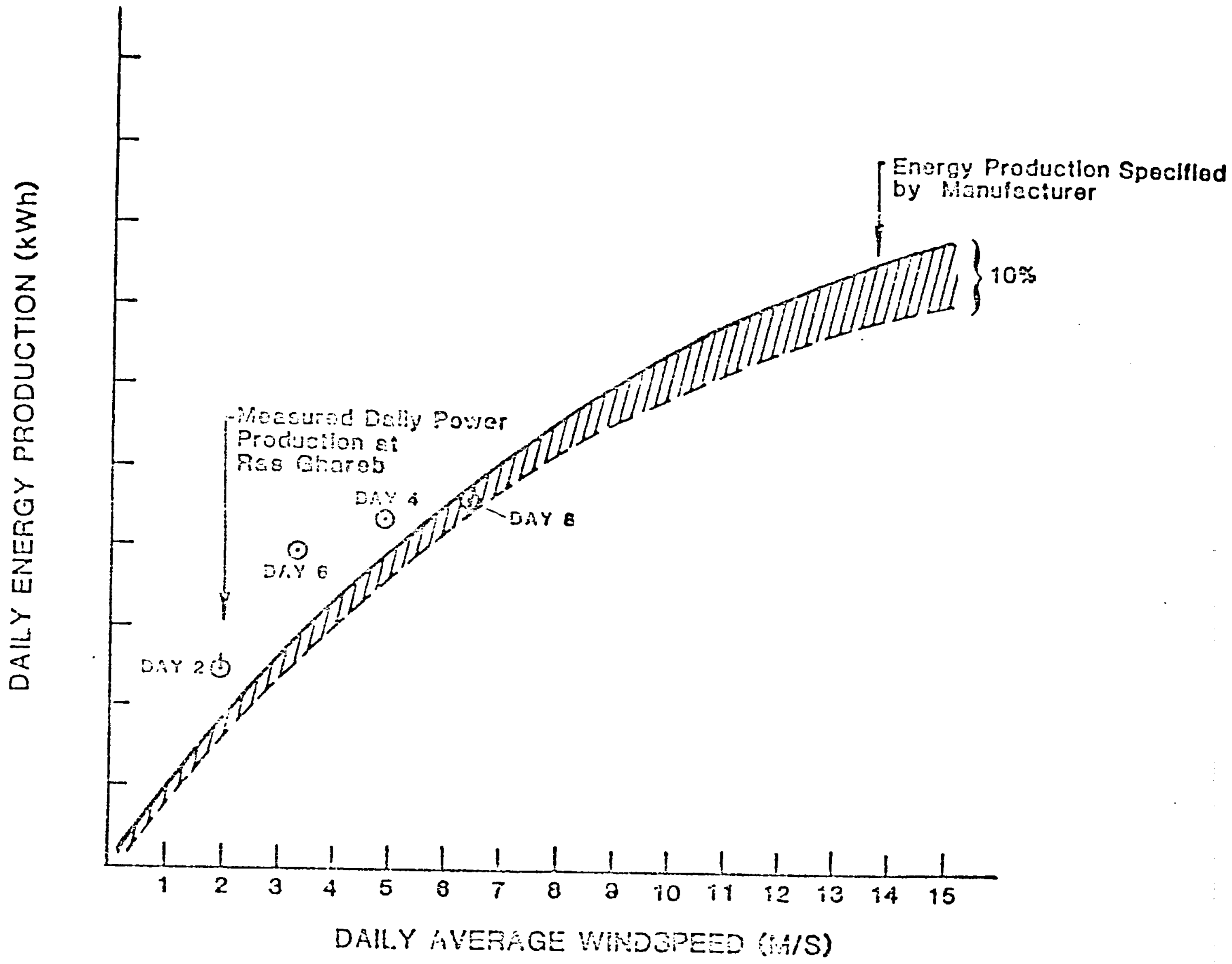


Exhibit 5-1. TURBINE PERFORMANCE VERIFICATION

The system design shall include installation of utility lines and/or conduit pipes to the point of connection to the existing lines, including all transformations from distribution to utilization voltage as may be required.

Site Planning and Construction

The system design shall indicate minimum soil conditions which are necessary for the proposed design of the foundations, earthwork, and drainage, and methods to prevent or minimize erosion.

Environmental/Climatic Conditions

The proposed wind farm will operate in the wind, temperature and humidity conditions specified below. The design shall describe in detail measures that would be taken to protect all hardware installed in an environment of airborne dust and sand and a salt spray typical of nearshore applications. Measures to protect hardware for a sulphur environment that causes moderate to severe corrosion to unprotected and simple galvanized metals shall be part of the system designs. All parts shall be certified to withstand these conditions for the 25 year life expectancy.

- o Wind: The wind turbine shall operate in wind speeds from any direction of up to cut-out wind speed for the turbines proposed. The turbine and tower shall be capable of withstanding wind speeds of up to 54 meters/second averaged over a period of 15 minutes.
- o Temperature Range: Ambient air temperature range of 0 to 45 degrees centigrade.
- o Humidity: up to 95%

5.2 Operating Concept

The general concept of the wind farm is to generate electricity that will be fed into the existing 6.6 KV grid at Ras Ghareb. The proposed wind farm is small enough (250 kW minimum, 400 kW maximum) to interconnect with the grid at a single point (Exhibit 5.2). Each turbine has its separate control instrumentation. Care must be exercised to incorporate sufficient electrical protection devices in the interconnect to isolate each part of the system in case of failure along the line. Protective relays which sense parameters such as voltage levels, current levels, frequency and phase sequence on the power line must be used to protect the turbines, transformer, transmission lines and maintenance personnel.

A system control and performance monitoring system is also required (Exhibit 5.3). The performance monitoring system is independent of the turbine control system. A failure in the monitoring system must not affect the overall operation of the wind farm. Specifications for this system are included as Appendix C.

Generators used in wind turbines are one of three standard types: synchronous generators, commonly referred to as alternators; induction generators; or direct current (DC) generators. Synchronous generators (alternators) produce an AC voltage at a frequency that is proportional to shaft speed. Even with rotor speed regulation there will still be enough of a variation in frequency and phase to prevent connection of an alternator directly to the utility grid. Thus the alternator is allowed to turn at different speeds, producing a variable-frequency output. The alternator output is then rectified, converting it to DC. The DC is fed to a synchronous inverter, at a line frequency output that can be connected directly to the utility grid. With this configuration the need for a transmission to connect the rotor and generator is eliminated and the alternator can be connected directly to the rotor. A diagram of this configuration is shown in Exhibit 5.4.

An induction generator is well suited for grid connected applications. They are self-regulating, in adjusting to varying torques and load conditions, and can act as motors for starting. A picture of this system is shown in Exhibit 5.5. As a result of their simplicity of design, operation and control

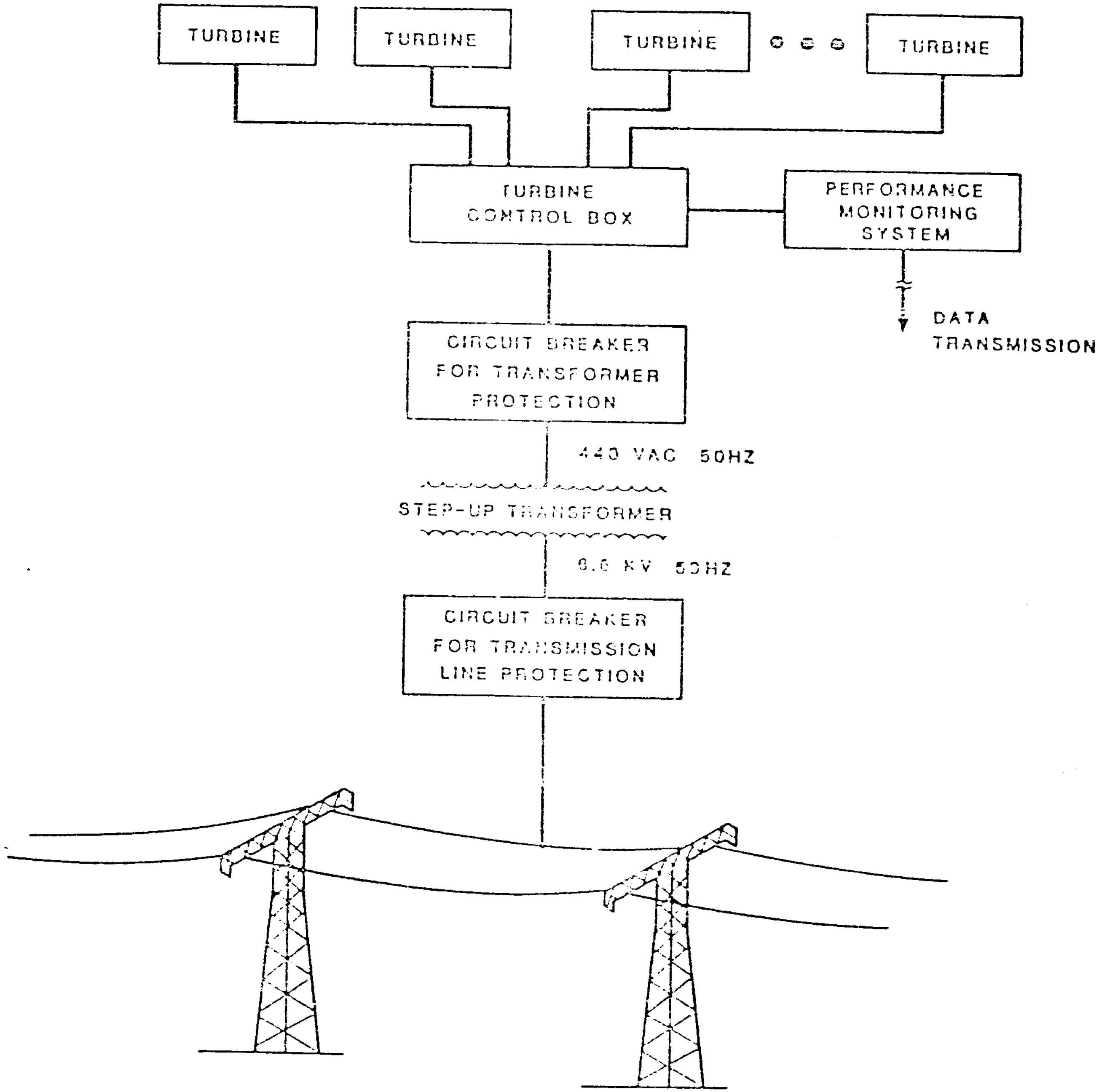


Exhibit 5.2 WIND FARM INTERCONNECTION BLOCK DIAGRAM

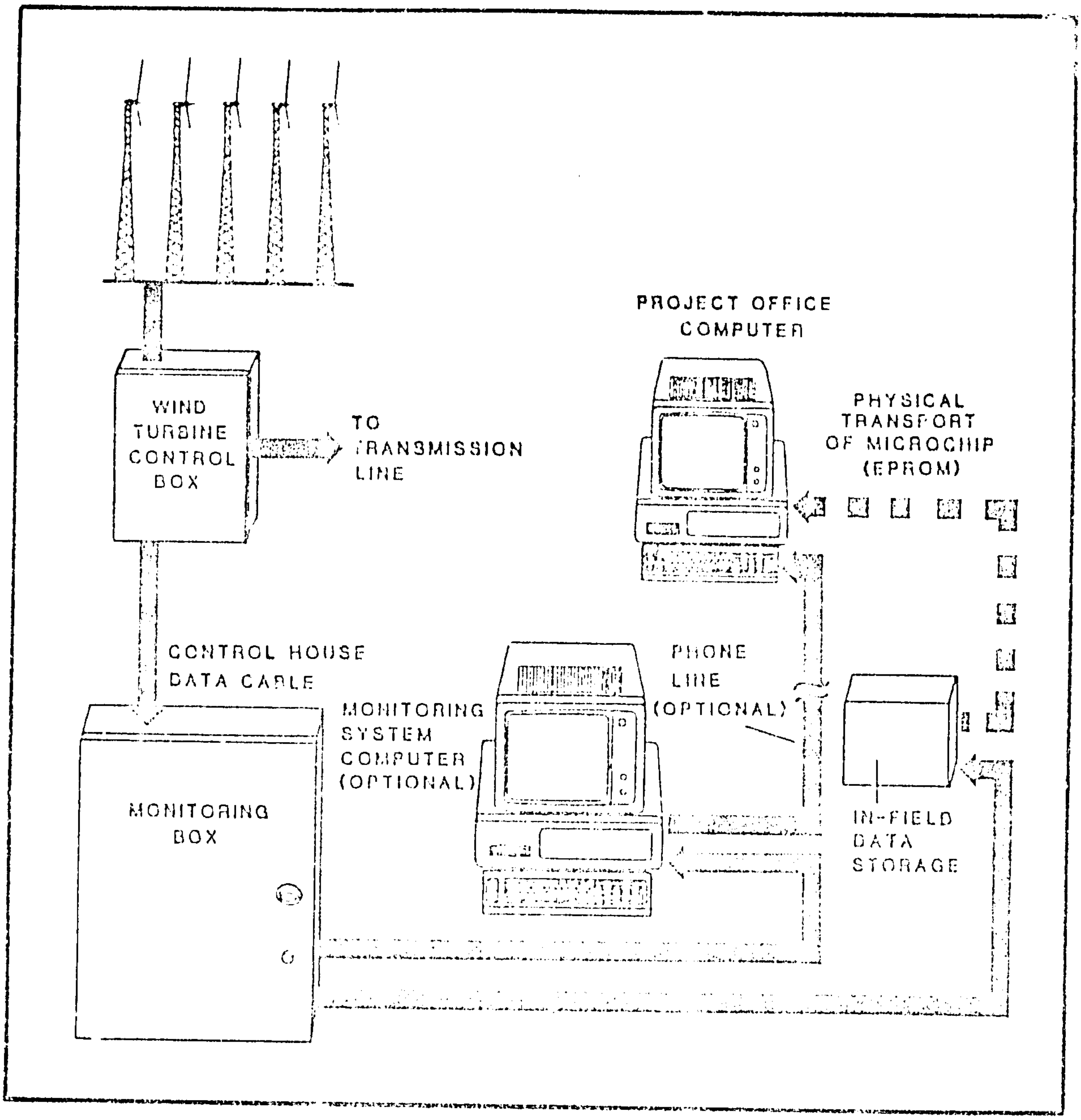


Exhibit 5.3 CONTROL AND PERFORMANCE MONITORING SYSTEM

Exhibit 5-4
DIAGRAM OF A WECS USING A SYNCHRONOUS ALTERNATOR

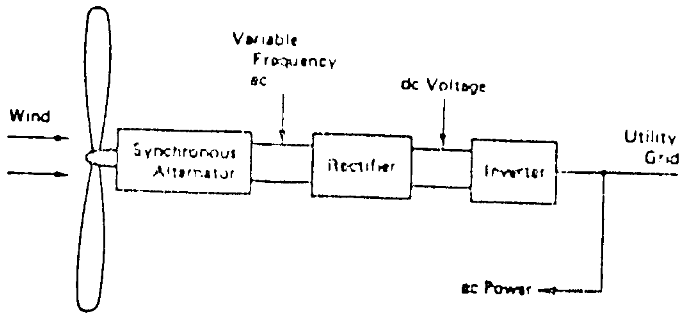


Exhibit 5-5
DIAGRAM OF WECS USING AN INDUCTION GENERATOR

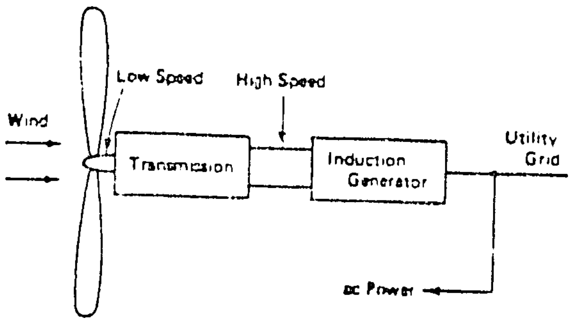
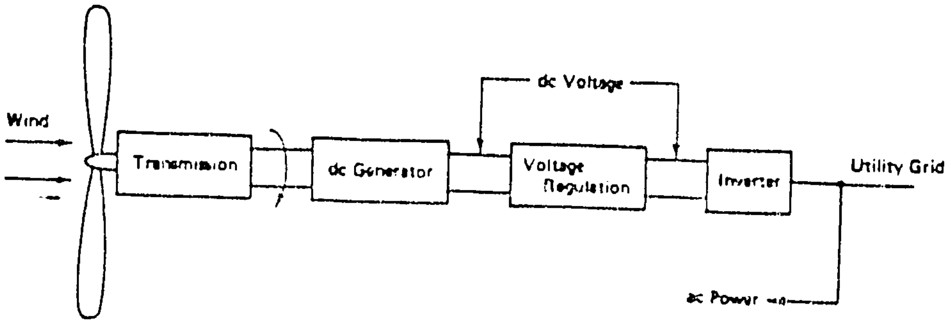


Exhibit 5-6
DIAGRAM OF WECS USING A DC GENERATOR



most grid-connected wind farm applications currently use induction generators. The typical induction generator, without power factor correction, will have an average power factor of 50 to 65 percent when it is operated over varying power and speed conditions. With the use of a capacitor bank, which is an integral part of the power generation section, the average power factor can be increased to 85 percent or greater. This would be an acceptable value from a utility's point of view.

The final method used for generating utility grade AC power is by using a DC generator with an inverter. The generators used in such applications are 3-phase brushless alternators. For design simplicity a standard inverter is located on the ground adjacent to the wind turbine. A DC voltage regulator is required to maintain a consistent input voltage to the inverter. This arrangement is shown in Exhibit 5.6.

5.3. System Configuration

5.3.1 Turbine Specifications and Performance Parameters

The candidate conceptual wind farm for this example consists of five 50 kW wind turbines interconnected through a single control box that generates 250 kilowatts of power at a rated wind speed of approximately 15 meters/second. Exhibit 5.7 presents specifications of a typical wind turbine system.

Many possible turbines use a fixed pitch rotor, the simplest and most reliable rotor design option. To work effectively, the fixed pitch rotor must operate at a relatively constant speed. This can be achieved by coupling the rotor to a 3-phase induction generator tied directly into the utility line power (after necessary protection switchgear are used). Induction generators contain no slip rings or brushes and no rotating windings. They are very reliable with an operating efficiency typically over 90 percent.

A typical turbine uses 6.7 meter (22 foot) rotor blades which are constructed of wood laminates and epoxy resin and covered with fiberglass. The

SYSTEM	
Type	Utility Interface at 50 Hertz
Output Power & Windspeed	30 kW at 10m/s (22.4 mph) 50 kW at 14.75 m/s (33 mph) 55 kW at 24.6 m/s (55 mph)
Axis of Rotor	Horizontal
Location of Rotor (with respect to tower)	Downwind
Number of blades	3
Rotor Diameter	13.4 m (44 ft)
Centerline Hub Height	25.0 m (82 ft)
System Weight (less tower)	1,815 kg(4,000 lbs) (approx.)
Total System Weight (including 24.4 m tower) (80 ft.)	4,550 kg (10,000 lbs) (approx.)
PERFORMANCE PARAMETERS:	
Cut-In Wind Speed	3.8 m/s (8.5 mph)
Cut-Out Wind Speed	25 m/s (55 mph) - 60 sec. average
Survival Wind Speed	54 m/s (120 mph)
Start-up Wind Speed	5.8 m/s (13 mph) - 60 sec. average
Shut-Down Wind Speed	4.0 m/s (9 mph) - 60 sec. average

Exhibit 5.7 Typical Wind Turbine System Specifications

result is a waterproof, non-corrosive structure that will resist changes in humidity, rot and insect damage. The turbine can be a free-yaw, downwind type and use three rotor blades.

The wind turbine in this example employs two separate braking systems to greatly reduce the possibility for a single failure to cause a hazardous situation. Tip speed brakes are employed that automatically limit rotor speed to negate an overspeed condition. The speed brakes are deployed mechanically by centrifugal force associated with an overspeed condition. The deployment of any two of the three tip brakes will limit rotor speed to safe limits in any wind condition.

The primary braking system for the turbine is a two-stage electrodynamic brake. The first stage is an AC dynamic brake which lowers the frequency of the generator, thereby forcing it to slow the rotor and convert rotational energy to electrical energy. The second stage is a disc parking brake which engages a few seconds after the dynamic brake bringing the rotor to a complete stop.

5.3.2 Possible Wind Farm Layout

The layout of a wind farm must take into account the nature of the prevailing wind, the site topography and turbine spacing and tower height (Appendix D). For the proposed Ras Ghareb site, the wind is from the north and northwest over 95 percent of the time.[4] The selected ridge line is unobstructed to the prevailing wind and appears to have a uniform flow along the ridge at a 30-meter height.[5]

The topography of the site indicates that site preparation in the form of access roads will be minimal. The distance to transmission lines is on the order of two hundred meters. It is still beneficial to group the turbines as close as possible to minimize interconnection wiring and access roads. Exhibit 5.8 is a possible layout for the conceptual wind farm. Turbine spacing in a direction perpendicular to the prevailing wind should be at least two rotor diameters, in this case approximately 26.8 meters (88 feet). In the downwind direction, turbine spacing should be approximately 10 rotor diameters to avoid wake effects, in this case 134 meters (440 feet).[6]

The turbines can be mounted on 24.4 meter (80 foot) galvanized, self-supporting, steel lattice towers (Exhibit 5.9). However, care must be taken to insure that the tower is adequately protected in the apparent corrosive environment of Ras Ghareb. Selection of a tower is often made when a turbine is selected because turbine manufacturers have towers designed specifically for

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4 Egyptian Wind Resource Assessment Project, Interim Site Data Report, April-September 1985; Battelle Pacific Northwest Laboratories; January, 1986.

5 Kite Anemometer Studies at the Proposed Ras Ghareb Wind Farm Site, Battelle Pacific Northwest Laboratories, February 8, 1986.

6 Meteorological Aspects of Siting Large Wind Turbines, Battelle Pacific Northwest Laboratories, January 1981.

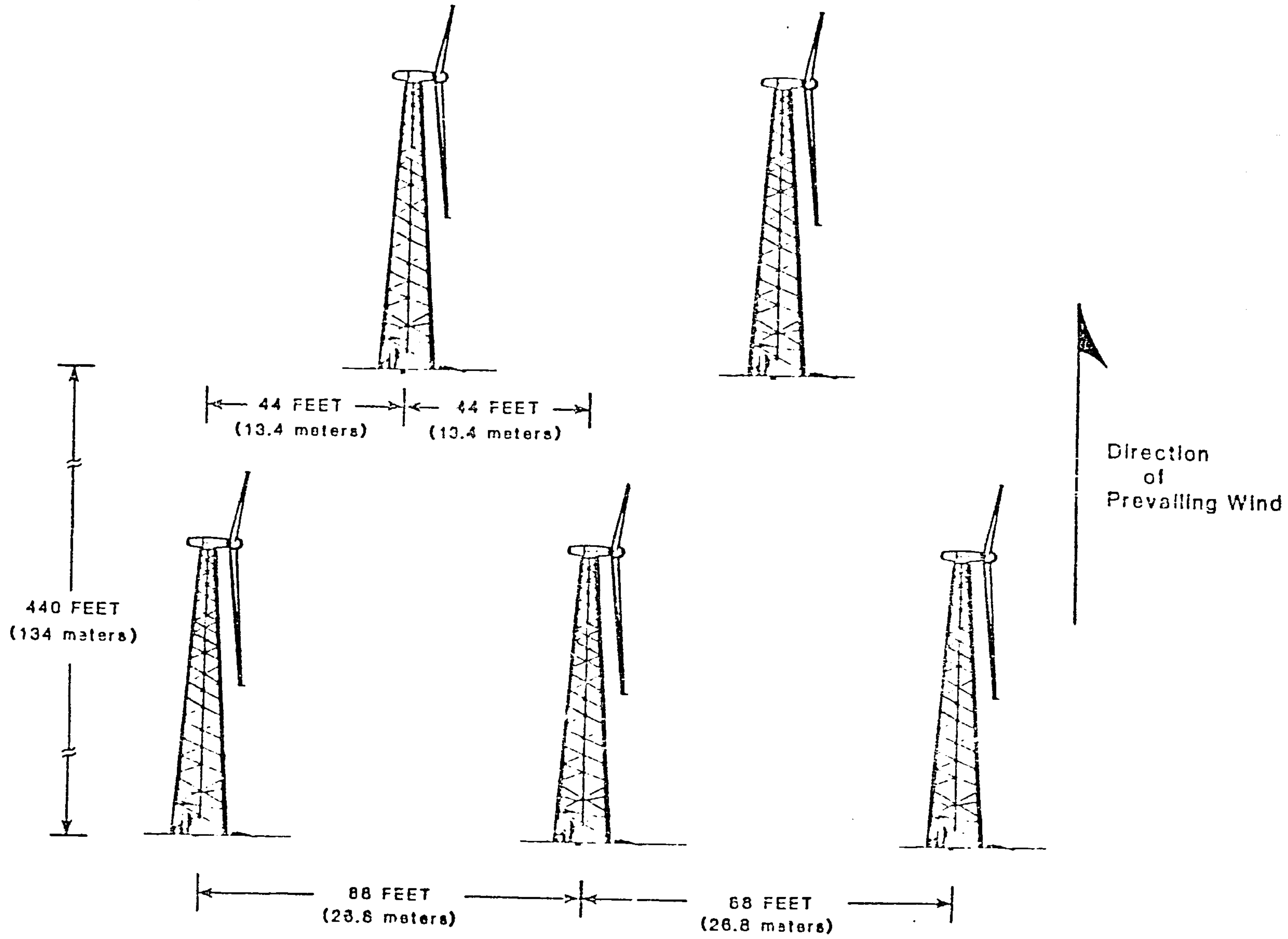
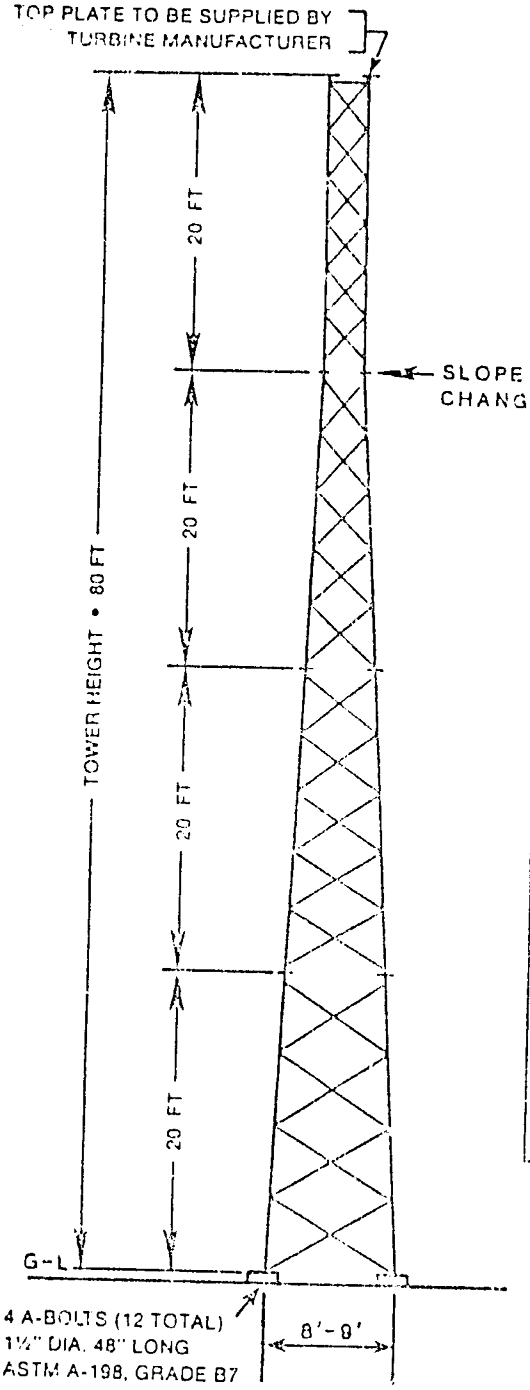


Exhibit 5.8 SCHEMATIC OF POSSIBLE TURBINE SITING



TOWER DESIGN LOADING		
WIND LOAD = 58 P.S.F. W/E L.A. STANDARDS THIS TOWER IS DESIGNATED TO SUPPORT THE FOLLOWING LOADS		
ELEVATION (FT)	TURBINE TYPE	PROJECTED AREA (SF)
82 (2' ABOVE APEX)	50kw WIND TURBINE THIS TOWER IS DESIGNED TO SUPPORT A MAXIMUM LATERAL THRUST OF 6800 LBS. AT TOP OF TOWER.	117

DESIGN NOTE:

TOWER DESIGN BASED ON STATIC LOADING CONDITIONS ONLY. HARMONICS AND/OR DYNAMICS HAVE NOT BEEN CONSIDERED.

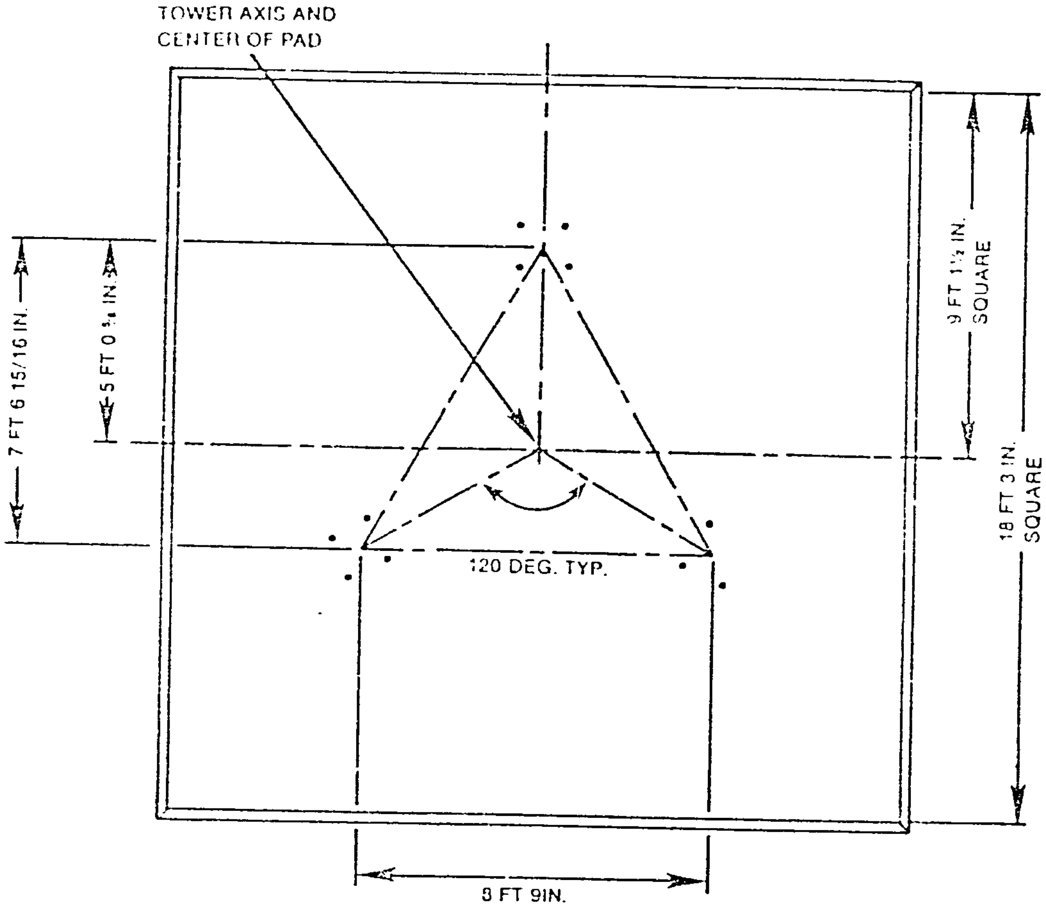
Exhibit 5.9 80 FOOT LATTICE TOWER DESIGN DETAIL the turbine system weight and dynamic loading stress. Many manufacturers will offer different types of towers however. This tower is a reasonable compromise between ease of maintenance, cost, and potential for local fabrication in futur. installations throughout Egypt.

The tower can be installed on two types of foundations; a concrete slab or "mat" foundation and a pier-type or "bell" foundation. Example foundation details are given in Exhibits 5.10 and 5.11 for an 24.4 meter (80-foot) tower. The "General Notes" in the exhibits specify that the foundation design assumes "normal soil" conditions. Specific soil conditions for the Ras Ghareb site must be analyzed before foundation specifications can be completed.

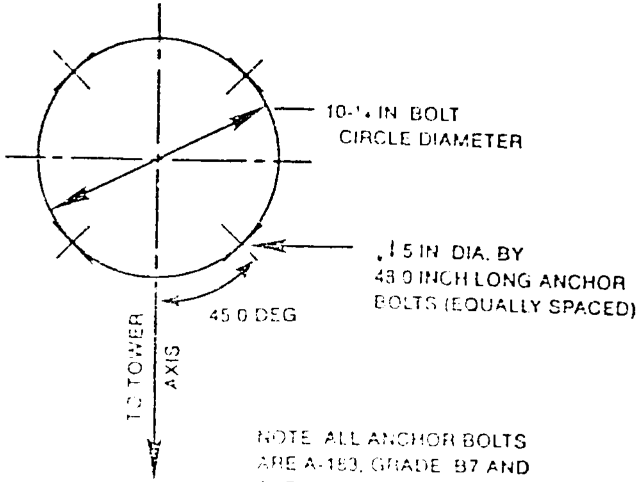
5.4 System Performance

System performance of the wind turbines will be measured in accordance with system acceptance test requirements that will be specified in the field test statement-of-work. These requirements were summarized in Section 5.1. As an example, the monthly power production for a 40 kW, 60 hertz wind turbine was estimated using a computer system model and 9-months of actual measured wind data at a height of 10 meters above ground level at the proposed Ras Ghareb wind farm site. Results are given in Exhibit 5.12. Approximately an 18 percent increase in power production over that shown could be expected with a 50 kW, 50 hertz wind turbine.

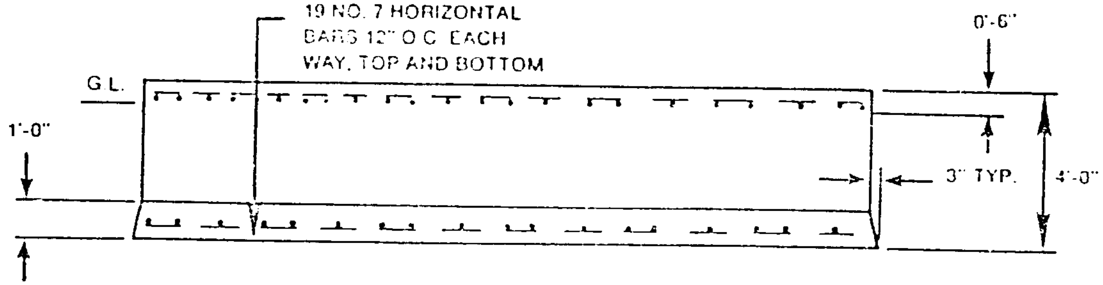
Capacity factor for the candidate wind turbine is the ratio of the kilowatt-hours produced given the measured wind speed to the kilowatt-hours that would be produced at rated wind speed for the same time period. Also note that the candidate wind turbine produces 9.4 percent more power in the actual wind frequency distribution at a 10 meter height at Ras Ghareb than would be expected if the wind speed was Raleigh distributed (140,488 kilowatt-hours versus 128,371 kilowatt-hours).



PLAN VIEW



NOTE: ALL ANCHOR BOLTS ARE A-193, GRADE B7 AND ARE HOOKED 180 DEG. AT THE BOTTOM. ANCHOR BOLT PROJECTION IS 8.0 INCHES ABOVE THE TOP OF THE FINISHED CONCRETE.

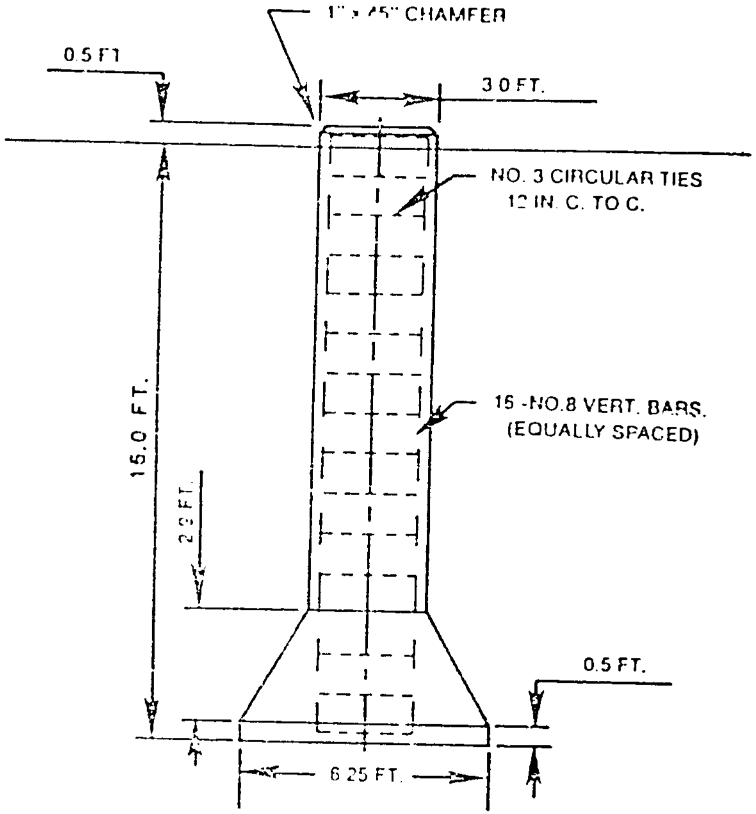


ELEVATION VIEW

GENERAL NOTES

1. ASTM A-615 GRADE 40 DEFORMED REBARS.
2. CONCRETE, 3,000 P.S.I. MINIMUM ULTIMATE STRENGTH AT 28 DAYS.
3. ALL FORMS MUST BE REMOVED FROM CONCRETE BEFORE PLACING COMPACTED BACKFILL.
4. MINIMUM CONCRETE COVER ON ALL REBARS IS 3 INCHES.
5. FOUNDATION DESIGN ASSUMES EIA RS-222-C NORMAL SOIL. NORMAL SOIL IS DEFINED AS:
   (A) COHESIVE DRY SOIL
   (B) PASSIVE RESISTANCE OF 400 PSF/FT OF DEPTH
   (C) 4,000 PSF BEARING CAPACITY

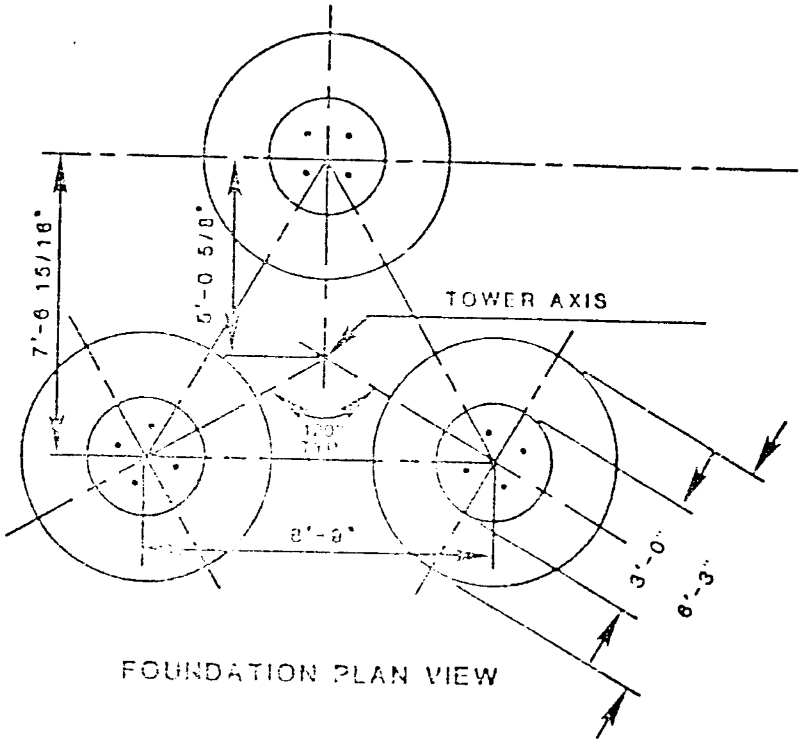
Exhibit 5-10 MAT FOUNDATION DETAIL FOR AN 80 FOOT TOWER



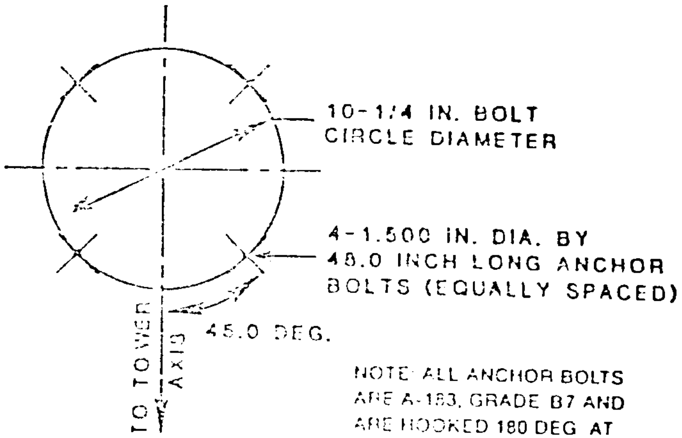
FOUNDATION ELEVATION

GENERAL NOTES

1. ASTM A-615 GRADE 40 DEFORMED REBARS.
2. CONCRETE 3,000 P.S.I. MINIMUM ULTIMATE STRENGTH AT 28 DAYS.
3. ALL FORMS MUST BE REMOVED FROM CONCRETE BEFORE PLACING COMPACTED BACKFILL.
4. MINIMUM CONCRETE COVER ON ALL REBARS IS 3 INCHES.
5. FOUNDATION DESIGN ASSUMES EIA RS-222-C NORMAL SOIL. NORMAL SOIL IS DEFINED AS:
   (A) COHESIVE DRY SOIL
   (B) PASSIVE RESISTANCE OF 400 PSF/FT OF DEPTH
   (C) 4,000 PSF BEARING CAPACITY



FOUNDATION PLAN VIEW



NOTE: ALL ANCHOR BOLTS ARE A-193, GRADE B7 AND ARE HOOKED 180 DEG AT THE BOTTOM. ANCHOR BOLT PROJECTION IS 8.0 INCHES ABOVE THE TOP OF THE FINISHED CONCRETE.

Exhibit 5.11 ***BELL FOUNDATION DETAIL FOR AN 80 FOOT TOWER***

Month	Kilowatt-hours	Capacity Factor (%)
April	11,697	41
May	15,397	52
June	20,297	71
July	19,369	65
August	18,257	65
September	19,589	68
October	16,605	59
November	10,671	37
December	8,604	29
Based on Actual Wind Velocity Distribution (10 meters AGL):	140,488	54
Based on Raleigh Distribution of Wind Velocity	128,371	49

Reference: Battelle Pacific Northwest Laboratories

Exhibit 5.12 40 kW, 60 Hertz Wind Turbine Performance at Ras Ghareb

APPENDIX A

Engineering Cost Estimate

The engineering cost of a wind farm at Ras Ghareb is dependent on the specific turbines installed, the type of tower used, the size of the foundation required, and the extent of civil work required for access roads and interconnect. The following cost estimate is based on average costs of a range of similar equipment and the following assumptions:

a. Freight cost for one 40-foot shipping container from the U.S.A. to Egypt is $3,600. Turbine and tower shipment requires one container per system.

b. Tower foundations require 50 cubic yards of concrete at $59 U.S. per cubic yard.

c. Local labor required for installation is 24 man-hours per machine at $1.92 U.S. per hour.

d. Cost for U.S. contractor supervision is $400 U.S. per day per machine.

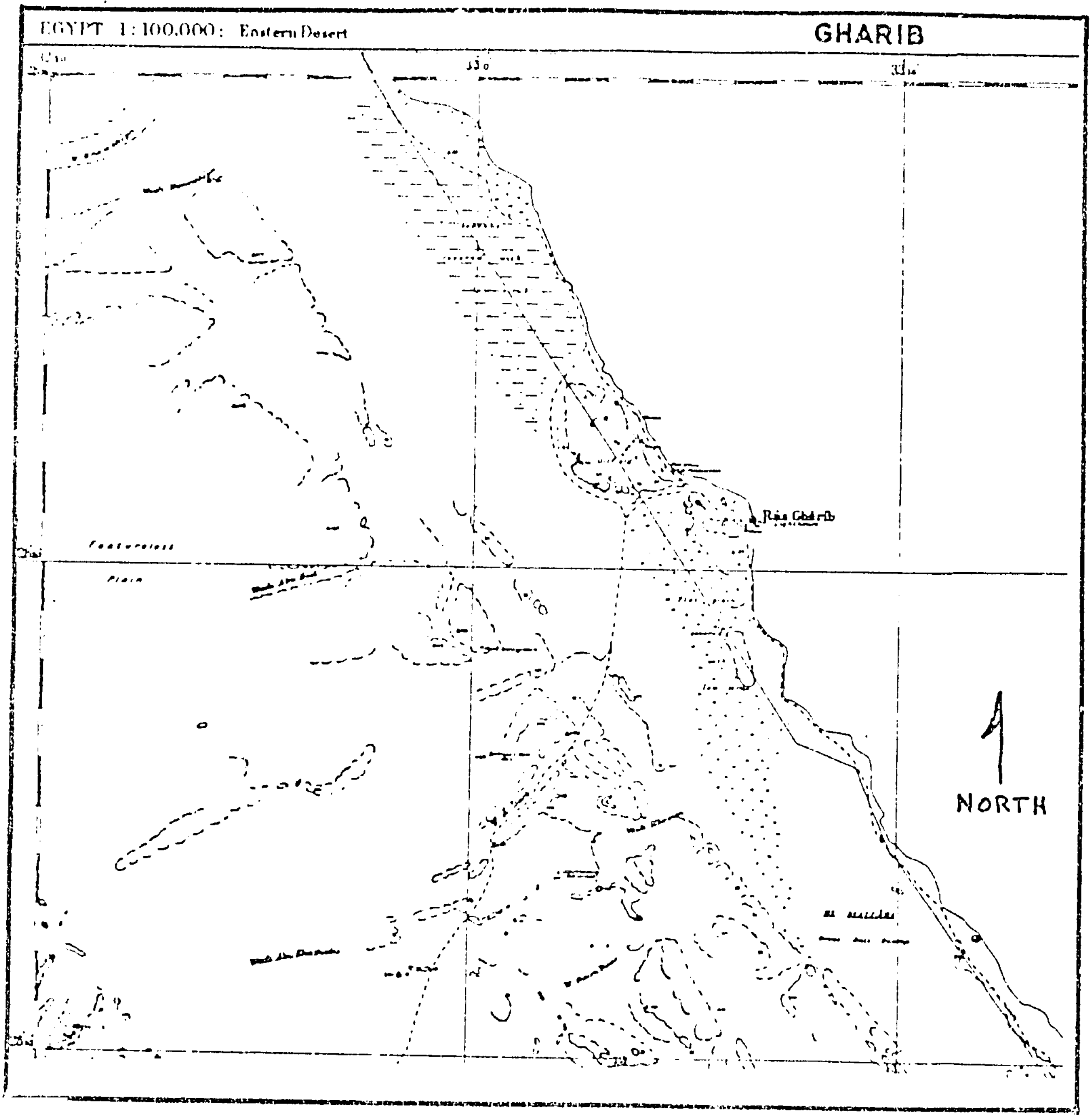
Engineering Cost Estimate (250-260 kW Wind Farm)

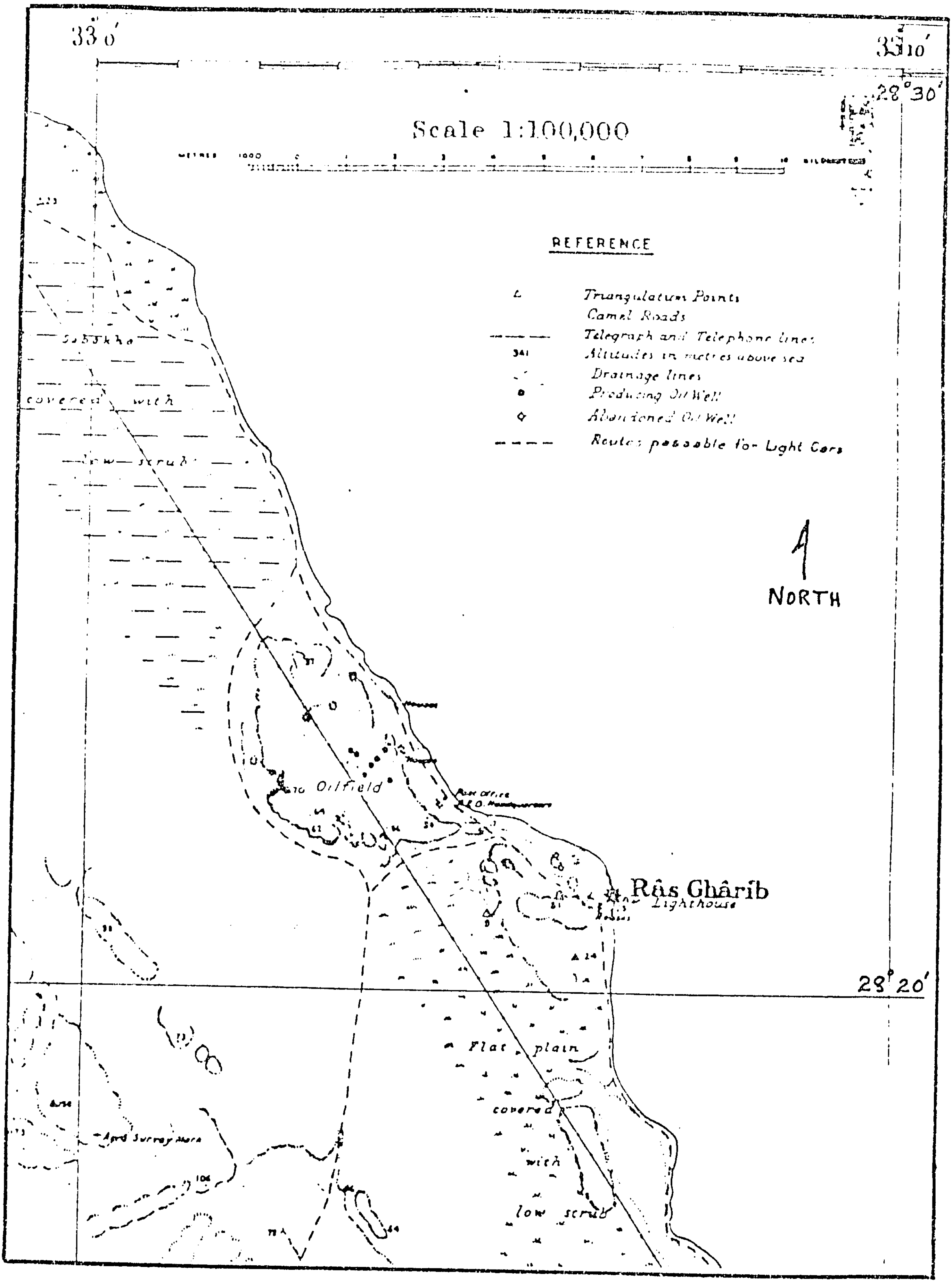
	5x50 kW turbines	4x65 kW turbines
Acquisition (Turbine, Tower, Controls) :	$217,500	$264,000
Transportation :	$ 18,000	$ 14,400
Foundations :	$ 14,750	$ 11,800
Interconnect (Transformer, Cable Conduit, Labor) :	$ 10,600	$10,600
Local Labor (one turbine per day) :	$ 230	$ 184
U.S. Supervision (one turbine per day) :	$ 2,000	$ 1,600
Total Cost:	$263,080	$302,584
Annual O&M Cost*:	$ 7067	$ 7561

* Based on 1985 California Wind Farm experience of $0.01 U.S. per kilowatt-hour generated (90 percent availability).

APPENDIX B

SITE TOPOGRAPHIC MAP
RAS GHAREB, EGYPT


EGYPT 1:100,000: Eastern Desert
GHARIB
Ras Gharib
Featureless
Plain
NORTH


33° 0′
33° 10′
28° 30′
28° 20′
Scale 1:100,000
REFERENCE
Triangulation Points
Camel Roads
Telegraph and Telephone lines
Altitudes in metres above sea
Drainage lines
Producing Oil Well
Abandoned Oil Well
Routes passable for Light Cars
NORTH
Sabakha
covered with
low scrub
Oilfield
Râs Ghârib
Lighthouse
Flat plain
covered
with
low scrub

APPENDIX C

Instrumentation Requirements and Specifications

SPECIFICATIONS FOR A FIELD TEST INSTRUMENTATION SYSTEM

The Renewable Energy Field Test instrumentation system will be used to monitor IPH, PV and wind energy system installations at urban and remote desert locations in Egypt. These energy systems include main power sources (solar collectors, PV arrays and wind turbines) as well as ancillary subsystems depending on specific field test applications. These subsystems include ice-making equipment, desalination systems, a variety of load characteristics ranging from small DC loads to grid-connected applications and back-up power systems (diesel engines and batteries).

The instrumentation system must be a stand-alone system. Failure of the instrumentation system must not affect the performance of the field test system that is being monitored. The instrumentation system must have an on-site data storage system that is non-volatile and capable of easy physical removal and transport to another location for data removal and long-term storage. One form of the non-volatile storage system must be a microchip/ EPROM or CMOSRAM - Type system that can be "milked" on-site easily and without danger of a loss of data.

The instrumentation system must be a microcomputer based data logger with programmable input channels and output formats both analog and digital. The user must have control over sampling frequency and output period for each channel. The capability to muliplex some of the channels is also required. Primary design objectives for the instrumentation system should be reliability, simplicity, small size, low power and the ability to operate in environmental extremes as specified (especially high temperature, sand/dust and tropical/sea coast). The unit must be capable of stand-alone battery operation for a period of at least one month, preferably for two months.

The following minimum specifications are required for the instrumentation system. If an exception must be taken to one or more of these requirements, the exception shall be noted and a clear explanation given as to why the bidder believes that the exception should be acceptable to the purchaser.

Physical Specifications

- Small, stand-alone, self-contained system in an environmental enclosure
- Desired weight: less than 10 pounds
- Desired size: less than 10 inches x 10 inches x 6 inches

System Power Requirements

- Capable of operation using self-contained batteries
- Capability for the use of an external power source to allow continued data collection while changing batteries is desirable.
- Capable of transient protection from spurious electrical charges or lightning.

Environmental Specifications

- Ambient Temperature: -25 deg. C to +50 deg. C
- Relative Humidity: 0 to 90 percent non-condensing
- Impervious to a tropical, oceanside environment with occasional high airborne sand/dust and/or sulphur levels

Analog Inputs

Number of Channels: At least 12 channels

Voltage Measurement Types: Differential or single-ended

Accuracy of Measurements: at least ± 0.5 percent

Range and Resolution: Selectable for any input channel from microvolts to several volts full scale

Sample Rates: At least once per second for each channel

Multiplex capability: at least four channels

Pulse Inputs

Number of Pulse Counter Channels: at least 4 channels

Analog and Digital Control Outputs: a total of three resettable channels is desired with a range of 0 to $\pm$ 5 volts with a 0.5 volt resolution

Multiplex capability: at least three channels

Output Signal Interface

Memory: Capable of storing at least 3000 data points per day for a period of one month (two months desirable)

Display: A visual display of stored data is required on-site for data verification before data removal

Peripheral Interface: Downloading of data at the site should be by physical removal of the data storage device or simple, reliable data downloading to a non-volatile storage device. Storage data files shall be IBM-PC compatible on floppy disc either directly from the data logger or through a simple, fast, reformatting technique.

FIELD TEST PERFORMANCE MONITORING DATA REQUIREMENTS

Field Test #11 (Wind Farm)

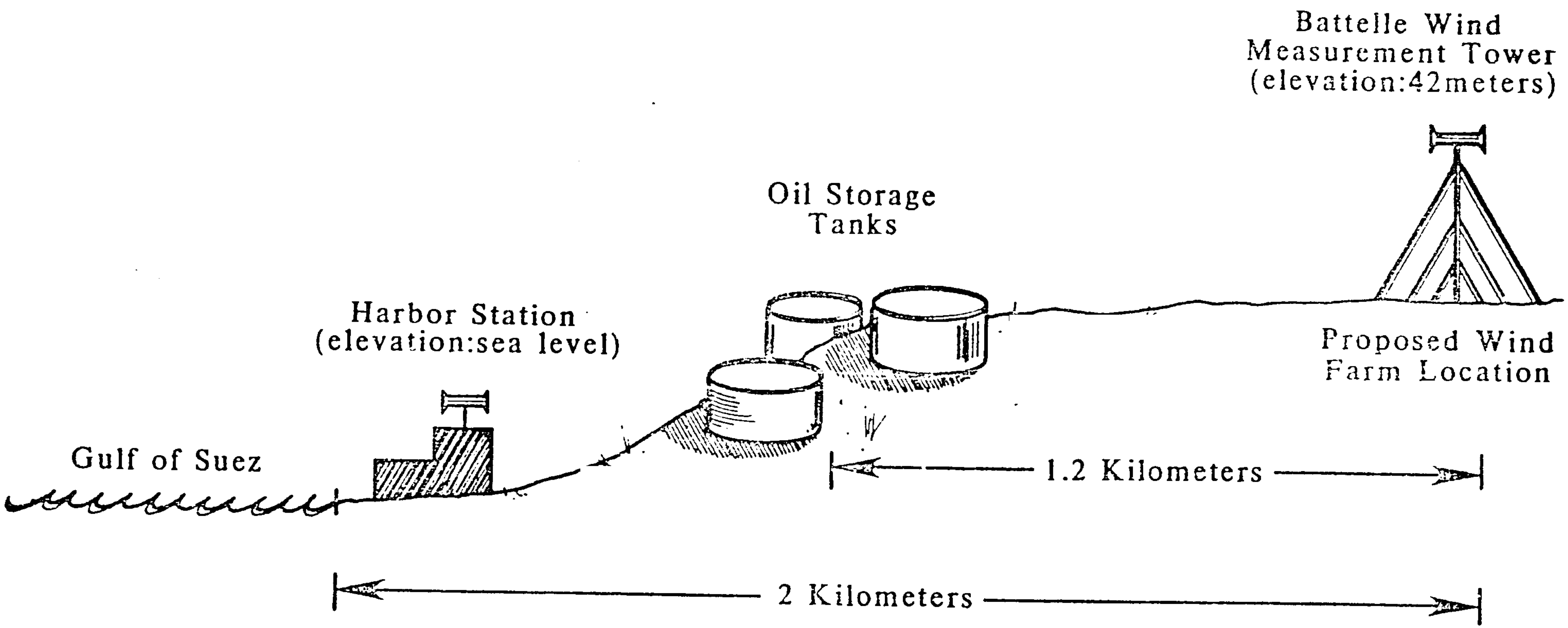
Parameter	Channel Type	Output Interval
Turbine Power (kW)	P	10 min.
Generator Voltage (volts)	A	10 min.
3 ϕ Generator Current (Amps)	A	10 min.
Frequency (Hz)	A	10 min.
Reactive Power (VAR)	A	10 min.
Power Factor	A	10 min.
Rotor RPM (Rev/min)	P	10 min.
Number of On-off Cycles (Turbine)	P	Daily

Meteorological Station

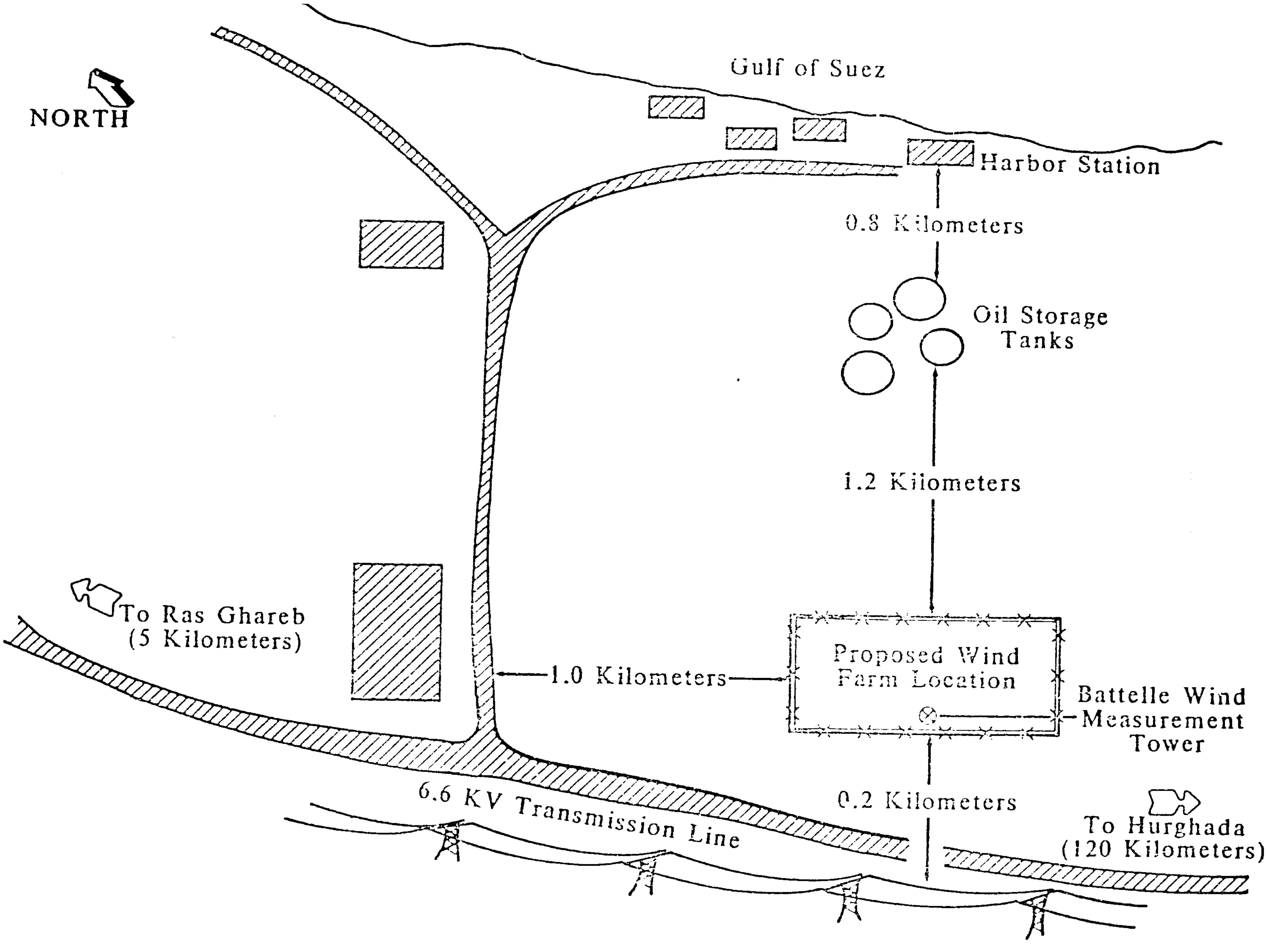
Parameter	Channel Type	Output Interval
Horizontal Insolation (kW/m^2)	A	10 min.
Plane of Array Insolation (if appropriate) (kW/m^2)	A	10 min.
Ambient Temp. (°C)	A	30 min.
Humidity (%)	A	30 min.
Air Pressure ($kgrms/m^2$)	A	30 min.
Wind Speed (m/sec)	A	10 min.
Wind Direction (degrees)	A	10 min.

APPENDIX D

Schematic Layout of
Wind Farm Location



SCHEMATIC OF PROPCSED WIND FARM LOCATION-PLAN VIEW



SCHEMATIC OF PROPOSED WIND FARM LOCATION-TOP VIEW