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TUNISIA RENEWABLE ENERGY PROJECT

SMALL WIND ENERGY CONVERSION SYSTEM SUBPROJECT

EVALUATION REPORT

JANUARY 1983

Prepared for
U.S. Agency for International Development
Tunisia Mission
and
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TUNISIA RENEWABLE ENERGY PROJECT

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I. Summary and Recommendations

The objective of the Small Wind Energy Conversion System (SWECS) subproject is to field test different functional designs of wind turbine systems: e.g., a stand-alone system with battery storage, a stand-alone system with diesel augmentation and a grid interconnected system. After visits to the two potential application areas proposed by STEG, Kerkenna Island and Sidi Mechrig, it was agreed that the grid interconnected SWECS proposed for Kerkenna Island would be inappropriate. The decision was reached after evaluating the technical and social aspects of the site which consisted of a deserted village with little assurance of attracting permanent residents.

The remaining area, Sidi Mechrig, proved to be an excellent area for installation of a stand-alone SWECS. Two sites within this area were identified, each site will service 25 to 35 residences, one site contains a clinic and community house and the other site a small shopping area.

An analysis of the wind resources, see Annex, and design options has led to the judgment that wind turbines delivering about 13,000 to 16,000 kw-hrs/year will be sufficient to satisfy the residential and community perceived energy requirements. The expected mean annual wind speed at hub height is approximately 6m/s (13.4 mph). Each residence would be supplied with sufficient power for about 4 lights and radio with some of the residences having a small TV and/or a refrigerator. The shops and clinic would have enough power for lighting while the community center would have enough power for an entertainment center with a TV.

The total cost of the subproject including material procurement, installation, checkout and warranty is estimated at between $240K to $260K. This excludes a GOT contribution estimated at $60K for site preparation and installation assistance and a wind monitoring program estimated at $45K. The estimate includes appropriate site visits, one of which has been completed with PNL, U.S. testing of systems prior to shipment, and shipping to the Tunisia port-of-entry. The estimated time to complete the subproject is 60 weeks from the wind resource assessment visit just completed to the installation and checkout of the SWECS at the two sites in Sidi Mechrig.

It is recommended that the final design, procurement, and U.S. testing of the SWECS be subcontracted to the DOE Rocky Flats Facility in Boulder Colorado.

It is also recommended that the PASA with NASA be extended from the current termination date of March 1983 to March of 1984, with no increase in funding, to complete the subproject. This will allow sufficient time, with reasonable contingencies, for proper checkout and qualification of the SWECS prior to turning the systems over to the GOT. Since there are no wind monitoring stations at the proposed sites, it is further recommended that the GOT install small meteorological wind stations at Sidi Mechrig.

II. Background

A preliminary wind resource analysis, see Annex, had shown that, among others, the east coast islands and the north coast of Tunisia are candidate regions having sufficient wind resources warranting further investigation. STEG proposed two areas within these regions; the Island of Kerkenna, east of Sfax, and Sidi Mechrig located between Tabarka and Bizerte. STEG arranged for the team to visit Bounouma on the Island of Kerkenna and three small settlements in Sidi Mechrig.

Boumouma is a small village on the north coast of the Island of Kerkenna. By official count, there are 25 temporary residences. The residences are used as summer homes and temporary shelters for fishermen from nearby villages during the fishing seasons. The grid will be extended in 1983 to a small village, Marsa 20, 2 to 3 km away from Bounouma. This will be the furthest extension of the grid on the Island. If a grid interconnected small wind energy conversion system (SWECS) was deemed feasible at Bounouma, STEG would extend the grid to Bounouma, in order to strengthen the grid at this furthest point by using the SWECS.

Bounouma is a reasonable wind site well exposed to the prevailing winds. However, due to the numerous application aspects listed below, further consideration of Bounouma as a possible site for a SWECS has been postponed.

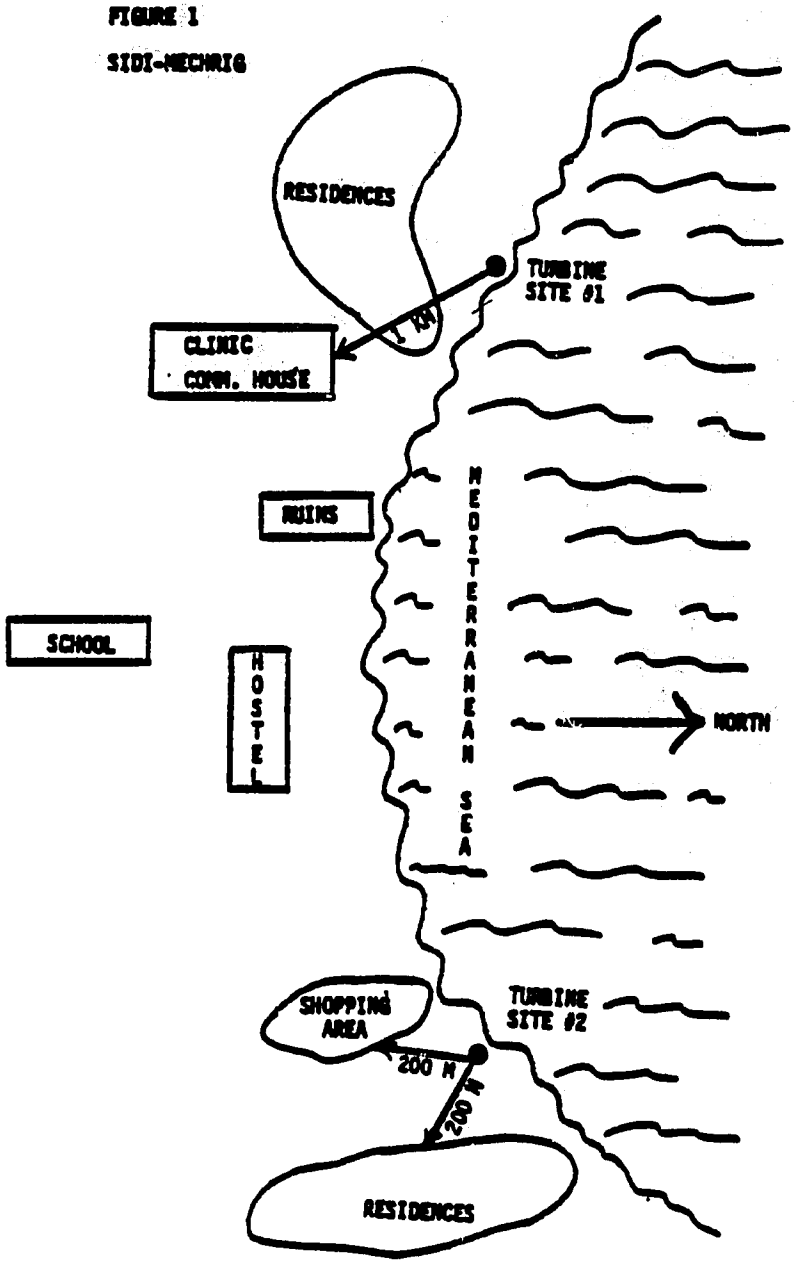
- o Lack of permanent residences
- o Uncertainty as to whether the fishermen will move into the village if electricity is available
- o Lack of fresh water
- o Timing of extending the grid into Bounouma from Marsa 20
- o Desirability of supplying electricity through an AID project to a village containing a number of vacation cottages

Sidi Mechrig is a small village containing three settlements surrounding a resort hostel. Two of the settlements are on the coast flanking the hostel, while the third is located somewhat inland. This third settlement was subsequently selected by STEG for another project. The two settlements, designated site #1 for the settlement west of the hostel and site #2 east of the hostel, have excellent wind resource potential and are well exposed to the NW prevailing winds. A rough sketch of the Sidi Mechrig area is shown in Figure 1.

Site #1 has 25 permanent residences, a clinic and community house. A school, which is part of this site will not be electrified because of its distance from the main part of the settlement. Site #2 is comprised of two segments: a shopping area (5 residences, 3 shops and a grain grinding hut), and a residential segment containing 30 residences. The wind system proposed for site #1 is a stand-alone SWECS with battery storage. The wind systems proposed for site #2 is a stand-alone SWECS with a diesel.

FIGURE 1

SIDI-MECHRIG



III. Subproject Field Test Elements

A. Wind Resource Assessment for Sidi Mechrig

1. PNL has performed a wind resource assessment for Sidi Mechrig. Using data from the Italian island of Pantelleria and Bizerte Tunisia, PNL has estimated the mean annual wind speed of Sidi Mechrig to be 5.8 m/s at 10 meters, (see Annex for details). The estimated seasonal/diurnal variations are given in Table 1 below showing wind energy flux and calculated wind speed assuming a Raleigh frequency distribution.

TABLE 1

Wind Resource at Sidi Mechrig
(Wind Resource at 10 meters)

Time	Annual w/m^2	Annual m/s	Winter w/m^2	Winter m/s	Summer w/m^2	Summer m/s
0000-0600	155	5.1	266	6.1	64	3.8
0600-1200	253	6.0	352	6.7	155	5.1
1200-1800	336	6.6	437	7.2	228	5.8
1800-2400	184	5.4	279	6.2	100	4.4
Avg.	228	5.8	321	6.5	129	4.8

As shown, the wind resources are highest during the winter months and lowest during the evening and morning hours.

2. A recommended wind monitoring program for Sidi Mechrig is given in Appendix A of the Annex. The purpose of the program is to provide the detailed site specific wind data desirable for the final design of the proposed SWEC systems and to permit accurate system performance evaluations during the field testing phase. The estimated cost of the program including instrumentation, data acquisition system and one-year data analyses by the contractor is $45K. A cost breakdown is given in Appendix A. It is recommended that if this program is adopted, that STEG contract directly with Pacific Northwest Laboratory for the service.

B. Stand-Alone SWECS/Battery Storage Field Test - Site #1 Sidi Mechrig

1. Performance Requirements Assumptions - Each residence (25 total) will have 4 lights and radio, 20 percent of the residences will have a refrigerator, and 50 percent of residences will have a TV. The clinic will have four lights, one in each room. The community house will have one light and a TV. The resultant design load profile is shown in Figure 2. A summary of this daily load profile is given below in Table 2.

FIGURE 2

LOAD REQUIREMENTS

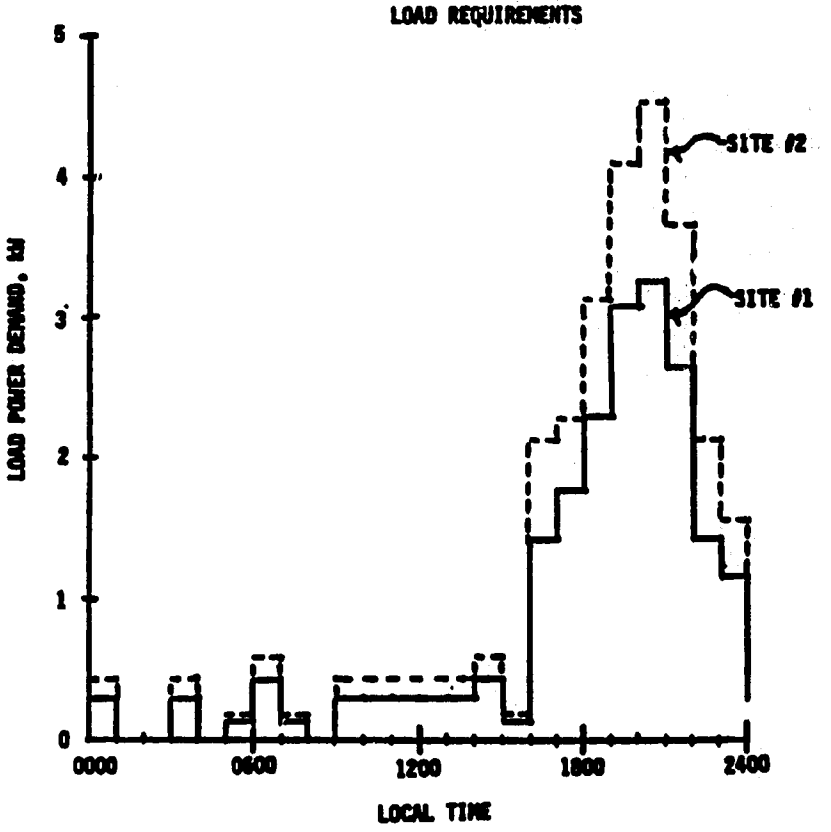


TABLE 2

PERCEIVED LOAD REQUIREMENTS FOR SITE #1 IN SIDI MECHRIG

Time	Energy kw-hrs	Peak Power kw at hr
0000-0600	.73	.3 at 0100 and 0400 hrs
0600-1200	1.45	.4 at 0700 hrs
1200-1800	4.37	1.8 at 1800 hrs
1800-2400	13.89	3.2 at 2100 hrs
Total	20.44 kw-hrs/day (7500 kw-hrs/yr)	

2. Design Criteria - The SWECS/Battery field test must be able to supply about 7500 kw-hrs/yr to the settlement at site #1. Assuming transmission line losses of 30 percent and inverter losses of 10 percent, the SWECS should be sized to deliver at least 13,000 kw-hr/yr. For design purposes the mean annual wind speed is assumed to be 6.0 m/s at wind turbine hub height. Though 6.0 m/s is greater than the 5.8 m/s mean speed quoted in section III.A.1, 6.0 m/s is judged to be a conservative design wind speed averaging out year-to-year variations and hub heights higher than 10 meters.

   Comparing Table 1 and Table 2 shows that the the load energy requirement is highest during 1800-2400 hrs, yet the wind resource is low during this period. The need for battery storage is obvious. As an estimate, the battery storage is sized to meet the load demands assuming 1 day of little or no wind. Lead-acid batteries rated at approximately 40 kw-hrs will supply the load with sufficient energy and not exceed 80 percent depth-of-discharge.

   A 220V-50 Hz inverter is required to condition the power generated by the turbine or extracted from the storage system. The size of the inverter (2x peak power demand) should be approximately 6 kwe.

3. Conceptual Design Features - A block diagram of the stand-alone SWECS with battery storage is shown in Figure 3. Tentative specifications are given in Table 3.

FIGURE 3

SWECS BLOCK DIAGRAM OF SITE #1

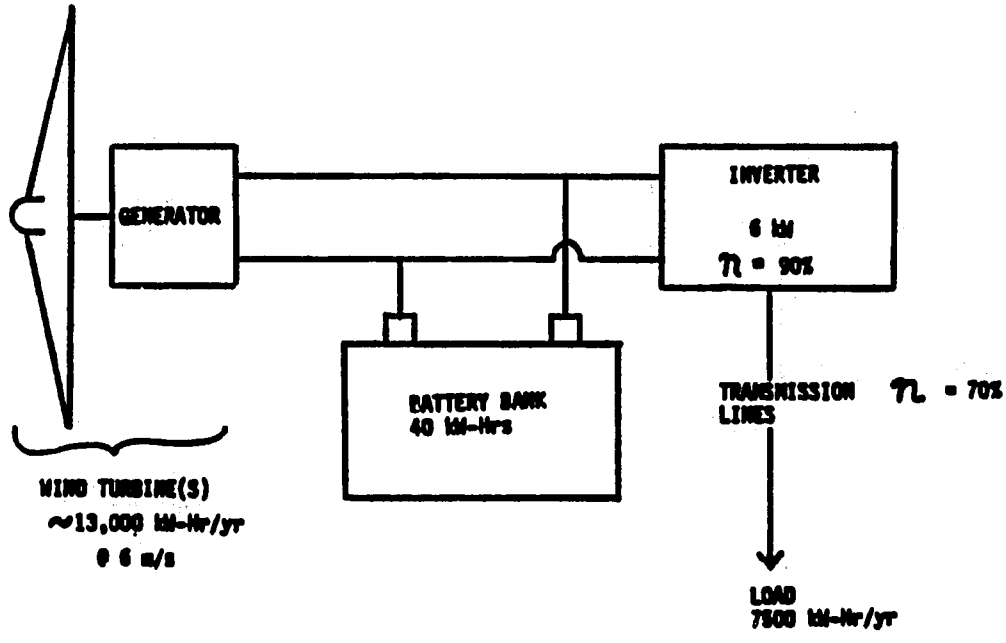


TABLE 3

SWECS/Storage Specifications

Component	Specifications
Wind Turbine(s)	ä 13,000 kw-hr/yr at 6 m/s Survival Speed - 100 mph Salt spray and sand resistant 60 to 80 ft tower
Battery Storage	Long life Pb-Acid Batteries 40 kw-hr rated
Inverter	6 kw-rated electrical output 220V - 50 Hz output D.C. input

The battery storage consists of multiple single cells connected in series to provide power at a nominal 120 V DC. The battery will supply power to the inverter during wind lull periods of up to 1 day and also satisfy peak power demands. Excess wind power will be used to recharge the batteries. The inverter, sized to meet peak power demands of the load, will convert the 120 V DC power from the batteries or wind turbine to 220 V AC - 50 Hz to be used by the load.

The wind turbine(s) is sized to deliver at least 13,000 kw-hr/yr at a 6 m/s mean annual wind speed. Oversizing is desirable due to the expected seasonal variations in wind speed, the discretionary aspect of the load, and lack of hard data on wind speeds in Sidi Mechrig. One large or 2 smaller wind turbines acting together can satisfy the energy requirements. Because of the availability and reliability of smaller wind turbines, using multiple smaller wind turbines may be a more viable approach.

4. Hardware and Shipping Cost Estimates - Several cost scenarios, varying from generic cost curves to specific hardware costs from manufacturers, have been analyzed. This analysis has resulted in costs as shown in Table 4 below.

TABLE 4

COST ESTIMATES FOR SITE #1 IN SIDI MECHRIG

Material	
Turbine, Tower	$40K
Controls	2K
Inverter	10K
Storage	6K
Wiring, Drawing	8K
Shipping	6K
Total	$72K

The final cost will depend on the availability of wind turbines, their reliability in a hostile environment and final engineering specifications.

C. Stand Alone SWECS/Diesel Field Test - Site #2 Side Mechrig

1. Performance Requirements Assumptions - Each residence (35 total) will have the same loads specified in section III.B.1. In addition the shops and grain grinding hut will have one light each. The resultant design load profile is shown in Figure 2. A summary of this daily load is given below in Table 5.

TABLE 5

PERCEIVED LOAD REQUIREMENTS OF SITE #2 AT SIDI MECHRIG

Time	Energy kw-hrs	Peak Power kw at hr
0000-0600	1.02	.42 at 0100 and 0400 hrs
0600-1200	2.03	.60 at 0700 hrs
1200-1800	6.04	2.28 at 1800 hrs
1800-2400	19.17	4.54 at 2100 hrs
Total	28.26 kw-hrs/day (10,000 kw-hrs/yr)	

2. Design Criteria - Two designs were considered to size the components of the SWECS/Diesel Field Test. One design, called the diesel charger design, requires the wind turbine to generate sufficient energy to satisfy the yearly load requirements of the village. The load requirements, including transmission losses (30 percent) and a 10 percent loss in the inverter requires the wind turbine to generate at least 16,000 kw-hr/yr. The diesel generator will function as a battery charger only. A 4 kw diesel generator should charge the batteries in less than a day after they have supplied energy to the load for one day and have fallen to 80 percent depth-of-discharge. An 80 percent maximum depth-of-discharge dictates the battery size of 56 kw-hrs assuming a 30 percent loss in transmission lines and a 10 percent loss in the inverter. The inverter rated at 12 kw should satisfy peak power requirements and allow for inductive load power spikes.

The other design considered, called the diesel power supply, requires the diesel generator alone to satisfy the village load requirements during the evening hours. A 9 kw diesel generator feeding the transmission lines directly and operating at 75

percent load should satisfy the evening peak power demands and possibly perform emergency battery charging. The wind turbine is sized to meet the energy demands of the village during the morning and afternoon hours. During the evening hours the wind turbine will charge the batteries which have supplied peak power to the village during the previous morning and afternoon. A wind turbine rated at 14,000 kw-hrs/yr at a mean annual wind speed of 6 m/s should satisfy all energy requirements. As a conservative estimate an 18 kw-hr battery will supply twice the peak power demands of the village and still not exceed 25 percent depth-of-discharge daily. The inverter rated at 6 kw should satisfy the peak power demands of the village during the morning and afternoon hours.

The choice of which design to implement will depend on refined cost and technical analysis performed during final system design by the support contractor

3. Conceptual Design Features - Two block diagrams of a stand-alone SWECS/Diesel field test are given in Figure 4. Figure 4A is the diesel charger system while Figure 4B is the diesel power supply system. Tentative specifications for both designs are given in Table 6 below.

TABLE 6

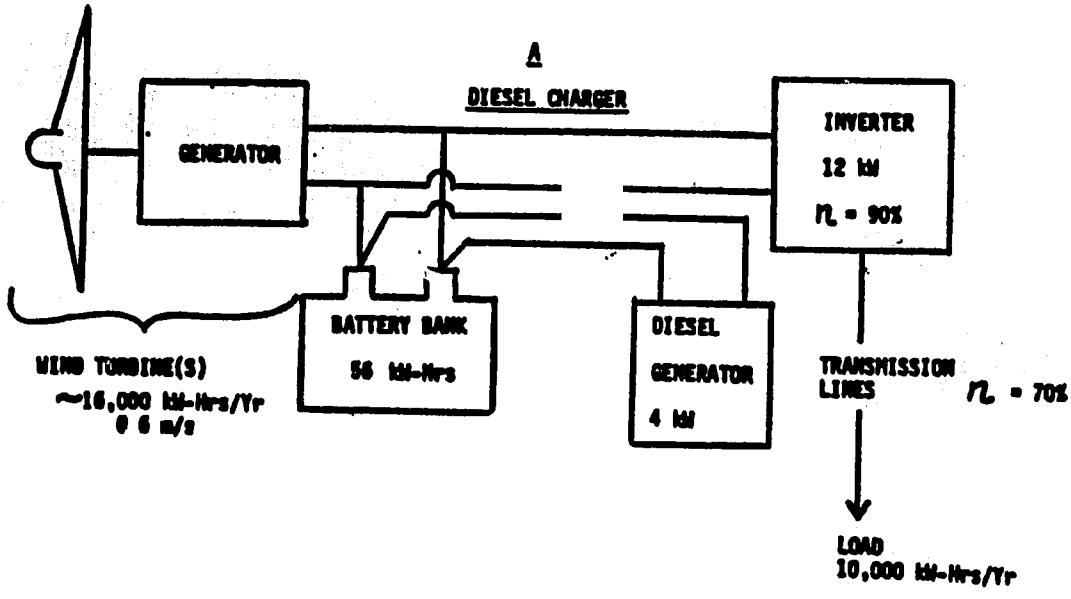
SWECS/Diesel Specifications

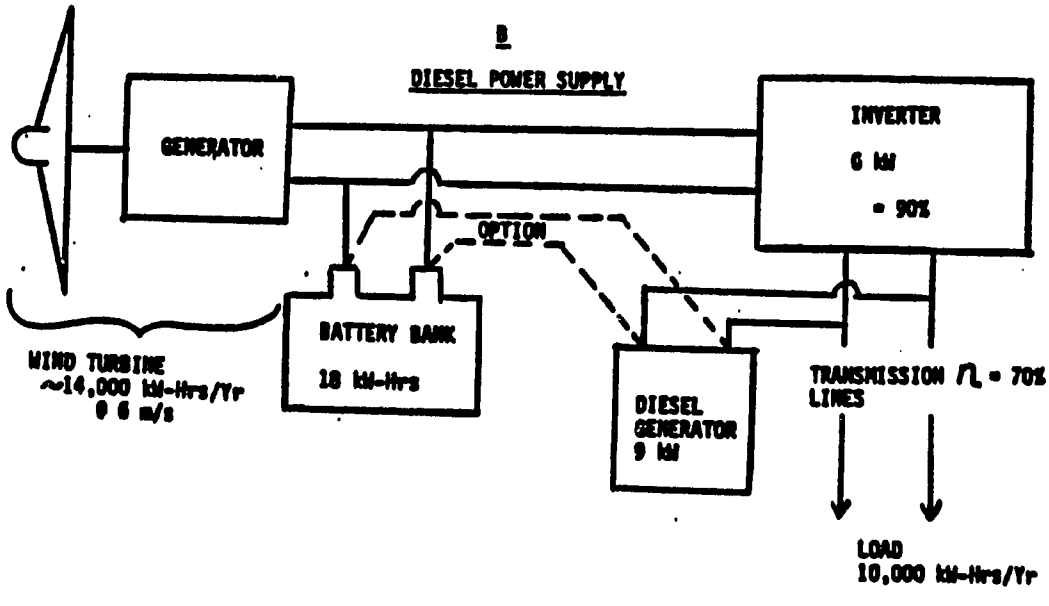
Component	Specifications
Wind Turbine	14,000 to 16,000 kw-hr/yr at 6 m/s Survival Speed - 100 mph Salt spray and sand resistant 60 to 80 ft tower
Battery Storage	Long life Pb-Acid Batteries 18 to 56 kw-hr rated
Inverter	6 to 12 kw rated 220V - 50 Hz output D.C. input
Diesel	4 kwe DC output or 9 kwe 220V - 50 Hz output with DC charging option

The minimum size of the wind turbine ranges from 16,000 kw-hr/yr for the first design shown in Figure 4A to 14,000 kw-hr/yr for the second design shown in Figure 4B. Either size turbines will be able to satisfy the daily load energy requirements, including reasonable transmission losses and component inefficiencies, depending on which system design is selected.

FIGURE 4

SMECS BLOCK DIAGRAM OF SITE #2





4. Hardware and Shipping Cost Estimates - As with the cost analyses of site #1, generic and specific hardware costs were analyzed. The two costing columns in Table 7 below reflect the two designs described earlier.

TABLE 7

Cost Estimates of Site #2 at Sidi Mechrig

	A (Diesel Charger)		B (Diesel Power Supply)
Material			
Turbine, Tower	$40K		$40K
Controls	2K		4K
Inverter	20K		20K
Storage	8K		3K
Fuel Storage	1K		1K
Diesel	5K		6K
Shipping	9K		6K
Total	$85K	Total	$70K

The choice of final design will depend on engineering specifications derived by a support contractor.

IV. Subproject Management

A. Contracting Procedures

In order to expedite procurement of the SWECS and insure proper operation prior to shipment, a support service subcontract is recommended with the DOE Rocky Flats Facility in Boulder, Colorado. Rocky Flats has been designated by the DOE as a center of excellence for small wind turbine development and testing. Recent activities by Rocky Flats included installation of small wind turbines within the continental U.S. as well as the South Pacific Islands. Responsible personnel within Rocky Flats have expressed a willingness to do the proposed work.

The proposed work for Rocky Flats would include the specification, procurement, testing, shipping, installation, checkout and warranty of the SWECS.

B. Resource Requirements

The following table, Table 8, contains the estimated costs to complete the SWECS subproject. The subproject costs are brokendown by major cost elements and both AID and GOT costs are estimated. Element #1 (Wind Resource Assessment) has been completed and the results are presented in the Annex.

TABLE 8

Estimated Costs

Element	Activity	Estimated Cost U.S. $ AID	GOT
1	Wind Resource Assessment		
	Support Contract		
	Labor	$ 17K	$ 7K
	Travel	$ 3K	--
2	SWECS Procurement and Installation		
	Support Contract		
	Site Visit		
	Labor	$ 5K	$ 3K
	Travel	$ 6K	
	Material (depending on final design)	$130-142K	
	Testing		
	Labor	$ 9K	
	Shipping	$12-15K	
	Installation		
	Labor	$ 10K	$10K
	Travel	$ 9K	
	Material	--	$47K*
	Warranty	$ 15K	
3	Project Management		
	Site Visits		
	Labor	$ 4K	
	Travel	$6.4K	
	U.S. Travel		
	Labor	$1.2K	
	Travel	$1.4K	
	Labor	$ 14K	
			$60K

*Includes: soil investigation, in-country shipment, site preparation, and tool supply.

C. Schedule

Figure 5 indicates the schedule of events leading to the installation and turnover of SWECS to the GOT or its designee. The filled-in portion of the schedule indicates activities completed.

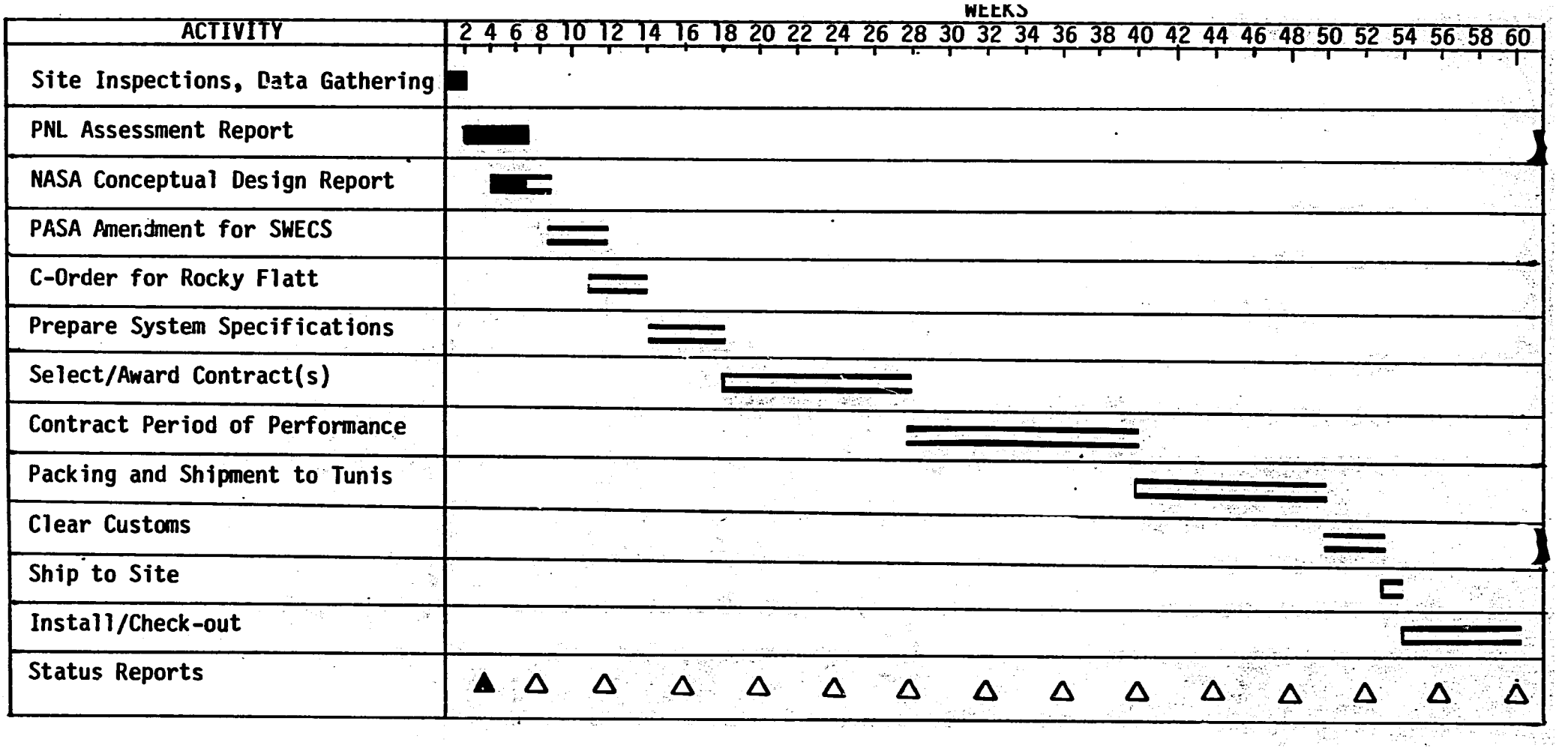
D. Implementation Plan

The Implementation Plan for the Tunisia Renewable Energy Project will be amended to establish the detailed procedures for implementing this subproject and to identify the responsibilities of all subproject participants.

FIGURE 5.

TUNISIA RENEWABLE ENERGY PROJECT

SWECS Subproject



ANNEX

ASSESSMENT OF THE WIND RESOURCE AND EVALUATION OF SITES IN TUNISIA FOR THE POTENTIAL INSTALLATION OF SMALL WIND ENERGY CONVERSION SYSTEMS

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December 1982

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TASK 1. PRELIMINARY WIND RESOURCE ASSESSMENT

Existing wind data and other available information that would be useful in making a preliminary assessment of the wind energy resource in Tunisia were identified. These included previous wind energy surveys, climatological reports, summarized surface and upper-air data relevant to Tunisia, and topographical maps. The world-wide wind resource assessment by Pacific Northwest Laboratory (PNL) was examined to get a general overview of the distribution of the annual mean wind energy potential in the region of Tunisia. The assessment shows areas of class 4 and higher wind resource along the north and east coasts of Tunisia, with the class 4 area also extending across part of southern Tunisia (1). Class 4 wind resource corresponds to a wind energy flux of 200 to 250 W/m^2 at 10 m above ground level. The corresponding wind speeds for a class 4 resource are 5.6 to 6.0 m/s at 10 m, assuming a Rayleigh distribution for the wind speed frequency distribution. The estimates in the world-wide assessment are intended to represent typical well-exposed sites over a large area. Because local terrain features can cause the mean wind energy to vary considerably over short distances, especially in coastal, hilly, and mountainous terrain, there will be local areas in Tunisia with considerably higher or lower wind energy than shown on the world map.

In order to obtain a more refined preliminary assessment of the spatial and temporal distribution of the wind energy resource in Tunisia, existing wind data at PNL were analyzed more discretely, considering the regional topography and representativeness of the data. Mean annual wind speeds for stations in the Tunisian region are shown in Figure 1-1. The Tunisian region here is also taken to include surrounding areas with available data. The height of the wind measurements is generally around 10 to 12 m above ground for stations in Tunisia. The mean wind energy flux in W/m^2 was computed for stations for which the wind speed frequency distribution was available and is shown in Figure 1-1 at stations where wind energy flux exceeded 150 W/m^2. Of the six stations for which the wind speed frequency distribution was not available, the mean annual wind speeds were 4.6 m/s or less except at Jerba Island, which had a 7.0 m/s wind speed.

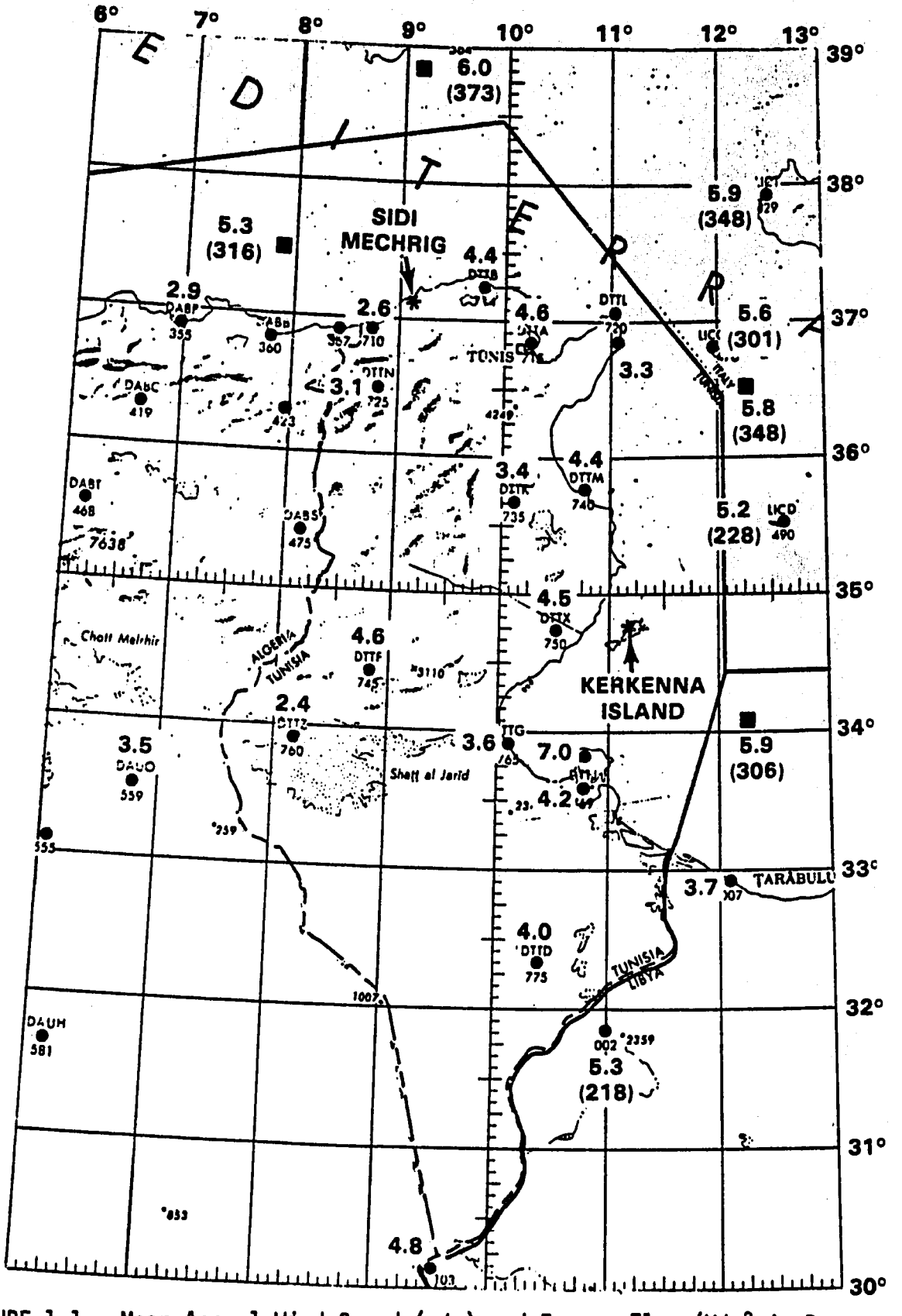

FIGURE 1-1. Mean Annual Wind Speed (m/s) and Energy Flux (W/m^2 in Parentheses) at Stations in the Tunisian Region. Square symbols denote marine areas with winds based on ship observations. Asterisks denote the potential sites visited and evaluated (see Task 2).

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The four locations, denoted by square symbols in Figure 1-1, represent the approximate center of coastal marine areas where the wind speeds were derived from ship observations. Although these values must be used with caution because of the possible variability in the heights of the measurements above ocean level and the variability of the ship locations within the marine area, they are useful here as an approximate indicator of the magnitude of the wind resource offshore and at well-exposed coastal locations. The mean annual wind speed and energy flux at Pantelleria Island, located in the straits between Tunisia and Sicily, is only slightly lower than that of the coastal marine area.

From the surface data alone, two striking observations can be made. One, none of the stations in Tunisia, except Jerba Island, show mean annual wind speeds over 4.6 m/s. (The 7.0 m/s wind speed at Jerba Island is very questionable, for reasons to be pointed out later in the report.) Two, the offshore data show mean annual wind speeds in the range of 5.2 to 6.0 m/s and wind energy fluxes in the range of 228 to 373 W/m^2. Thus, the offshore stations indicate considerable wind energy potential, whereas coastal and inland stations in Tunisia indicate a relatively low wind energy potential.

However, detailed assessments in the United States and various other regions of the world have demonstrated that existing wind data, not originally intended for wind energy assessment purposes, are typically not located in areas well exposed to the wind. For example, in hilly and mountainous terrain, stations are typically located in the more sheltered valleys rather than on the ridges or plateaus. Thus, in order to make a more complete and reliable preliminary assessment, it was necessary to utilize available additional information including:

1. Upper-air data to evaluate the variation of wind speed and direction with height in the lower 600 m above the surface.

2. Topographical maps to evaluate station locations with respect to terrain features that may influence the wind characteristics.

3. Seasonal and directional variability of the station's wind characteristics.

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The purpose of this more detailed analysis was to gain a better understanding of the general wind conditions over the Tunisian region, not to evaluate each station's characteristics in detail. Thus, only selected stations from which upper-air and/or directional and seasonal data were available were evaluated further.

UPPER AIR DATA ANALYSIS

One year's wind data derived from weather balloon observations at Tunis were analyzed. There were four observations daily at 0200, 0800, 1400, and 2000 LST, and at heights 500, 1000, 1500, 2000 feet above the earth's surface. The winds at 500 ft and above are less influenced by surface roughness features and are more representative of the free-flow wind characteristics than surface winds. The highest terrain features within 10 km of the Tunis Airport are hills to the west and west-northwest, ranging from 150 to 330 m (500 to 1100 ft) in elevation. Terrain is generally flat to rolling in other directions with elevations less than 150 m (500 ft).

Table 1-1 summarizes the wind speed and direction at Tunis for each level. The mean surface wind speed is 4.2 m/s (based on the same four observations/day), compared to a 20-year mean of 4.6 m/s (based on 24 observations/day). The annual surface wind energy flux of 120 W/m^2 for that year agrees well with the long-term mean of 119 W/m^2 based on "N summary" wind speed frequency distribution data. The striking features in the wind characteristics are the strong free-air flow at 500 ft and above, and the predominance of the strong northwest to west winds. Surface winds are considerably weaker and more variable in direction than at the 500-ft and higher levels. Southwest winds occur more often at the surface than at higher levels but average only 3.5 m/s at the surface, as compared to 6.0 m/s for northwest winds. Thus, the directions of the prevailing strong winds are northwest to west, with free air speeds of the northwest wind averaging around 10 to 12 m/s at heights of 500 to 2000 ft. Winds from northwest quadrant (270° to 360°) occur about 50 to 60% of the time in the free air.

Table 1-2 shows the diurnal variation of speed with height above ground at Tunis. The diurnal character of the wind speed changes dramatically between

TABLE 1-1. Summary of Annual Wind Speed and Direction With Height at Tunis

Height (ft)	Mean Wind Speed (m/s)	Mean Wind Energy Flux (W/m^2)	Prevailing Wind Direction(s)	Mean Wind Speed (m/s) at Most Prevailing Direction	% Occurrence in Northwest Quadrant
Surface (40)	4.2	120	NW-W, SW-SSW	6.0 NW	37
500	8.0	790	NW-WNW	10.6 NW	52
1000	8.5	994	NW-WNW	10.6 NW	52
1500	9.1	1170	NW-WNW	12.2 NW	59
2000	9.5	1165	NW-W	10.9 NW	63

TABLE 1-2. Diurnal Variation of Annual Wind Speed (m/s) With Height at Tunis

Height (ft)	Hour (LST) 0200	0800	1400	2000
Surface (40)	2.8	3.8	6.2	3.8
500	7.8	7.5	8.0	8.8
1000	8.7	8.2	8.3	8.9
1500	9.3	8.7	9.0	9.2
2000	9.8	9.2	9.4	9.7

the surface and 500-ft level. During the night and morning hours, mean surface wind speeds are low (<4.0 m/s) but increase to over 6 m/s in the afternoon. At 500 ft and above, there is little diurnal variation in the wind speed. The wind speed difference between the surface and 500 ft is 5 m/s at 0200 LST and 2000 LST, compared to only a 1.8 m/s difference at 1400 LST. Thus, although a good wind energy resource exists at 500 ft and above, this indicates that nighttime stable conditions are very effective in reducing the near-surface wind speeds.

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Only limited upper air data were available for other locations in Tunisia, including Kairouan, Jendouba, Sfax, Gabes, Gafsa, and Remada. Tunis was the only station with adequate data for evaluating the directional and diurnal characteristics of the free air flow. The other stations either had incomplete records, e.g., missing months or seasons, or an insufficient number of daily observations, e.g., two or fewer observations per day. However, it is anticipated that the seasonal, diurnal, and directional characteristics of the free air flow in southern Tunisia and the interior desert regions may be substantially different from those in northern Tunisia because of the strong influence of the Sahara Desert on the wind flow patterns in southern Tunisia. Limited upper-air data for southern Tunisia, such as the 600 m AGL data for Africa used in the world-wide assessment, indicate strong free-air flow at 600 m, from which the class 4 wind resource estimate was made. Although none of the surface stations in southern Tunisia reflected this good wind resource at 600 m, a relatively high elevation and well-exposed station in northwest Libya (very near the Tunisian border) does have a class 4 observed wind resource. The station, Nalut, is situated near the crest of a broad ridge at an elevation of 2036 ft (620 m) and has an annual speed of 5.3 m/s and annual wind energy flux of 218 W/m^2, based on the observed wind speed frequency distribution. Thus, the class 4 wind resource estimate for southern Tunisia appears reasonable for elevated, well-exposed areas.

SEASONAL ANALYSIS

One year's wind data are not sufficient for reliably estimating long-term monthly or seasonal wind speeds in the Tunisian region because of large variations that can occur from year to year in the monthly wind speeds. For example, January of one year may be much windier than January of the next year. Five years of data are recommended for reliably estimating the mean monthly or seasonal wind speeds. (This is not necessarily the case in all regions of the world, such as those regions where the seasonal wind resource varies little from one year to the next.) Thus, the one year of upper-air data from Tunis is not too useful for estimating mean monthly and seasonal variations in the free air wind resource.

Table 1-3 shows the mean seasonal wind speed and energy flux for selected surface stations/areas with five or more years of data. The locations are grouped into two categories: 1) coastal and interior stations in Tunisia, and 2) offshore islands or marine areas. The coastal and interior locations have a relatively low wind resource compared to the offshore locations. At the coastal and interior locations, spring appears to be the season of maximum wind resource, with a minimum in the autumn. At the offshore locations, winter is the season of maximum wind resource, with a minimum in the summer.

TABLE 1-3. Seasonal Wind Speed and Energy Flux at Selected Stations/ Areas in the Tunisian Region With Five or More Years of Data

	Mean Speed (m/s)				Mean Energy Flux (W/m^2)			
	Win	Spr	Sum	Aut	Win	Spr	Sum	Aut
Coastal and Interior								
Bizerte	4.0	4.5	3.7	2.8	68	97	53	25
Gafsa	3.6	4.7	4.1	3.5	49	110	73	45
Sfax	4.0	4.6	4.1	3.5	70	104	75	45
Tunis	4.4	4.9	4.4	3.7	128	157	121	77
Offshore								
Annaba Marine Area	7.1	5.4	3.9	5.0	623	317	109	243
Lampedusa Island	6.6	5.4	4.3	4.4	379	239	135	137
Pantelleria Island	7.0	6.2	4.3	5.2	425	381	168	251
SW Sicily Marine Area	7.3	6.1	4.2	5.4	610	388	152	270

It must not be assumed that all coastal and interior locations in Tunisia have similar seasonal variations to the stations shown here. At well-exposed coastal sites in northern Tunisia, the seasonal trend is anticipated to be more similar to that of the offshore areas with a winter maximum. However, the magnitude of the seasonal trends at exposed coastal sites in Tunisia may be modified significantly from that of offshore areas due to sea-breeze circulations during the warmer months. (Note that the magnitude of the seasonal variations at the two offshore islands is significantly less than that of the

marine areas.) At well-exposed elevated sites (such as ridge crests) in northern Tunisia, a winter maximum in the wind resource is also anticipated.

In southern Tunisia, seasonal variations are more difficult to assess because of the possible influence of the Sahara Desert and anticipated large temperature gradients between the Mediterranean Sea and the interior desert region. There may be local areas, such as passes and other wind corridors, where strong channeling of the winds may occur. This flow is probably the greatest when local thermal/pressure gradients are at a maximum, which may be typically the spring and summer season. However, even in southern Tunisia it is anticipated that exposed high elevations and ridge crests may have a substantial wind resource in the winter season, although not as pronounced as in northern Tunisia.

WIND RESOURCE ASSESSMENT

Topographical maps are necessary in a wind resource assessment for estimating the interaction of the free air flow with the terrain features and for estimating a station's/area's exposure considering nearby terrain features and their possible influence on the wind flow. Northern Tunisia is mostly hilly and mountainous, with highest mountains rising to 1400 m (4500 ft). Because of the prevailing strong northwest winds, open ridge crests aligned roughly northeast to southwest, perpendicular to the direction of the prevailing winds, are estimated to have good wind energy potential, especially during the winter and spring seasons. In southern Tunisia, the mountain/ridge areas are more isolated and generally lower than 1000 m (3200 ft) in elevation. As indicated by Nalut, a well-exposed station in northwest Libya (near the Tunisian border), which is located near a broad ridge crest at 2036 ft, elevated areas in southern Tunisia may have considerable wind energy resource. Nalut, for example, has an annual average wind energy flux of 218 W/m^2. There may be numerous other areas, in addition to ridge crests, in southern Tunisia that could have considerable wind resource, but these areas cannot be defined at this point.

Coastal areas in northern Tunisia that are well exposed to the prevailing northwest winds are expected to have good wind energy potential. However, the wind resource may decrease abruptly within just a few kilometers inland, especially in hilly areas. This is apparent from the relatively low wind speeds at Tabarka and Bizerte, both of which are near the coast but appear to be shielded, or at least partially shielded, from the prevailing northwest to west winds by hilly terrain. Along the east coast, the prevailing northwest air flow is generally over land and, as shown earlier in the case of Tunis, nighttime wind speeds near the surface are typically much lower than free-air wind speeds. Moreover, the effects of terrain roughness and surface roughness over land tend to reduce the magnitude of free air speed as compared to that over water at an equivalent height. This is readily apparent for the stations along the east coast, such as Monastir, Sfax, and Gabes, which have relatively low wind speeds and energy fluxes compared to offshore locations. Islands off the east coast, such as Kerkenna Island and Jerba Island, may have considerably higher wind resource than the east coast because of the open water fetch and the modifying effects of the water on the nocturnal stability conditions. (Although a mean annual wind speed of 7.0 m/s is shown for Jerba Island in Figure 1-1, this value appears excessively high in relation to other offshore wind speeds and one year of additional data acquired later for the Jerba station.)

In summary, areas in Tunisia estimated to have good wind energy potential (>200 W/m^2 at 10 m above ground) are as follows:

- coastal areas and islands that are well exposed to prevailing winds from the northwest quadrant
- well-exposed ridge crests, especially those in northern Tunisia aligned roughly northeast to southwest
- passes and wind corridors where the wind flow may be channeled and enhanced.

TASK 2. IN-COUNTRY INSPECTION OF POTENTIAL SWECS SITES

Preliminary meetings for identifying and selecting areas to visit and inspect for the possible installation of SWECS were held on September 29, 1982, with officials of the Government of Tunisia (GOT) and the United States Agency for International Development (AID). GOT identified two areas - Kerkenna Island and Sidi Mechrig - that they were interested in having evaluated for their feasibility as potential SWECS sites.

Kerkenna Island is located just off the east coast across from Sfax (see Figure 1-1). A utility grid network supplies electricity to most of the island, with power provided by diesel generators. However, GOT's Society of Electricity and Gas (STEG) plans to expand the utility grid system to accommodate new residences and a fishing village. This increase in load, plus expected growth increases, could push the current generation system to its limit, especially during periods of peak power demand. Wind energy is being considered a feasible alternative to supplement the power, especially during periods of peak power demand, in these additional area(s) to be connected to the grid. Thus, the SWECS would be used in a grid interconnection mode, rather than as stand-alone units. PNL discussed the preliminary assessment of the wind energy resource potential in Tunisia and identified Kerkenna Island as an area estimated to have moderate-to-good wind energy potential, although no wind data were available for the island. So a decision was made to visit Kerkenna Island and carry out further evaluations.

Sidi Mechrig is located on the north coast, about 45 km northeast of Tabarka. There are three small fishing villages at Sidi Mechrig, but the area is not serviced by STEG's utility grid network. The area is very remote, with difficult access, and STEG has made no plans to extend its utility network to service the area in the near future. Thus, the SWECS would be used as stand-alone units or with diesel backup. PNL's preliminary assessment indicated that areas on the north coast that are well exposed to the prevailing northwest winds are estimated to have good wind energy potential. Although no wind data were available for Sidi Mechrig, its location on the

topographic map indicated good exposure to prevailing northwest winds anticipated for that area. A decision was made to visit Sidi Mechrig, following the visit to Kerkenna Island.

VISIT TO KERKENNA ISLAND

On September 30, team members from NASA, PNL and STEG traveled to Kerkenna Island. Meetings were held with local government officials on the scope and purpose of our visit and the potential benefits of the project for the island. The local STEG office provided information on the monthly power consumption for the island. The highest power consumption is in the summer months because this is the peak tourist season. Peak loads during the summer are from 1900 LST to 2300 LST, with a maximum at 2000 LST. An area being considered for the SWECS - the deserted village of Bou Nouma - was visited. A potential site for the SWECS was identified, which was situated on a low rise at 4 m MSL with excellent exposure to the winds in all directions. Figure 2-1 is a view looking west toward the site. There is open water to the north and west of the site. The palm trees at the site showed no obvious signs of flagging, but some of the palm trees appeared to be slightly flagged by northerly component winds. Other indications of tree flagging by northerly winds were seen a few miles away near the hotel where the team resided (see Figure 2-2). Local fishermen were interviewed about the wind conditions throughout the year. After some debate, they concluded the strongest winds are in December and are from the west. They said these winds are often so strong they do not go out in their sailboats.

On the return trip to Tunis, team members stopped in Sfax to visit the meteorological station. The wind sensors were on a mast 12 m above ground and appeared to have good exposure. The meteorologist on duty said the sensors had been in the same location since 1944 but new sensors had been installed in the last three or four years. The terminal building, 17 m in height, is located about 100 m north-northwest of the wind sensors and was determined to have little effect on reducing the mean wind speeds. Recorded wind speeds are 10-minute averages on the hour. Thus, it was concluded that the wind data should be representative of an exposed site in that area.

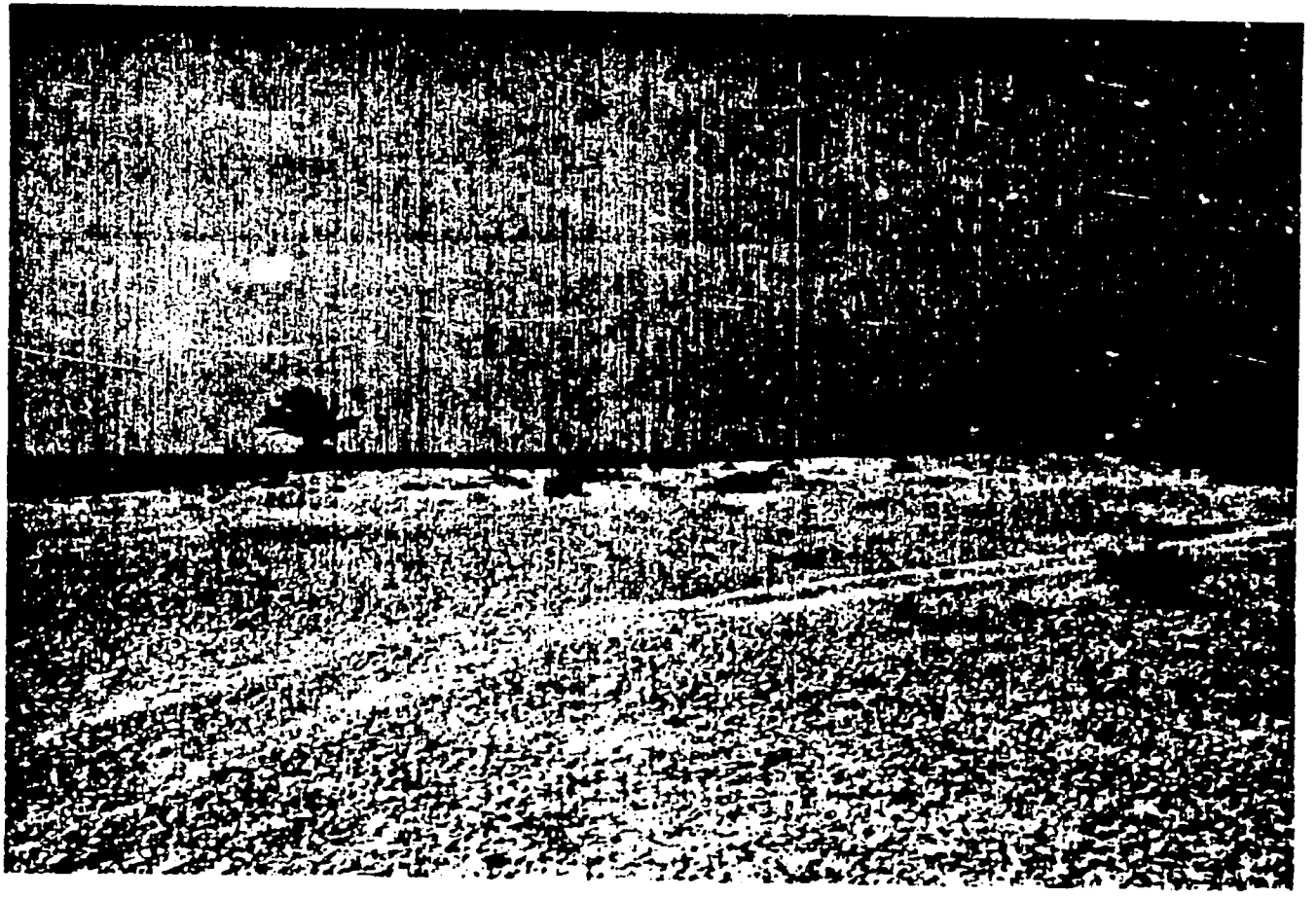

FIGURE 2-1. View Looking West at Possible SWECS Site in Bou Nouma, Kerkenna Island

FIGURE 2-2. View, Looking West, of Flagged Trees Along Coast Near Farhat Hotel, Kerkenna Island

However, prevailing winds at Sfax are from the westerly component and, thus, the magnitude of the wind speed at the site on Kerkenna Island is anticipated to be greater than that at Sfax because of the open water fetch at Kerkenna. Yet, the big question remains: How much greater?

VISIT TO SIDI MECHRIG

On October 4, team members from AID, NASA, PNL, and STEG left Tunis to visit Sidi Mechrig on the north coast. The team spent the night in Tabarka and visited the meteorological station at Tabarka the next morning. Tabarka is the nearest meteorological station to Sidi Mechrig, about 45 km to the northeast. The meteorological station is located about 6 km southeast of town in a rural area. The meteorologist on duty said the station had been in its current location for only 1-1/2 years and that the previous location was in the town of Tabarka. The data that were used in the preliminary assessment were from the old location in town, where the mean annual speed was only 2.6 m/s (see Figure 1-1). However, it was obvious by the view from the new location that the town is in a sheltered depression at the base of high hills to the west and northwest. The current location is at a higher elevation and appears to have somewhat better site exposure than the previous location. The wind sensors, mounted on a 12-m tower, looked to have fairly good exposure although there is a row of wind-breaker type trees about 150 m west of the mast and 8- to 10-m high trees and an office building about 50 m south of the tower. Distant hills are located to west and northwest of the station, but terrain is fairly level in the northerly direction (northwest to northeast) with the sea about 4 to 5 km to the north. Closer hills are located in the other directions.

Team members stopped in Sejnane, where local officials joined the team for the trip on to Sidi Mechrig. The first major observation upon arriving in Sidi Mechrig was the flagged vegetation, as seen in Figures 2-3 and 2-4. Both pictures are taken looking toward the northeast, roughly perpendicular to the direction of flagging. From the flagging, it was evident that the prevailing strong winds are from the northwest.

FIGURE 2-3. Flagged Trees at Sidi Mechrig. View looking northeast, roughly perpendicular to direction of flagging (northwest).

FIGURE 2-4. Flagged Tree at Sidi Mechrig, Near Site #2. View looking northeast, with Mediterranean Sea in the background. Tree is primarily flagged by northwest winds.

The team visited two fishing villages in Sidi Mechrig being considered by STEG for possible SWECS installations. The first village has 27 residences, a school, clinic, and community house. A good site for a potential wind turbine installation was identified on the promontory approximately north of the center of the village. This site is about 800 m from the school and clinic. The site has excellent exposure to winds from the west to northeast directions, with open water fetch. Figure 2-5 is a view west toward the potential wind turbine site. To the southwest are a range of hills, so it was recommended that the turbine site be located as far north and near to the coast as feasible to reduce any possible shielding of the winds by the nearby hills.

The second village is located a few kilometers to the east-northeast of the first village and the third village is located about 800 m from the second village. A small rise was identified as being an excellent location for a potential SWECS. The second village has 36 residences and 4 stores, and the third village has 30 residences. The potential SWECS site is ideally located about equal distance between the residences and stores of the first village (about 200 m away) and is about 800 to 1000 m from the third village. The exposure at this site appeared slightly better than at the first SWECS site, as the second site was further removed from the hills to the southwest and at a higher elevation.

After leaving the second village, the team continued along the coast toward Cape Serrat. Near Cape Serrat, a strip-chart recording anemometer mounted on a 6-ft mast on top of a hill was being used to collect information for a project managed by the Germans. We were informed that the data from the site were sent to Germany for reduction and analysis and were given the appropriate contacts for possibly obtaining summaries of the wind data.

After leaving Cape Serrat, the team returned to Sidi Mechrig for dinner and then went back to Tunis.

VISIT TO NATIONAL METEOROLOGICAL INSTITUTE

On October 6, NASA, PNL, and STEG visited the National Meteorological Institute of Tunisia, with headquarters in Tunis, to discuss wind data needs

FIGURE 2-5. View Looking West at Possible SWECS Location For Site #1. Some of the village residences can be seen to the left.

and to obtain, if possible, data for selected stations in Tunisia. The Institute did not have wind data already summarized in the form desired by PNL, but agreed to provide logs of the 3-hourly wind data for the year 1981 for the stations requested: Bizerte, Jerba, Sfax, and Tabarka. Although it was agreed that five years of data would be more useful and representative for the wind assessments, the Institute said it could not provide that much data at the time but would send the additional data later. The primary purpose of obtaining the 3-hourly data was to analyze the diurnal and seasonal variation of the wind resource and the frequency distribution of wind speeds.

PERCEIVED ENERGY REQUIREMENTS AND SWECS RECOMMENDATIONS

Following the visits to Kerkenna Island and Sidi Mechrig, NASA and PNL consulted with GOT on the perceived energy requirements of the proposed sites and ranking the sites in importance. It was concluded that preference would be given to Sidi Mechrig because of the more immediate need for power and the higher estimated wind resource. Additionally, because of funding limitations, it was decided to concentrate efforts at Sidi Mechrig for now and perhaps later at Kerkenna Island if additional funds become available.

Based on input obtained through consultation with GOT and from the site visits, preliminary estimates of the perceived energy requirements were made for the two proposed village sites in Sidi Mechrig. The average energy requirements per residence were estimated to be 284 kWh/yr, based on the energy usage scenario shown in Table 2-1. Site 1 turbine(s) would need to supply the energy requirements for 27 residences, a school, clinic, and community house. The total perceived energy requirements for Site 1 were estimated to be 8240 kWh/yr. Site 2 turbine(s) was initially assumed to serve 66 residences and 4 stores, requiring 18970 kWh/yr. Assuming a 30% line loss, the energy generated by the turbines must be at least 11,770 kWh/yr at Site 1 and 27,100 kWh/yr at Site 2. Further, assuming a 20% loss in the electrical equipment of the SWECS, the energy generated by the turbines must be at least 14,710 kWh/yr at Site 1 and 33,870 kWh/yr at Site 2.

TABLE 2-1. Perceived Energy Usage for Residences in Sidi Mechrig

Item	% Residences	Watts	Hours/Day
3 lights	100	40	4
1 outside light	100	40	1
1 refrigerator	20	60	12
1 television	50	50	3
1 radio	100	5	10

The rated power output of a turbine needed to provide these energy requirements is estimated using Figure 2-6. Assuming a 6 m/s mean annual wind speed for both sites, we estimated that Site 1 should have at least a 5.6 kW rated turbine and Site 2 a 12.5 kW rated turbine to meet the perceived energy requirements.

TASK 3. COMPLETE WIND RESOURCE ASSESSMENT AND MAKE FINAL RECOMMENDATIONS OF SITES AND SWECS

After we returned to the United States, the wind data acquired from the National Meteorological Institute of Tunisia were processed and analyzed. These data consisted of one year of three-hourly wind speed and direction observations for three stations: Bijerte, Jerba, and Tabarka. The Bizerte and Tarbarka data were analyzed and evaluated in an effort to gain a better understanding of the wind characteristics along the north coast of Tunisia and at Sidi Mechrig. Figure 3-1 shows the approximate locations of the Bizerte and Tabarka stations and the Sidi Mechrig site.

Jerba's data were also processed and analyzed, but since Jerba's data were intended for use in estimating the wind resource at Kerkenna Island, the results of the data analysis will not be presented here. The only item to be pointed out here regarding the Jerba data is the discrepancy between annual wind speed computed for the year 1981 and the mean annual speed for the 10-year period 1961-1970 that was provided. The annual wind speed at Jerba for 1981 was 4.6 m/s, compared to a mean of 7.0 m/s given for the period 1961-1970. The 7.0 m/s value appears unrealistically high, compared to that at well-exposed offshore stations (see Figure 1-1). However, the 4.6 m/s value for 1981 is lower than expected (considering the apparently good exposure of the Jerba station), unless 1981 was a low wind speed year.

The following wind characteristics were computed and evaluated for Bizerte and Tarbarka:

- annual, seasonal, and monthly means of wind speed and energy flux
- diurnal (3-hourly) means of wind speed and energy flux
- mean wind speed and energy flux versus direction, and occurrence of direction
- frequency distribution of wind speed and Weibull function shape and scale factors.

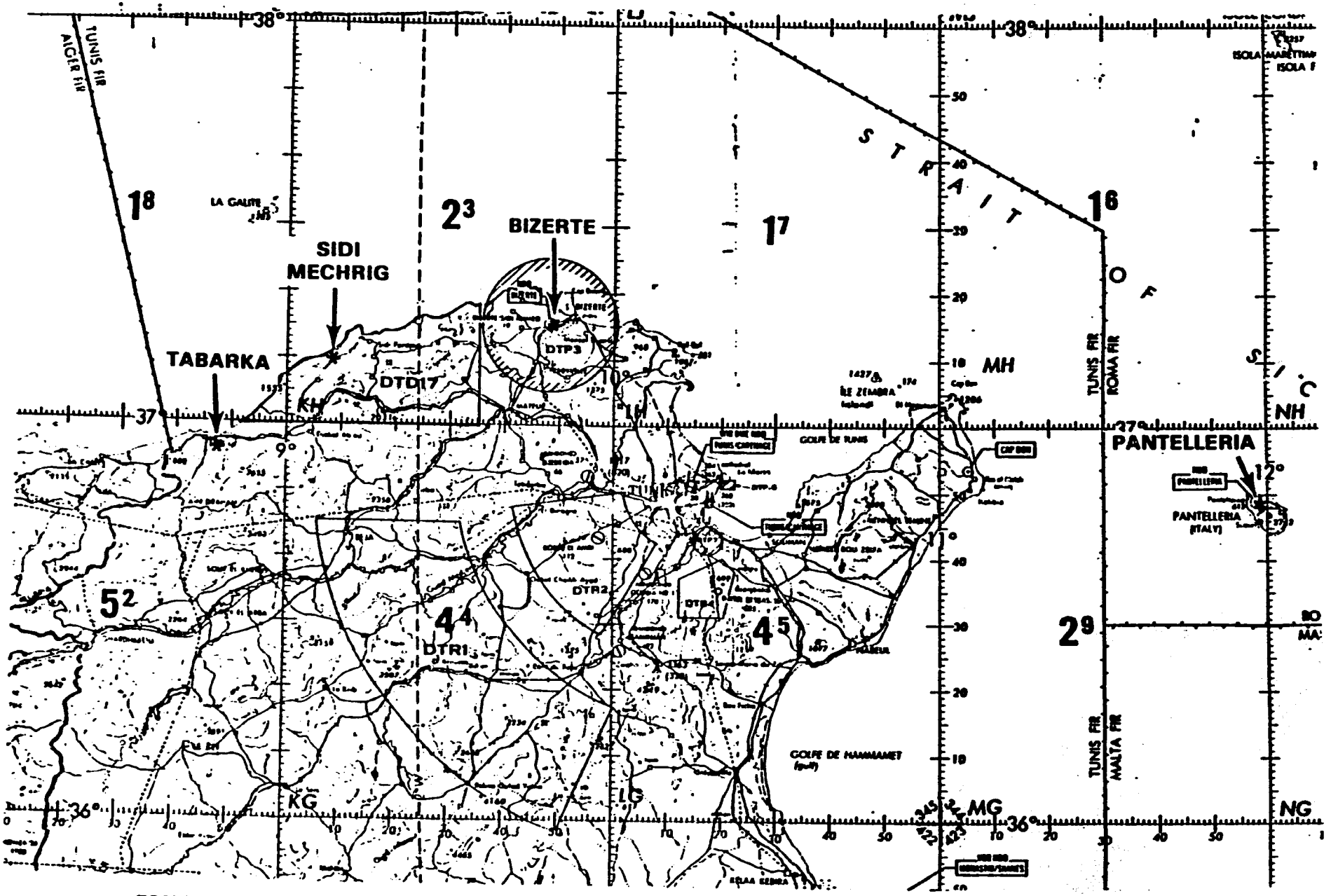

FIGURE 3-1. Northern Tunisia Region Showing Approximate Locations of Proposed Site at Sidi Mechrig and Meteorological Stations at Tabarka, Bizerte, and Pantelleria

Rather than present the results of all the data computations listed above, only the highlights of the data analysis will be discussed. A computer printout of the computations can be provided.

The values of Weibull distribution scale factors (c, m/s) and shape factors (k, dimensionless) are computed from the cumulative probability function (velocity duration curve) using a method described by Justus et al. (2). It must be pointed out that not all wind speed frequency distributions are adequately approximated by a Weibull distribution. In those cases where the distribution is not well approximated by the Weibull, the wind energy flux computed from the Weibull distribution may be significantly different from the wind energy flux computed from the actual frequency distribution.

The Rayleigh distribution has been found to provide a fairly adequate description of the wind speed distribution at many locations in the United States and other areas and, for this reason, has commonly been assumed for use in wind power estimates in the absence of actual distribution data. The Rayleigh distribution is a subset of the Weibull with $k = 2$. For values of k less than 2, such as $k = 1.5$, the distribution is typically broader or more skewed than the Rayleigh distribution, and the corresponding wind energy flux is greater than that of the Rayleigh (for the same mean wind speed). Conversely, for values of k greater than 2, such as $k = 2.5$, the distribution is typically more narrow than the Rayleigh distribution, and the corresponding wind energy flux is less than that of the Rayleigh (for the same mean wind speed).

Thus, for the reasons described above, the use of the actual (observed) wind speed frequency distribution or an approximated wind speed frequency distribution (derived from available data in the region at locations estimated to have similar wind characteristics) is more reliable than the use of an assumed distribution (such as the Rayleigh). However, given an observed distribution, it is useful to know how well the Rayleigh distribution or other Weibull distribution approximates the observed distribution. For convenience, the most desirable distribution (for the engineer) is probably the Rayleigh

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distribution, since most information regarding power estimates from wind machines usually relates to mean wind speeds based on a Rayleigh distribution. Conversely, the most undesirable distribution is probably one that is not well approximated by any Weibull distribution, such as a highly skewed distribution or distribution with more than one prominent peak in the frequency of occurrence.

TABARKA

At Tabarka the annual speed for 1981 was only 2.9 m/s and the energy flux 61 W/m^2. The maximum mean monthly speed was 5.6 m/s (January) and the minimum was 2.1 m/s (October). Calm conditions were observed 25% of the year. Mean hourly speeds (annual) ranged from 2.2 m/s at 0000 and 0300 LST to 4.4 m/s at 1200 LST and 4.1 m/s at 1500 LST. The most frequent directions were south (16%), north-northwest (11%), and west (10%). Highest mean wind speeds occurred with west-northwest winds (5%), averaging 5.5 m/s. The Weibull c and k are 3.52 m/s and 1.29, respectively. .The annual wind speed distributions - actual, Rayleigh, and Weibull - for Tabarka are shown in Figure 3-2. Thus, the Tabarka station's wind regime can be summarized as being mostly light and variable and sheltered to a considerable degree by local terrain. The wind characteristics at Tabarka are not expected to be very representative of the predominant wind conditions at Sidi Mechrig.

BIZERTE

At Bizerte the annual speed for 1981 was 4.5 m/s and the energy flux 162 W/m^2. The maximum mean monthly speed was 7.8 m/s (January) and the minimum was 3.2 m/s (March). (See Table 3-1.) Calm conditions were observed 12% of the year. Mean hourly speeds (annual) ranged from 3.1 m/s at 0300 and 0600 LST to 6.2 m/s and 6.7 m/s at 1200 and 1500 LST, respectively. Diurnal variations in wind speed and energy flux for the year, winter, and summer seasons are shown in Table 3-2. The most frequent directions were west-northwest (18%), west (16%), and northwest (9%). Highest mean wind speeds occurred with west-northwest winds (the most frequent direction), averaging 6.8 m/s. Although the Bizerte station is located 10 km south of the

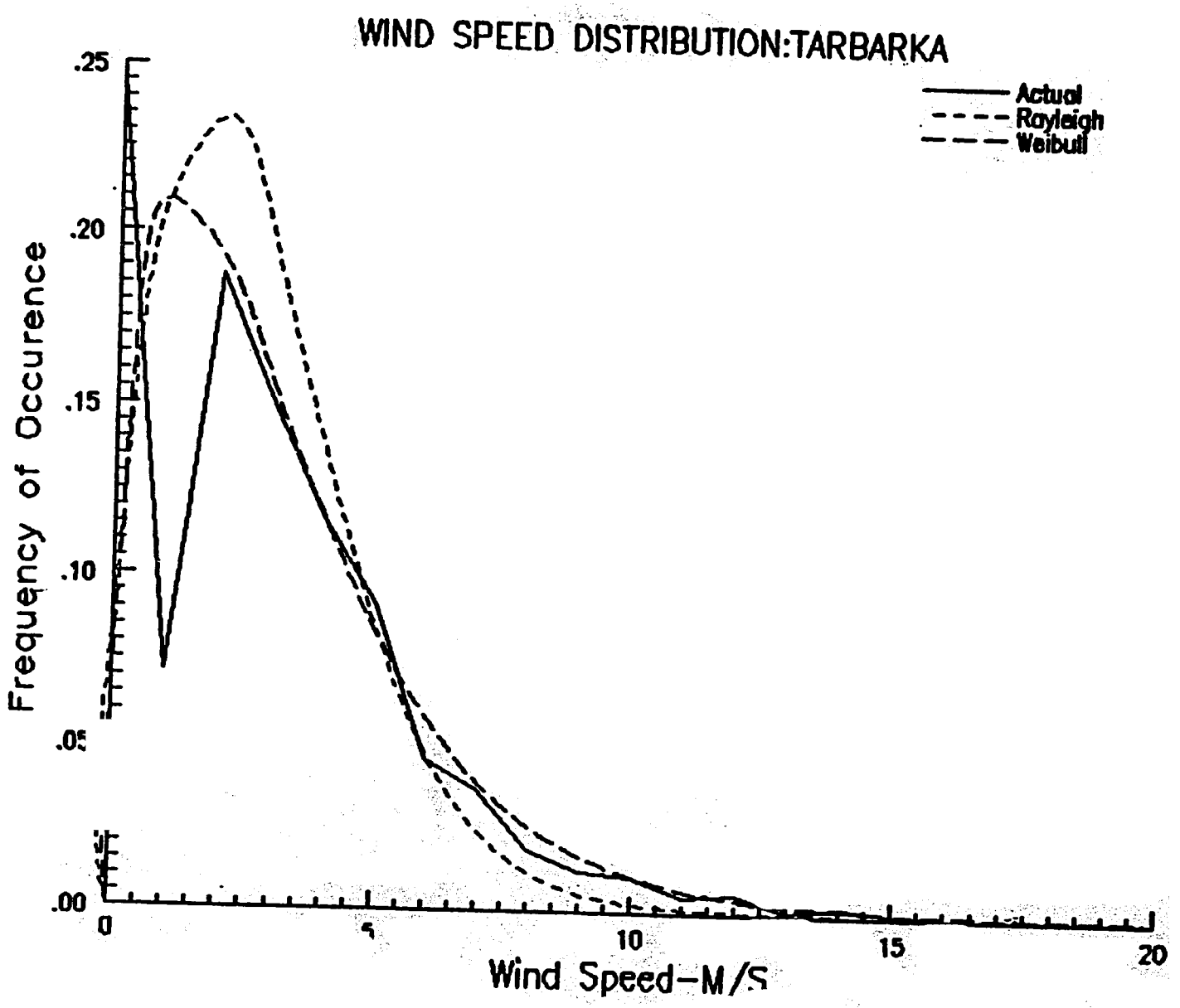

FIGURE 3-2. Wind Speed Frequency Distribution for 1981 for Tabarka, Tunisia

TABLE 3-1. Monthly Wind Speeds (m/s) and Wind Energy Fluxes (W/m^2) at Bizerte in 1981

Month	Speed (m/s)	Energy (W/m^2)
1	7.8	554
2	3.4	111
3	3.2	94
4	3.7	85
5	4.5	114
6	4.5	107
7	5.9	225
8	3.7	75
9	4.2	103
10	3.8	95
11	3.5	104
12	5.3	270
All	4.5	163

TABLE 3-2. Mean Wind Speed (m/s) and Energy Flux (W/m^2) Versus Time of Day at Bizerte in 1981

Hour (LST)	Wind Speed (m/s) and Wind Energy Flux (W/m^2)					
	Annual		Winter		Summer	
	m/s	W/m^2	m/s	W/m^2	m/s	W/m^2
0000	3.2	109	4.4	252	3.2	70
0300	3.1	101	4.7	260	3.0	61
0600	3.1	107	4.8	268	3.0	66
0900	4.9	170	5.8	307	5.1	151
1200	6.2	257	7.2	446	6.8	249
1500	6.6	276	7.1	452	7.2	261
1800	5.0	172	5.5	318	5.6	159
2100	3.6	109	5.0	240	3.6	70
All	4.5	163	5.6	318	4.7	136

Mediterranean coastline and with a low range of hills to the north of the station, average winds from the west to northwest directions are quite strong (5.2 to 6.8 m/s) and frequent (43% of all occurrences).

The annual wind speed distribution (actual, Rayleigh, and Weibull) for Bizerte are shown in Figure 3-3. The Weibull c and k are 5.23 m/s and 1.46, respectively. The corresponding wind energy fluxes computed from the actual, Rayleigh, and Weibull distributions in Figure 3-3 are 162.6 W/m^2, 104.9 W/m^2, and 183.7 W/m^2, respectively. Thus, the annual wind speed frequency distribution at Bizerte is definitely not well approximated by the Rayleigh and only fairly approximated by a Weibull distribution.

In Summary, there are three notable features about the wind characteristics at Bizerte in 1981:

1. Most of the wind energy resource comes from the west to northwest sector.

2. Most of the wind energy resource occurs between late morning and late afternoon (e.g., wind energy flux during this period averages 2 to 3 times greater than that during the night and early morning hours).

3. The monthly mean wind energy resource can vary enormously (e.g., January averaged 554 W/m^2 and March only averaged 93 W/m^2).

It is anticipated that these features will be reflected at Sidi Mechrig, but the magnitude of the wind resource should be significantly greater at Sidi Mechrig than at Bizerte.

PANTELLERIA ISLAND

Pantelleria Island is located in the Straight of Sicily between Tunisia and Sicily. However, it is the nearest meteorological station to Sidi Mechrig that has excellent exposure to the prevailing strong northwest winds of the northern Tunisian region. Figure 3-1 shows the approximate location of the meteorological station on Pantelleria Island. The elevation of the station is 538 m MSL and the period of record is 1957 to 1971. The mean annual wind speed of Pantelleria is 5.6 m/s; however, the mean annual wind energy flux is

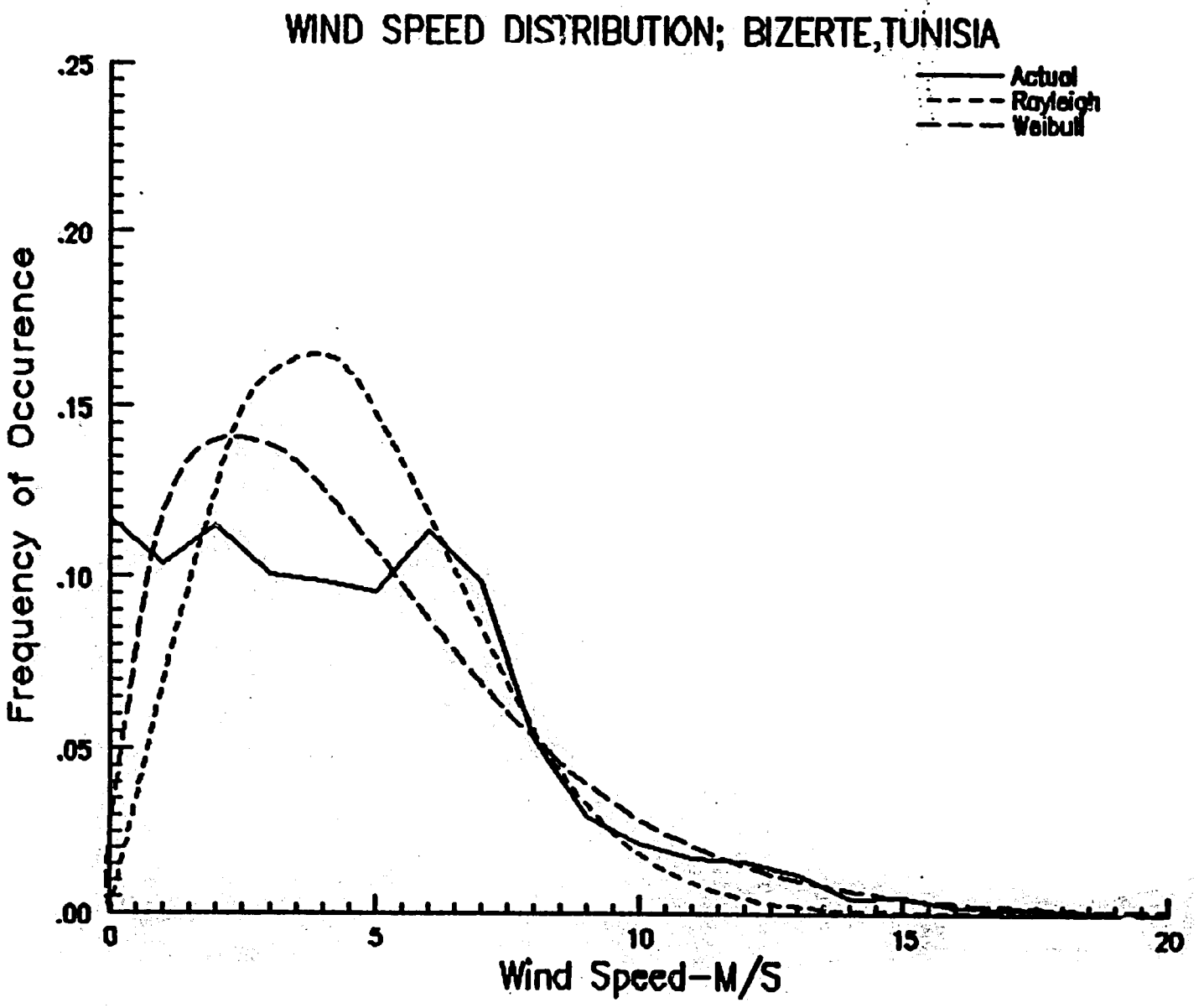

FIGURE 3-3. Wind Speed Frequency Distribution for 1981 for Bizerte, Tunisia

301 W/m^2, calculated from the actual wind speed frequency distribution, shown in Figure 3-4. This energy flux is equivalent to a Rayleigh distribution with a mean speed of 6.4 m/s. An interesting feature in the annual wind speed frequency distribution for Pantelleria is high percentage of calms (12.8%) and high percentage of wind speeds greater than 16 knots, 8.2 m/s or 18.3 mph (23.5%). Wind speeds exceed 10 knots, 5.14 m/s or 11.5 mph 45.8% of the time annually, with seasonal percentages as follows: winter, 61.1%; spring, 50.4%; summer, 31.1%; and autumn, 40.1%. The seasonal wind speeds and energy fluxes for Pantelleria are given in Table 1-3 (see Task 1), and the frequency distributions of wind speeds are given in Table 3-3.

TABLE 3-3. Percent Frequency of Occurrence of Wind Speeds at Pantelleria Island. Period of record 1957 to 1971. Number of observations 20,664.

	Mean Speed (kts)	Wind Speed Interval (knots)									
		Calm	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	40-46
Winter	13.6	8.8	2.6	10.3	17.4	25.9	17.9	11.2	4.1	1.4	0.4
Spring	12.1	10.6	4.7	13.7	20.6	23.8	11.7	8.4	4.5	1.7	0.4
Summer	8.4	16.7	9.4	21.1	21.7	18.5	6.8	4.0	1.4	0.3	0.1
Autumn	10.1	15.0	6.0	16.0	22.9	21.0	9.3	6.6	2.5	0.7	0.1
Annual	11.0	12.8	5.6	15.2	20.6	22.3	11.4	7.5	3.1	1.0	0.2

The Weibull distribution scale and shape factors are given in Table 3-4. Values of the Weibull factors have been computed two ways - with occurrences of calms and without occurrences of calms in the observed wind speed frequency distribution. Even without calms, the annual Weibull k is 1.29, indicative of a very broad distribution in comparison to the Rayleigh distribution.

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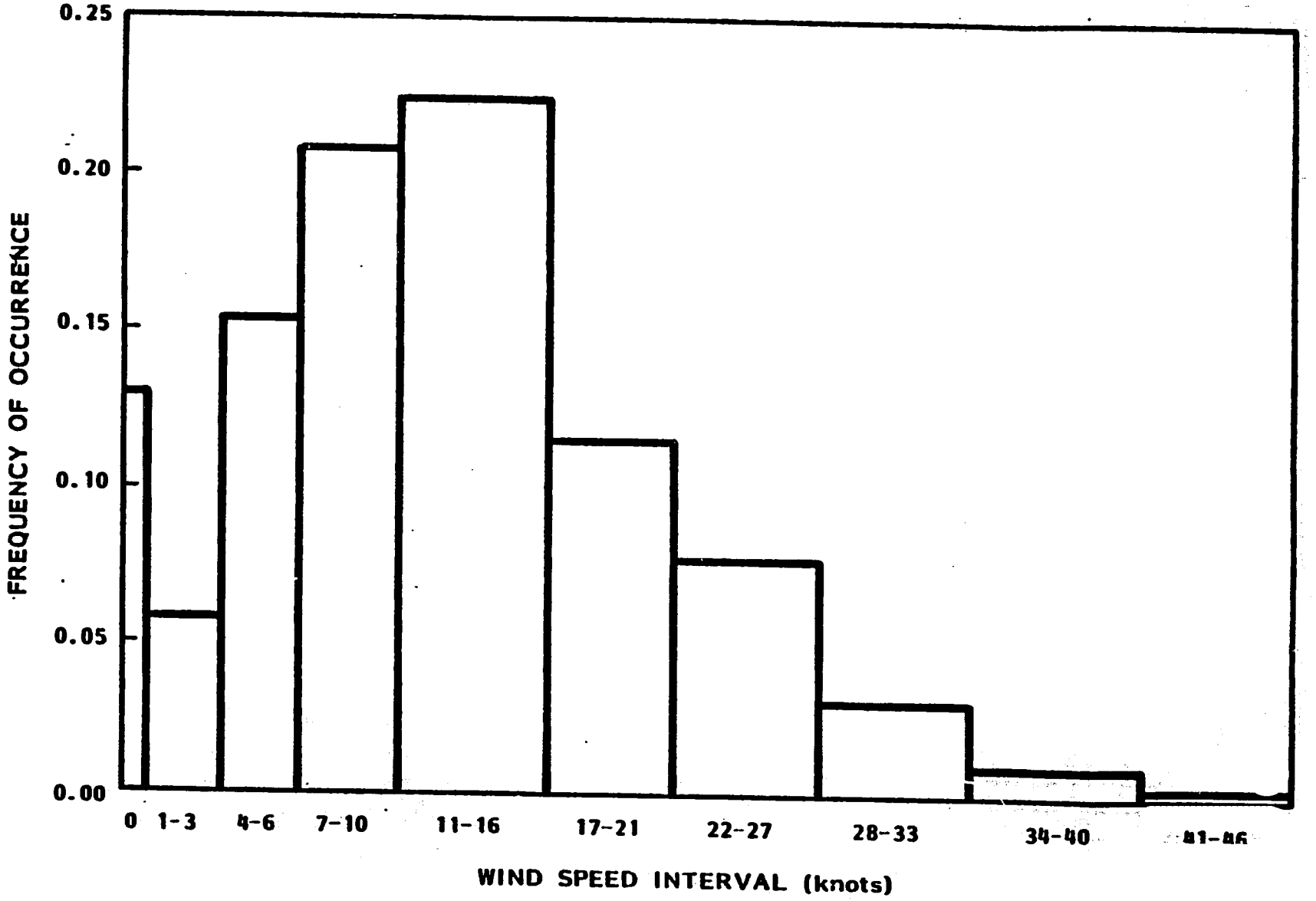

FIGURE 3-4. Histogram of Annual Wind Speed Frequency Distribution for Pantelleria Island

TABLE 3-4. Calculated Seasonal and Annual Values of Weibull Distribution Scale Factors (c, m/s) and Shape Factors (k, dimensionless) for Pantelleria Island

	V (observed) m/s	Weibull Factors			
		With Calms		Without Calms	
		c, m/s	k	c, m/s	k
Winter	6.99	6.42	1.24	7.22	1.52
Spring	6.22	5.65	1.15	6.39	1.36
Summer	4.32	3.79	1.04	4.37	1.22
Autumn	5.19	4.50	1.08	5.24	1.30
Annual	5.65	5.18	1.07	5.85	1.29

Although it is anticipated that the mean wind speeds and energy fluxes at Sidi Mechrig may be slightly lower than at Pantelleria, the seasonal variation and the shape of the wind speed frequency distribution curve are expected to be similar to that of Pantelleria, due to the nature of weather pattern climatology over the northern Tunisian region.

ADDITIONAL WIND DATA

In the late 1940's and early 1950's, eleven stations in Tunisia were instrumented with wind energy counters (3). However, there are considerable omissions in the data on which means are based, and the anemometer heights varied from 12 to 47 m among the eleven stations. Thus, the wind energy estimates must be used with this caution in mind. Table 3-5 gives the seasonal and annual wind energy fluxes for the four stations on the north coast. Cap Serrat and Cap Bon appeared to be located on relatively high terrain features where the speed of the air flow was probably enhanced by the terrain feature. Ile Cani and Ile Plane are two small islands east of Bizerte and north of Tunis. The seasonal wind energy fluxes show maximum resource in the winter and a minimum in the summer, except at Cap Bon where the winter and spring resources are about equal. Sidi Mechrig's wind resource is anticipated to be slightly less than that at Ile Cani and Ile Plane since the islands appear to have excellent exposure to winds from all directions, whereas

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TABLE 3-5. Seasonal and Annual Wind Energy Flux at Stations on North Coast of Tunisia

Station	Altitude (m)	Sensor Height (m)	Wind Energy Flux (W/m^2)				
			Win	Spr	Sum	Aut	Annual
Cap Serrat	188	28	1090	770	430	645	730
Ile Cani	18	24	580	425	205	425	410
Ile Plane	8	16	365	285	180	240	270
Cap Bon	393	28	1190	1200	725	990	1030

Sidi Mechrig has excellent exposure to winds from the west to the northeast directions (clockwise). However, since most of the wind energy resource has been estimated to come from the northwest quadrant, Sidi Mechrig may have as much as 80 to 90% of the wind energy potential of the islands. On the other hand, if the terrain is acting to channel and enhance the winds at Sidi Mechrig, it could even have greater energy potential than the islands. During the warmer months (April to September), the wind resource may be greater at Sidi Mechrig than at the small islands (Ile Cani and Ile Plane) because of an anticipated stronger sea breeze circulation and greater wind speeds from 1100 to 1700 LST at Sidi Mechrig than at the islands.

ESTIMATED WIND CHARACTERISTICS AT SIDI MECHRIG

Based on the results of this comprehensive data analysis, the annual, seasonal (winter and summer), and diurnal wind speeds at Sidi Mechrig will be estimated. Since SWECS power output estimates are usually related to mean wind speeds that assume a Rayleigh wind speed frequency distribution, equivalent Rayleigh distribution wind speed estimates (as opposed to actual wind speed estimates) will be used. The mean annual wind energy flux at Pantelleria Island is 300 W/m^2, which is equivalent to a Rayleigh distribution mean speed of 6.4 m/s, although the actual speed was 5.6 m/s. Table 3-6 provides the estimated (derived) wind speeds (Rayleigh equivalent) for Sidi Mechrig. The mean annual and seasonal (winter and summer) wind speeds were estimated by assuming the wind energy flux at Sidi Mechrig is 75% of that at Pantelleria Island (given in Table 1-3) and calculating the equivalent Rayleigh wind speed that corresponds to the estimated wind energy flux. The

TABLE 3-6. Estimated Wind Speeds for Sidi Mechrig at 10 m Above Ground

Hour (LST)	Mean Wind Speed (m/s) Annual	Winter	Summer
0000-0600	5.1	6.1	3.8
0600-1200	6.0	6.7	5.1
1200-1800	6.6	7.2	5.8
1800-2400	5.4	6.2	4.4
All	5.8	6.5	4.8

annual and seasonal diurnal wind speeds were estimated by scaling the mean annual and seasonal wind energy fluxes at Bizerte (given in Table 3-2) to match the estimated fluxes at Sidi Mechrig and then scaling the diurnal fluxes and calculating the equivalent Rayleigh wind speeds.

For example, the mean annual wind energy at Pantelleria Island is 300 W/m^2. The estimated mean annual wind energy flux at Sidi Mechrig is 75% of 300 W/m^2, or 225 W/m^2. This corresponds to a Rayleigh distribution wind speed of 5.8 m/s. The annual wind energy flux at Bizerte is 163 W/m^2 (from Table 3-2). The annual diurnal wind energy fluxes at Sidi Mechrig are estimated by multiplying the diurnal fluxes at Bizerte by the ratio 225/163 or 1.38, which is the ratio of the estimated annual flux at Sidi Mechrig to the annual flux at Bizerte. (This approach assumes that the diurnal variations at Sidi Mechrig are of the same trend and magnitude as those at Bizerte.) Then, the wind speeds corresponding to a Rayleigh distribution with these equivalent wind energy fluxes are calculated. These are the values shown in Table 3-6.

The Sidi Mechrig wind speed estimates in Table 3-6 are for 10 m above ground level. Assuming the hub height of the turbine is at 60 ft (18.3 m), the average wind speeds would be about 10% greater than those given. For example, the estimated annual wind speed at 60 ft (18.3 m) would be 5.8 m/s plus 0.58 m/s (10% of 5.8 m/s) or about 6.4 m/s. If the turbine hub were at 80 ft (24.4 m), then the average speed would be about 13% greater than at 10 m or about 6.6 m/s. The mean rate of increase of wind speed with height

above ground typically varies with time of day and wind speed. The wind shear is typically greater at night and early morning than in the afternoon (see Table 1-2) and decreases with increasing wind speed. However, for the purposes of this assessment, these variations in the shear will be ignored.

REVISION OF PERCEIVED ENERGY REQUIREMENTS AND SWECS RECOMMENDATIONS

In Task 2, preliminary estimates were made of the perceived energy requirements. However, based on updated information from the GOT, it was necessary to revise the estimates of the perceived energy requirements for Sites 1 and 2 in Sidi Mechrig. The new scenario for the village to be supplied by the Site 1 turbine is 25 residences, a clinic, a community house and a school. The school would operate only during the daytime and would not need lighting or electricity. The revised total perceived energy requirements for Site 1 are 7446 kWh/yr. (The average perceived energy requirements for each household is 284 kWh/yr, based on the energy usage given in Table 2-2.) The new scenario for Site 2 is 35 residences, 3 stores, and one grain grinder. The revised total perceived energy requirements for Site 2 are 10,330 kWh/yr.

The energy requirements are not constant but will vary with time of day and with season of the year. Since the major energy usage is for lighting, the energy requirements will be greater in the evening hours (1800 to 2400 LST) than during the rest of the day and greater in the winter than in the summer since days are shorter in the winter. In this evaluation, however, the seasonal variation of the energy usage will be neglected. The perceived energy requirements estimated for a typical day for each site are shown in Table 3-7. The estimated peak power demand occurs at 2100 LST and is 3245 W at Site 1 and 4535 W at Site 2.

Assuming a 30% line loss, the energy generated by the turbine must be at least 10,637 kWh/yr at Site 1 and 14,757 kWh/yr at Site 2. Further, assuming a 20% loss in the electrical equipment of the SWECS, the energy generated by the turbines must be at least 13,296 kWh/yr at Site 1 and 18,446 kWh/yr at Site 2.

TABLE 3-7. Variation of Peceived Energy Requirements in a Typical Day at Sidi Mechrig

Time (LST)	Energy Requirements (Watt-hr) Site 1	Site 2
0000-0600	725	1015
0600-1200	1450	2030
1200-1800	4370	6040
1800-2400	13890	19170
Total	20400	28300

Assuming that the wind turbine would be installed on a 60-ft tower, the estimated mean annual wind speed for both sites is 6.4 m/s at 60 ft. (This mean wind speed assumes a Rayleigh wind speed frequency distribution). Typical year-to-year variations in the annual wind speeds are 5 to 10% of the long-term mean. Therefore, to be conservative and to size the turbine for the low wind speed years, a mean wind speed of 6 m/s will be used. From Figure 2-6, it is estimated that Site 1 should have at least a 5-kW rated turbine and Site 2 a 7-kW rated turbine to meet the perceived energy requirements.

Comparing Tables 3-6 (the diurnal variation of wind speed) and 3-7 (the diurnal variation of the energy requirements), it is apparent that the winds and the power demand are somewhat out of phase. The maximum power demand is from 1800 to 2400 LST, whereas the maximum mean winds are 1200 to 1800 LST. Adequate battery storage is essential to meet the increased power demand as the winds diminish, especially in the summer when the mean speed for 1800 to 2400 LST is only 4.4 m/s at 10 m (or about 4.8 m/s at 60 ft hub height).

INVENTORY OF APPROPRIATE SWECS

An inventory of SWECS under 25-kW rated available in the United States was carried out and is summarized in Table 3-8. This is not expected to be a complete list as information was not received from several manufacturers (although it is anticipated that some of those may no longer be in business)

and additional SWECS may be available than shown in Table 3-8. It is anticipated that stand-alone SWECS in the 2-kW to 10-kW rated range will be most appropriate for the potential sites at Sidi Mechrig. Although the rated power output needed from wind turbines at Sites 1 and 2 is estimated to be about 5 kW and 7 kW, respectively, two or more smaller rated turbines (e.g., 2 to 4 kW rated) could possibly be combined to meet the perceived energy requirements, if this proves to be economical. There are fourteen different stand-alone SWECS listed in Table 3-8 that fall within the 2-kW to 10-kW rated range; these are denoted by asterisks. However, two of the machines (Aerowatt and Bertoia) appear to be designed more for low-to-moderate wind speed regimes and may not be suitable for the estimated high wind regime of Sidi Mechrig. Survival wind speeds for the machines should be at least 100 mph (45 m/s), because of the powerful storm winds that are anticipated to occur at Sidi Mechrig. The maximum wind speed observed at Bizerte, a more sheltered site than Sidi Mechrig, in 1981 was 72 mph (32 m/s) on January 20. Another hazard that should be considered in the SWECS selection is sea salt corrosion. It is estimated that the winds will be from the Mediterranean Sea (west to northeast directions) about 60% to 70% of the time.

Another important consideration in selecting appropriate SWECS is the manner in which the tower and generator will be transported and installed at the sites. The accessibility to the sites is via a narrow dirt road across mountainous terrain, which could require four-wheel drive, especially in the rainy season. Thus, consideration should be given to the size and type of vehicle needed to transport the tower and generator to the site. The installation and maintenance of the tower and generator should not require the use of a crane because of the difficulty of getting a crane to the site.

TABLE 3-8. Commercially Available Small Wind Systems (25-kW Rated and Smaller)

Manufacturer	Machine	Output	Est. Annual Output (kWh)	Comments
Aerolite, Inc.	Aerolite 1200/12		15,300 at $\bar{V}$=12 mph	Utility tie-in. Induction generator.
*American Energy Savers, Inc.	Model 5-24	5 kW at 24 mph	12,000 at $\bar{V}$=12 mph	Stand alone. Perm. magnet, 3-phase alternator. Max power 8 kW at 32 mph. Tested at Rocky Flats. Survival speed >120 mph. Installed throughout Midwest U.S. and sold unit to China. Can increase rotor diameter from 19 to 24 ft and max power to 12 kW.
Astral Wilson Company	AW 10-C	10 kW at 27 mph	18,000 at $\bar{V}$=12 mph	Utility tie-in. Induction generator.
*Automatic Power, Inc.	Aerowatt 4100 FP7	4.1 kW at 16 mph	13,000 at $\bar{V}$=10 mph	U.S. distributor for Aerowatt Generators out of Paris, France. Stand alone. Available in five sizes from 28 to 4100 W. Three-phase A-C power. Designed for low-to-moderate wind speed regimes.
	Aerowatt 1100 FP7	1.1 kW	3,900 at $\bar{V}$=10 mph	
Bergey Windpower Co., Inc.	BWC 1000	1.0 kW at 24.5 mph	2,200 at $\bar{V}$=12 mph	Stand alone. Survival speed 120 mph. Furling speed 30 mph.
*Bertoia Studio, Ltd.	AES-3	4 kW	Not Available	Stand alone. Three-bladed downwind rotor. Operating range of 7-21 mph. Rated speed is 1.7 times annual average speed. Survival speed 80 mph. Machine designed for low-to-moderate wind speed regimes.
*Bircher Machine, Inc. (Kanapolis, Kansas)		4 kW	Not Available	Stand alone. Rocky Flats lists as a manufacturer of a 4 kW system.
Carter Wind Systems, Inc.	Carter 25	25 kW		Utility tie-in. Induction generator.
*Elfin Corporation	Elfin 750	10 kW at 26 mph	17,000 at $\bar{V}$=12 mph	DC generator available for operation as a stand-alone system. 125 mph survival speed. Special protective treatments for salt spray.
Enertech Corp.	Enertech 1800	1.8 kW	4,320 at $\bar{V}$=12 mph	Utility tie-in. Induction generator.
	Enertech 4000	4.0 kW	9,720 at $\bar{V}$=12 mph	Utility tie-in. Induction generator.

TABLE 3-8 (continued)

Manufacturer	Machine	Output	Est. Annual Output (kWh)	Comments
Hedan U.S.A.	Model XS	12 kW at 18 mph	42,000 at $\bar{V}$=12 mph	Utility tie-in. Induction generator. Maximum power 20 kW at 24-27 mph. 16 kW rated turbine also available.
*Hummingbird Windpower Corp.	Hummingbird AXP 6000 RIN	6 kW at 26 mph	8,400 (?) at $\bar{V}$=12 mph	Stand alone. Direct current (DC) output, full wave, 3-phase rectified power for charging a battery bank. 110 VDC (nominal), 140 VDC cut-off (shut down).
*Jacobs Wind Electric Co.	Jacobs 10 kW	10 kW at 25 mph	Not Available	Stand alone system delivers up to 10 kW at nominal 120 volts D.C. to charge batteries. System requires a 56-cell, 120-volt battery.
	Model 60X	About 3 kW	>4,800	No longer available. In production from 1930-1960.
Megatech Corp.	Model WIP-A1	0.4 kW		Only 400-Watt system available.
*Millville - Hawaii Windmills, Inc.		10 kW at 25 mph 15 kW	Not Available	Can be self-exciting. 15-kW machines are in operation in Taiwan, Texas, and Michigan. 10-kW machine tested at Rocky Flats. Rated output of system can be changed. 90% units manufactured were for grid interface.
*North Wind Power Company	HR2	2.2 kW at 20 mph	6,600 at $\bar{V}$=12 mph	Stand alone. Has survived winds of 160 mph. Available in 24, 48, 110 vdc output.
*	L16	6 kW	20,600 at $\bar{V}$=12 mph	Single phase output. Snychronous alternator.
		14 kW	31,100 at $\bar{V}$=12 mph	Three phase output. Synchronous alternator.
Product Development Institute	Model 6500	6.5 kW at 26 mph	12,000 at $\bar{V}$=12 mph	Utility tie-in. Induction generator.
*Sencenbaugh Wind Electric	Sencenbaugh 2000	2 kW		Stand alone. 24 VDC.
	Sencenbaugh 1000	1 kW at 23 mph	2,550 at $\bar{V}$=12 mph	Stand alone. 24 VDC - widely tested in remote, harsh environments. Alaska and Colorado Rocky Mountains.

TABLE 3-8 (continued)

Manufacturer	Machine	Output	Est. Annual Output (kWh)	Comments
*Whirlwind Power Company	Model AA	4 kW at 22 mph 2 kW at 25 mph	Not Available	Stand alone systems for battery storage. Tested at Rocky Flats.
Winco	Windcharger	0.45 kW 0.25 kW	Not Available	Produces only 450W and 250W rated systems.
*Windworks	Windworker 10	9 kW at 20 mph	30,500 at $\bar{V}$=12 mph	Can be operated as stand-alone system.

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APPENDIX A

RECOMMENDATIONS FOR A WIND MONITORING PROGRAM AT SIDI MECHRIG

Two candidate sites have been identified at Sidi Mechrig for potential installation of SWECS. However, in the absence of wind data at Sidi Mechrig and any representative wind data along the coast of northern Tunisia, the wind resource estimates for the sites at Sidi Mechrig must be considered very preliminary. Thus, it is highly recommended that a wind monitoring program be initiated at Sidi Mechrig prior to the installation of SWECS. Although it is usually advised that at least one year of data be collected and evaluated prior to a SWECS installation, even just three to six months of data can provide a good indication of the estimated magnitude of the wind resource and the nature of the site's wind characteristics. These short-term data can be utilized in refining or adjusting the long-term wind resource estimates at Sidi Mechrig by comparison with conventional, existing data from the northern Tunisian region during the same time period.

The wind monitoring equipment should collect wind speed and direction data at a minimum height of 30 ft (9.1 m) above ground and should be located at or very near the candidate SWECS sites. Other useful meteorological information or data that should be recorded or capable of being processed from the data are the peak gust speed, the peak sustained wind speed, and the turbulence intensity. The equipment should be capable of collecting and recording or processing data unattended for periods of at least one month duration.

The wind monitoring equipment should be simple to maintain and to extract the data so that local personnel can be trained to reliably perform these services. The wind monitoring equipment should have been tested in and performed well in harsh environments where high wind speeds occur.

PNL has developed an accurate, reliable, and low-cost system suited for this purpose. This system is especially attractive in that it makes use of an advanced data field unit that field-processes and stores the wind data.

The data acquisition system consists of six components as shown in Figure 1. Wind sensors, consisting of a cup anemometer and a wind vane are mounted atop a mast or other tall structure. These sensors produce data in electrical form that is sent to a field unit. In this case, the field unit is known as the Wind Prospector's Instrument (WPI), which is a microprocessor-based data processor and storage device developed at PNL.

The sensors and the WPI remain in the field at all times during the measurement program. Figure 2 shows these units installed on the field. In this situation the wind sensors are located on a mast at a height of 30 feet.

The packet-size control and readout panel is brought to the field and plugged into the WPI when the instrument site is visited. Using it, one can extract data from the WPI and check on the health of the instrument. The data are transferred, in tone-encoded form, to a standard audio tape recorder. This recorder is usually a hand-held recorder that uses conventional audio cassettes. The cassettes are taken to the data processing facility where they are played back through a demodulator into any data or computer terminal with an RS-232 port. (Most terminals are equipped with this port.)

The heart of this system is the WPI. It is shown, along with the control and readout unit, in Figure 3. The WPI is an entirely electronic device and contains no moving parts. The electronics are enclosed in the 5.5 x 12.5 x 24.0 cm drawn aluminum drip shield. The instrument is powered by a 6-V lead-calcium rechargeable battery that is recharged using a small solar panel. In the unlikely event of a panel failure, the battery can keep the instrument operational for over a month. On the instrument's base is a terminal board for connection to the wind sensors and solar panel, and a small 9-pin connector into which the control and readout panel is connected when making a site visit. In this figure, the control and readout panel is plugged into the WPI.

The control and readout panel is used to perform all the normal operations that occur during a site visit. The keyboard is used to enter commands that control, for example, the extraction of data from the unit. A

response to a command is displayed on the liquid crystal display, and this response can be used to check if the command has been executed properly.

A normal site visit, which would include an extraction of data from the WPI and a visual check of the mast (or other supporting structures) and the sensors, can be completed by one individual in less than 15 minutes. The transfer of data from the WPI to the audio cassette takes only 3-1/2 minutes. It is recommended that two transfers of data be made to provide a backup copy of data. As two key strokes must be made simultaneously to clear the memory of old wind data, the chance of inadvertent data loss is minimized.

The field components of the data acquisition system--the sensors, mast (when used) or solar panel, and WPI--are neither heavy nor cumbersome and they are easily transported to the wind measurement site. When the sensors are placed at the 30-ft height, requiring a three-section mast, the entire system can be assembled and erected in about one hour by two people. Positioning the sensors at higher levels using more mast sections, will involve more time and an additional person. Once the system is erected, data collection can begin almost immediately. The field components have been used in harsh environments where high wind speeds and icing occur and have performed well.

PNL could provide instruction to designated Tunisian personnel on extracting data from the WPI at the wind monitoring sites, performing tests to check on the proper functioning of the equipment, and performing maintenance activities. Tunisian personnel could be shown how to replace, or repair, components of the wind sensors, which may be necessary if physical damage is found during a site inspection or if a part fails to operate properly. Spare parts could be provided by PNL to be kept by the Government of Tunisia for the replacement of any defective item.

It is expected that Tunisian personnel would visit each field site at least once every month to perform the following tasks:

1) testing of equipment performance
2) maintenance and necessary repairs
3) extraction of stored data.

The data extracted from the WPI would be put on an audio-cassette tape. At the extraction time, two tape copies would be made. One copy would be kept by the Government of Tunisia and the other cassette tape would be sent to PNL for processing and data analysis.

The data processing is made quite simple since the WPI does a considerable amount of field processing. The instrument acquires wind speed and direction data measured by the wind sensors once every 1.5 seconds. These high frequency data are averaged over a 6-min interval, then the averaged data are processed by the WPI to yield the following wind statistics:

- a wind speed frequency histogram
- a joint distribution of wind speed versus wind direction
- a joint distribution of wind speed versus time of day
- a joint distribution of wind direction versus time of day
- a turbulence intensity frequency histogram (using standard deviations based on the 1.5-sec sampling rate)
- recording of peak gust speed (maximum 1.5-sec speed) and peak sustained wind speed (maximum 6-min average speed).

These statistics are for the time interval between data extractions (about one month).

The WPI also computes frequency distributions of other useful meteorological parameters including temperature and solar panel current output. The solar panel output is a crude measure of solar insolation, and the temperature is measured roughly with a thermistor attached to the base of the WPI.

The audio cassette with the above statistics would be read through a demodulator into a Hewlett-Packard 2647A Graphics Terminal at PNL. This stand-alone microcomputer can display the data and produce graphs and tables of the wind characteristics. The graphs and tables would be used to check the data for reasonableness and to make a preliminary evaluation of the wind characteristics at each site.

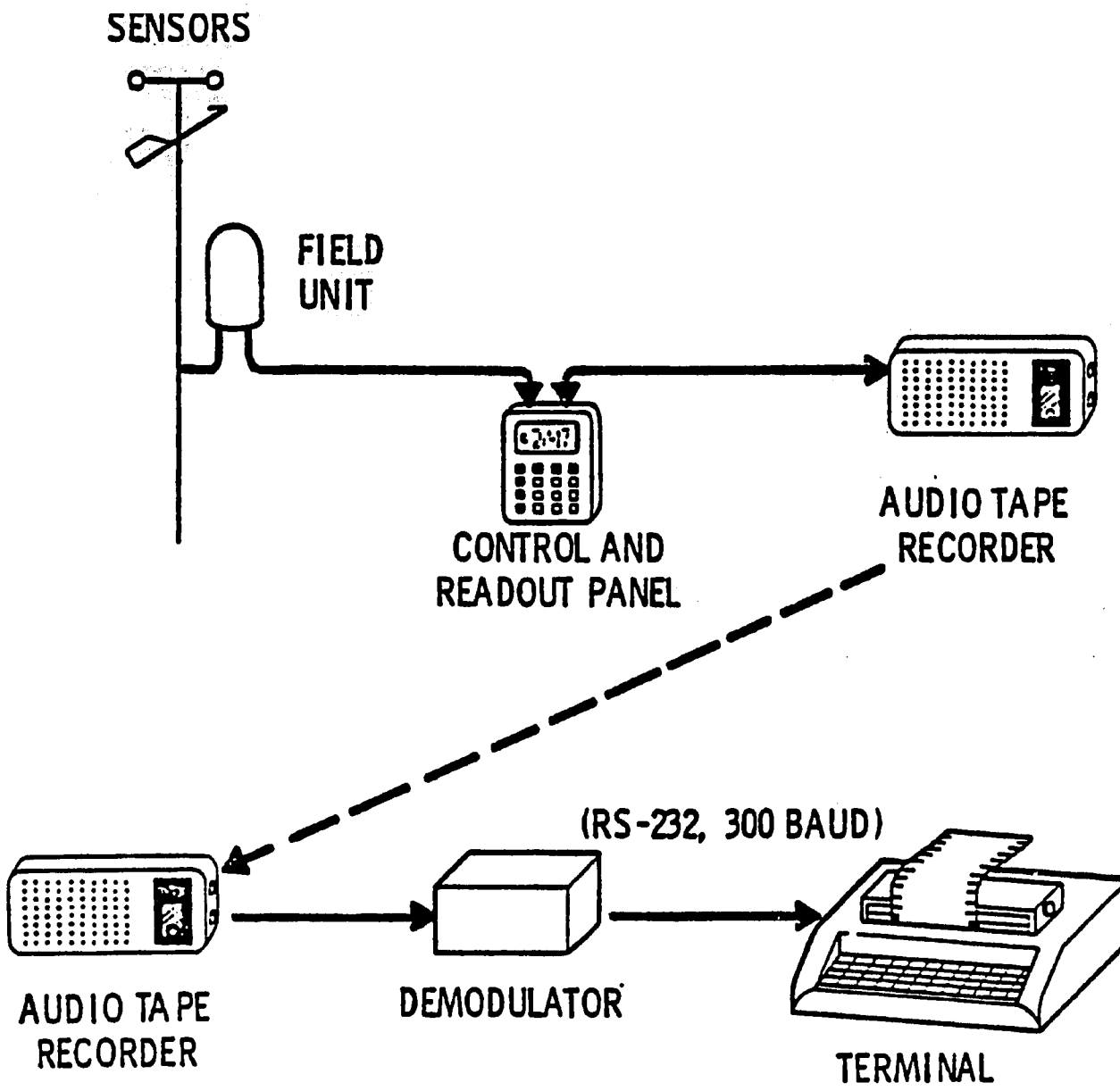

FIGURE 1. The System - Its Parts

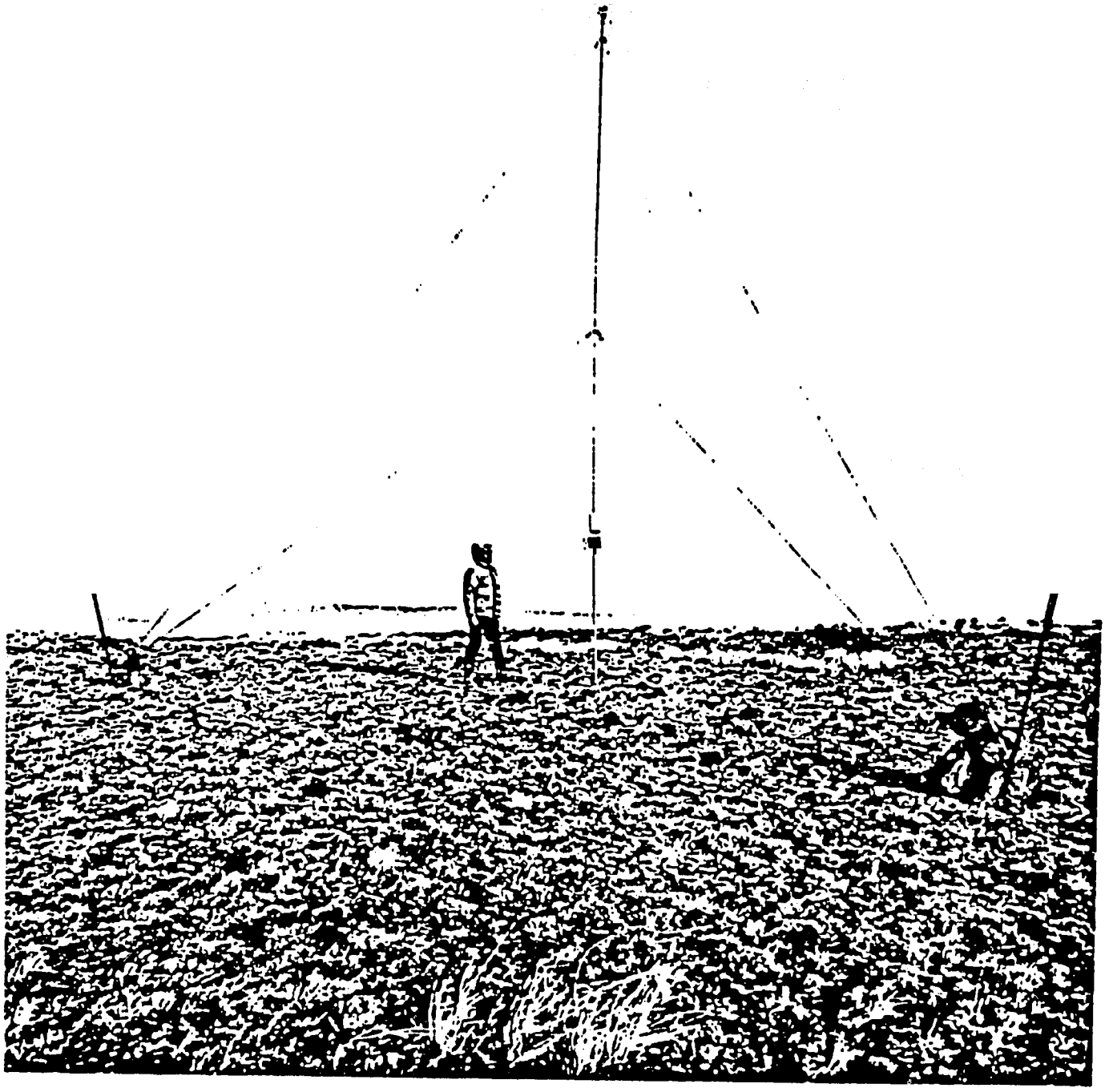

FIGURE 2. A Prospector Installation

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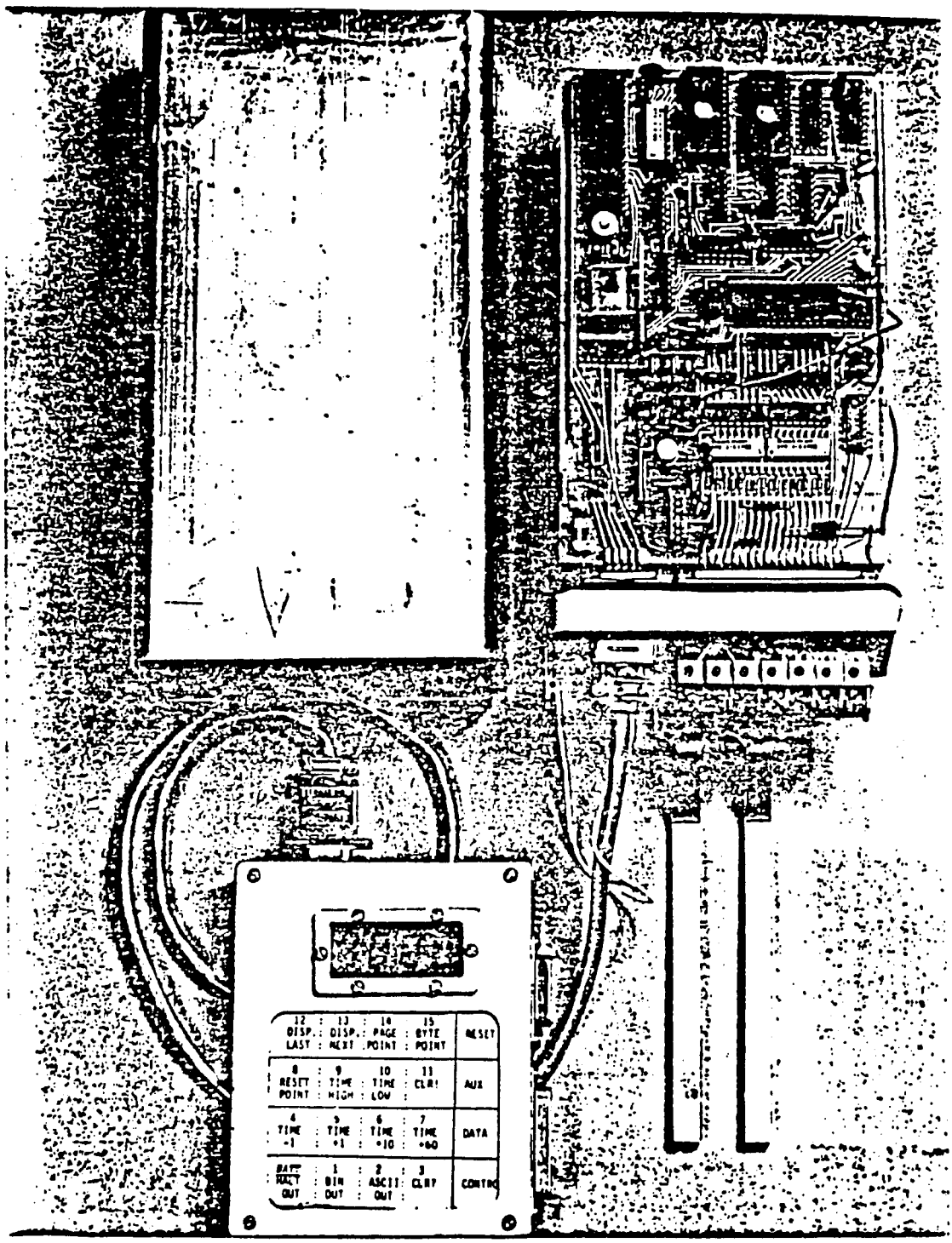

FIGURE 3. Field Unit and Control Panel

Meteorological Stations in Tunisia

Task I	Supply Tunisia with three meteorological units for measuring wind speed, wind direction, insolation and ambient temperature. o 30 ft towers o Solar panels with 6 v batteries o Microprocessors with tape	$15K
Task II	PNL personnel (2 for 1 week) to install and train GOT.	11K
Task III	Process tapes for 1 year at PNL.	9K
Task IV	Reports o Monthly reports o Final report	10K
		$45K