RENEWABLE ENERGY RESOURCES
FIELD TESTING

CONCEPTUAL DESIGN FOR FIELD TEST #6

PHOTOVOLTAIC/DIESEL POWERED ICE MAKING PLANT AT WADI EL RAIYAN

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FINAL

Prepared for

Egyptian Electricity Authority
Cairo, Egypt

U.S. Agency for International Development
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Submitted to

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FOREWORD

The Egyptian Electricity Authority (EEA), the 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 four-year program are: (1) to demonstrate the viability of renewable energy technologies in Egypt, (2) to comprehensively strengthen Egyptian technical 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.

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. Three of the eleven potential field test demonstration projects are photovoltaic (PV) energy system applications. The Conceptual Design for one of these three field tests, a PV/Diesel Powered Ice Making Plant, is presented in this document, which is the end product of subtask 3.6.3 under Contract AID 263-123C-00-4069-00, Task 3.

The proposed system is sited at Wadi El Raiyan near El Faiyum. The system consists of a six ton per day capacity ice making plant powered by a 35 kilowatt peak (kWp) photovoltaic array, with a 22 kW diesel and 233 kilowatt-hour (kWh) of battery storage. The power system is designed to operate as a PV/diesel hybrid system.

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1.0 EXECUTIVE SUMMARY

This document presents the conceptual design for a Photovoltaic/Diesel powered ice-making plant at Wadi El Raiyan (Field Test #6). The proposed field test is to provide the Egyptian Electricity Authority (EEA) with practical working experience with photovoltaic energy systems as a long term, least-cost remote power supply for refrigeration, as well as to serve as a demonstration of the capability of the combined technology of PV and diesel to reliably supply significant amounts of power in remote locations.

The candidate conceptual system design in this document is based on a DC system that produces flake ice. However, the recommendation for the tender document is that the ice maker and power system can be either an AC or DC design that produces flake or plate ice.

Whether an AC or a DC system is designed, the following components remain the same:

- o Rectifier (Battery Charger) for the diesel gen set.
- o PV Array size---35 kW (peak).
- o Ice maker---6 tons (5.5 tonnes) per day (whether plate or flake ice).
- o Storage Capacity---10 to 12 tons of ice for three days.

For an AC system, the following system component changes are required·

1. AC power systems and AC loads instead of DC power systems and DC loads.
2. Addition of a DC/AC inverter (rated at 30-50KW).
3. A nominal 25 kW AC diesel generator set instead of a more specific sizing of 22 kW.
4. Inverters must handle all power (instead of just for the ancillary loads).

The battery bank has the following design characteristics and constraints:

- o Capable of providing 233 kWh of energy.
- o Capable of being charged or discharged at up to 160 amps for short intervals. This current rating comes from the nominal array rating of

35 kilowatts at 220 volts and is the maximum charging or discharging current that the battery will experience.

o Deep discharge batteries designed for photovoltaic applications.

Several structures are required at the site to house system components. A main control building to house the inverter, the battery bank, the instrumentation system, and the controller is required. The total area of this building is approximately 37.2 m^2 (400 ft^2). A separate diesel building should be built so that the diesel generator can be placed on a concrete floor appropriately supported for vibration.

2.0 OBJECTIVES AND BACKGROUND

2.1 Objectives

The primary objectives of this field test are to provide EEA with practical working experience with photovoltaic energy systems, and to provide system design and operational training for Egyptian engineers for the purpose of assessing and implementing similar projects throughout Egypt. This field test will evaluate the viability of photovoltaic energy systems and PV in combination with diesel energy systems, through the demonstration of a PV/diesel powered ice making plant.

The application of a PV/diesel power system for ice making at Wadi El Raiyan will serve as a demonstration of the capability of the combined technology of PV and diesel to reliably supply significant amounts of power in remote locations. Other applications that are expected to have similar load levels and characteristics are communications and centralized village electrification. It is important that this field test be designed to distinguish between the performance of the PV/diesel power system and the performance of the ice making equipment and other related equipment such as instrumentation and water treatment so that the PV/diesel power system can be evaluated for other applications. This field test will also provide valuable data on the field performance of diesel generators in comparison to PV under similar levels of maintenance and operational support.

2.2 Background

The site chosen for a field demonstration of this application is Wadi El Raiyan, an area 140 kilometers south-west of Cairo, near El Faiyum. Wadi El Raiyan consists of two joined man-made lakes, currently totaling about 10,000 acres, being formed by the discharge of an agricultural canal flowing from the El Faiyum area (Exhibit 2-1).

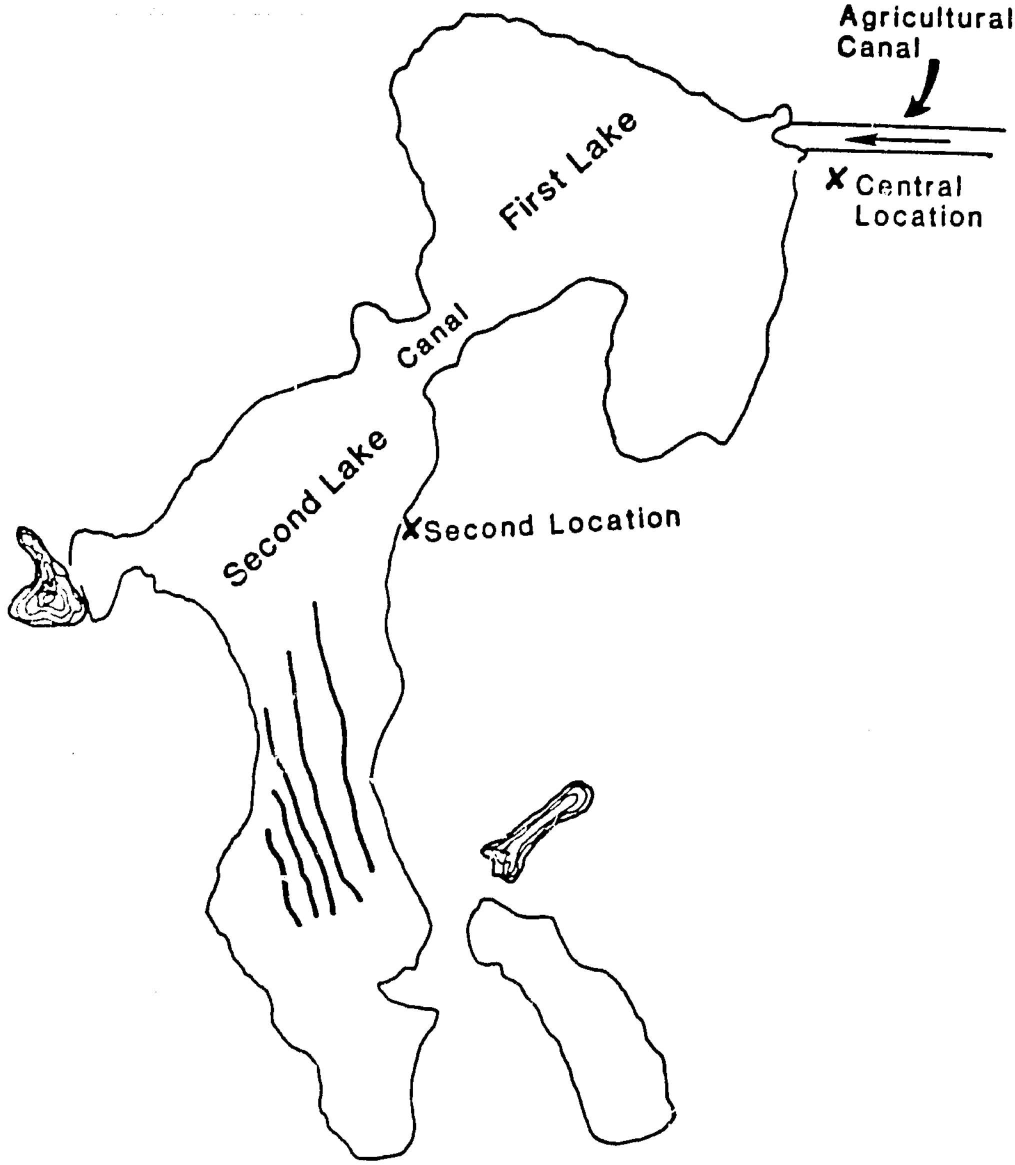

Figure 2-1. WADI EL RAIYAN LAKE AREA

The Wadi El Raiyan lake area has two fishing locations managed by the Fish Resources and Development Authority (FRDA). The "central location" is about 40 km west of El Faiyum on a bay of the first lake at the outlet of the agricultural drainage canal. The "second lake location" is about 30 km south-west of the central location on a newer, larger lake.

Ice is currently transported 40 km from El Faiyum to the fishing locations where fish are packed and trucked to markets in El Faiyum, Cairo and points as far as Alexandria. Some fish are sold direct to merchants at the lake location.

The ice making capacity of the El Faiyum area is approximately 421,000 blocks per year made in grid-connected ice plants. The resulting capacity tonnage is approximately 30 tonnes per day. The demand for ice in the El Faiyum area is significantly greater than the ice making capacity. In addition to the ice needed for fish and other food preservation, there is a steady demand for block ice for private use (home refrigeration). The installation of an ice making plant at the lake to serve the fishing sector will therefore also serve the surrounding area, especially during the summer and toward the end of the fishing season when the demand for ice for fish preservation declines.

2.3 Intent of the Conceptual Design

The Conceptual Design subtask resulting from the Application Review and the Technology Review provides the identification and quantification of system performance specifications, and hardware specifications where appropriate, to be used as a basis for 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."

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 FRDA, the future operator of the system. Elements of the conceptual design appear in the Application Review and the Technology Review as indicated below. Appropriate data from these documents will be included in the Statement-of-Work (SOW).

- o A site specific energy source profile and an application specific load demand profile are included in the FT #6 Application Review
- o Hardware performance and environmental specifications are included in the FT #6 Technology Review and repeated in this document as appropriate
- o System sizing and trade-off analyses are summarized in the Application Review
- o Field Test monitoring instrumentation requirements are included in both the FT #6 Application Review and the Technology Review. An updated requirements data list is included as Appendix B of this document

3.0 APPLICATION REVIEW SUMMARY

3.1 Criteria for Evaluation of the Field Test

An assessment of this specific field test must consider the criteria necessary for a successful demonstration of any PV/diesel power system. These criteria are comprehensively listed below, although not necessarily in the order of importance.

1. Current and future user needs
2. A viable solar and water resource
3. Proven, reliable and commercially available systems
4. Site characteristics and infrastructure for installation
5. Capability for successful operation and maintenance of the systems
6. Potential for widespread use in Egypt

The following paragraphs summarize the findings of various studies and analyses addressing these criteria.

3.2 Current and Future User Requirements

There are two principal fishing locations at the Wadi El Raiyan lake area. Approximately 90 oar powered boats operate from the Central Location bringing in about 1000 metric tonnes of fish per year.[1] Forty-six boats currently operate from the Second Lake Location providing approximately 400 tonnes of fish per year.[2] The combined fish production from the lake is therefore estimated as 1400 metric tonnes per year.

Fish Production

The fishing season may extend from September through April with daily catches ranging from 40 tonnes per day occurring in the early part of the season and tapering off toward the spring to as little as 0.2 tonnes per day. Currently, no fishing is permitted during the summer months of June, July and

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1 Data collected by Dr. Seyoum Solomon of Louis Berger International, Inc. during site visit October 1985.

2 Ibid.

August because of the spawning season. The average daily catch throughout the fishing season is estimated to be between 6 and 10 tonnes per day.

Ice Demand

The ice/fish ratio at Wadi El-Raiyan ranges from 1/2:1 to 2:1 depending on the market locations and the quality of ice used. Therefore the average season daily ice demand for fish preservation may range from 3 tonnes per day to 20 tonnes per day.

In addition to the ice demand for fish preservation, there is a steady ice demand in the El Faiyum area for home refrigeration. The demand for ice in the El Faiyum area is significantly greater than the ice making capacity. Therefore, a greater future utilization of a PV/diesel ice making plant throughout the year is possible if ice can be sold to non-fish specific markets.

3.3 The Resources at Wadi El Raiyan

Insolation data were calculated based on recorded data (sunlight hours) from a meteorological station in El Faiyum. Horizontal daily global insolation ranges from 3.4 kWh per m2-day in December to 8.1 kWh per m2-day in June. Appendix A provides solar insolation, ambient temperature, and water temperature data for the site.

Ambient temperature data are based on meteorological station data from El Giza. An additional two degrees has been added to each temperature to reflect the generally higher temperatures at the site. Average daily temperatures range from 30.2 to 15.2°C over the year.

Water temperature for the lake at Wadi El Raiyan is estimated to range from 8 to 28°C in the vicinity of the central location. For the candidate conceptual design in this document, it was assumed that the ice maker input water is potable. For the statement-of-work, water quality data from a Cairo University research study are provided to bidding contractors for their analysis of water treatment requirements for their specific hardware.

3.4 Preliminary Conceptual Design

Ice Plant Capacity Sizing

An ice plant capacity of 6 tons per day (12000 pounds per day)[3] has been selected as a candidate sizing. This sizing capacity will meet a significant portion of the average daily demand for ice. It is also a reasonable size for demonstrating the design, operation and maintenance, and evaluating the complete technical and cost performance of photovoltaic and diesel power systems for making ice. The two most important factors regarding ice plant sizing are that: (1) the demand for ice is greater than the ice production capacity of the area, and (2) the cost of the largest cost component of the PV/diesel ice plant, the PV array and battery system, is relatively linear with increasing array size. Therefore a 6 ton/day capacity ice plant and power system can be regarded as a "modular design." Over the course of this field test, the performance of the system can be evaluated. Modifications in design and operation can then be made to result in self-contained ice plants (ice maker and power system) with applicability at other locations throughout Egypt.

Power System and Ice Plant Design Selection

Plate or flake ice making technologies are the most suitable for fish preservation and are more energy efficient than block ice making which is currently practiced. The energy required to make ice by either plate or flake technology for Wadi El Raiyan ranges from 60 to 80 kWh per ton-day which includes the energy demand for ice making, storage, water supply and miscellaneous lighting loads. Based on a 6 ton/day ice demand and an average energy requirement of 70 kWh per ton of ice per day, the daily energy demand is calculated as 420 kWh per day.

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[3] U.S. ice maker rating are in "tons" (2000 pounds) as distinct form "tonnes" (2200 pounds or 1000 Kilograms)

The principal power system design question is the selection of either an alternating or direct current (AC or DC) system. For AC systems stand-alone inverters are required to convert DC power (from the PV array and battery) into AC power. The poor reliability, capital expense, and inherent energy conversion efficiency (80 - 90 percent) of stand-alone inverters favors a DC system design. However, because conventional ice making equipment uses AC motors, a DC system requires that AC motors be replaced by DC motors. Since the power system will integrate a diesel generator with a PV system, the diesel generator must also be capable of producing DC power either directly or through the use of a separate rectifier. These required modifications for a DC system may be justified on the basis of improved operating reliability and efficiency of the system.

An evaluation of the sizing of the PV array and battery system for the FT #6 Application Review has resulted in a determination that the optimum renewable energy system for ice making loads is a "hybrid" power system, combining the technologies of V and diesel generators. Hybrid power systems i.e. PV/diesel power systems, as referred to in this report, improve the performance of both diesel and PV power systems by increasing the operating capacity factor. The diesel generator is able to operate at rated capacity which results in the best fuel to electricity conversion efficiency. The size of the PV array and battery systems can be reduced because the diesel will provide power during extended periods of low insolation and during seasonal load and insolation variation. This effectively increases the capacity factor of the PV array and battery system.

Comparative Cost/Analysis

Cost projections for PV prices show that PV will become competitive with diesel in the 1995 timeframe at costs of about $0.27/kWh (Appendix D of FT #6 Application Review, May 1986). Based on projections to 1995 for PV, diesel, and battery energy costs, a PV array and battery system sized to provide between

30 and 40 percent of daily average load is justified. Specific sizing for the PV/diesel powered ice making plant components are as follows:

PV Array	35 kW
Battery Storage	233 kWh
Diesel Generation	22 kW
Ice Making Plant	6 tons/day

This component sizing is based on a DC system design incorporating the flake ice manufacturing process resulting in a continuous, stable load and a minimum of battery storage capacity. It is also based on a requirement to size the diesel to have the capacity to run the ice plant independently.

3.5 Status of Agreements and Responsibilities

The daily operation and maintenance associated with ice making dictate that full time operators be assigned to the location. EEA and FRDA have signed a contract, covering a two year period, for the operation, maintenance, repair and monitoring of the facility. Aspects of this agreement which are pertinent to the operation, maintenance, repair and monitoring should be made available to all involved parties (including bidding contractor) so that clear lines of responsibility will be understood.

3.6 Conclusions and Recommendations

The following conclusions and recommendations are provided.

Conclusions

1. The Wadi El Raiyan location is an acceptable application site for demonstrating the use of photovoltaics for ice making because there is an existing and growing demand for ice, the solar resource is exceptional, and the location represents a balance between remoteness and accessibility for monitoring and evaluation.[4]

2. The sizing of the ice plant is based on average daily ice demand because daily ice demand fluctuates over the season. A modular design using proven, reliable, and commercially available systems is considered so that additional capacity can be added in the future and the potential for other applications throughout Egypt is enhanced.

4 Assumes that potable water is available for ice making.

3. The most suitable ice making technologies are plate or flake because they are the most energy efficient and suitable for fish preservation.

4. The lowest cost, most reliable design choice, on a long term basis, is a PV/diesel hybrid power system with corresponding ice making loads.

5. The financial viability of PV/diesel remote power systems for ice making depends on the cost of photovoltaic energy compared with diesel produced energy.

6. The design, operation, maintenance, and repair experience with PV/diesel hybrid power systems that will be obtained through this field test will form a strong technical and cost data base for the design and application of PV/diesel power systems for other remote power applications.

Recommendations

A 6 ton/day ice making plant, powered by a 35 kW PV/22 kW diesel hybrid power system with 233 kWh of battery storage is recommended to be field tested at Wadi El Raiyan. This recommendation is based on the following assumptions:

1. The life cycle cost of PV power is likely to be less than the life cycle cost of diesel power in Egypt within the next 10 to 15 years.

2. The timeframe of 10 to 15 years is within the energy planning and institutional perspectives of the Egyptian Electricity Authority.

4.0 TECHNOLOGY REVIEW SUMMARY

General background technical information has been provided in the Technology Reference Notebook on equipment components related to photovoltaic systems. The Technology Review for this field test, a separate document, reviews the specific equipment technologies in use in this field test with emphasis on refrigeration and diesel generators. A summary discussion of the components most critical to the design and operation of the PV/diesel ice making plant is provided here.

4.1 Technology Background

Diesel Generators

Diesel generators are considered to be the existing technology. Diesel generators are available in a wide range of sizes from 2 kW up to several hundred kW rating. They operate with a thermal-to-electricity fuel conversion efficiency of 15-30 percent depending on capacity factor and the quality of maintenance.

Photovoltaic

Photovoltaic energy systems have been technically proven to be more reliable and require less maintenance than diesel systems for remote power supply. Photovoltaic energy, however is currently competitive to diesel generators only at low daily load levels, generally below 10 kWh per day. As the cost of photovoltaic energy continues to drop, the competitiveness of PV with diesel will improve. Under the assumptions provided, PV is likely to be competitive to diesel within the next 10 years for remote power applications such as ice making at the load levels required for this application.

PV/Diesel "Hybrids"

The characteristics of stand-alone PV energy systems indicate that competitive PV systems, sized to meet ice making loads, will be "hybrid" systems. Hybrid systems refer to the intermittent use of a diesel generator to provide power for periods of low insolation and to meet peak energy demands and thereby substantially reduce the required battery storage capacity that would otherwise be necessary if PV were used alone. The use of diesel generators in combination with photovoltaics also increases the reliability of the power system and can reduce the cost of delivered energy over either energy technology alone.

4.2 Technology/Component Data Base

There are three ice making technologies; block, plate and flake ice. Block ice is the current technology in use in the El Faiyum area. It is the least efficient of the three because of its relatively low surface area to weight ratio. However, it is best for transport and storage. Therefore it is the preferred choice for in-home use throughout Egypt.

Plate ice is commonly used in the fishing industry worldwide. It is made by passing water over refrigerated vertical metal surfaces and allowing a sheet or "plate" of ice to form. Plate ice technology is more efficient than block ice. The principal disadvantage of plate ice is the cyclic nature of the power demand.

The flake ice process is the most energy efficient and it results in a relatively continuous load. Flake ice is formed by a shaving process of rotating either a drum or blade to scrape thin layers of ice into flakes.

The first consideration for the power system to operate the ice maker is given to the choice of an AC (alternating current) or DC (direct current) power system. An AC system requires the use of a stand-alone inverter to convert PV and battery energy (DC) into AC power for use by conventional AC loads. The field performance of inverters has been poor and, because inverters are a critical link between PV array and the load, their failure can prevent the use of PV produced power. In addition, inverters are at best 90 percent efficient. The alternative is to eliminate the inverter by modifying load equipment to use

DC power. The use of DC loads results in the most efficient use of the PV/battery system and improves the system's reliability. The trade off is that the ice maker must be modified by changing AC motors to DC motors and a rectifier must be added to the diesel/generator to convert AC to DC power. It is recommended that the design not be required to be either AC or DC, but that the Statement of Work insist that bidders justify their design and respond to the concerns raised in the Field Test #6 Application Review.

There are three basic PV technologies with proven field experience: single crystalline, poly-crystalline, and ribbon. Any of these should be considered as acceptable for this field test. An adjustable tilt array should be required to provide for the maximum output of the PV array in the peak demand months and also throughout the year.

The power system controller should be capable of three functions: (1) efficient power conditioning of the PV array, (2) battery protection, and (3) power distribution of the PV, battery and diesel energy to the loads. Several controllers are commercially available that can perform these functions. They range from what may be described as "smart" or programable controllers to "basic" controllers that use preset relays and minimum amounts of logic circuitry. For either controller, it is likely that some customization will be required to meet specific design, operating and safety objectives. Specific emphasis should be placed on performance testing at manufacturer's plants and in the field and guarantees that may be offered.

There are two basic choices for a battery energy storage system, vented or sealed deep cycle batteries. Vented batteries are less expensive than sealed, however, the loss of electrolyte due to either evaporation or "gassing" can require frequent monitoring and maintenance. Vented batteries can be equipped with "recombination" caps to reduce the use of electrolyte. More expensive sealed batteries are the preferred choice for handling, shipping, and maintenance consideratio

4.3 Selection of System/Component Technology

Based on a review of available equipment and technology the following recommendations are made:

1. Plate or flake ice making technology is recommended. Power system design for use with plate ice making equipment must be capable of handling inherent cyclic loading while flake ice making technology must show that block ice can be made through the use of block presses to produce ice for commercial sale.

2. The ice maker and power systems should be of either an alternating or direct current design (AC or DC). A DC power system design is encouraged in order to maximize the efficiency and reliability of the photovoltaic power system.

3. Photovoltaic modules of single crystalline, poly-crystalline or multi-crystalline and ribbon technology are recommended.

4. An adjustable tilt array structure is recommended which permits manual adjustment of the array tilt, seasonally for at least three positions: 10, 29 and 40 degrees. Structural material should be aluminum, galvanized metal, treated wood or concrete. Designs should be encouraged which permit future fabrication in Egypt.

5. A power system controller with a field proven record of performance is recommended. The power system controller should be as simple as possible, providing the ability to easily troubleshoot problems and make component replacement and repairs. A maximum power tracking controller is recommended. Also a microprocessor-based design is acceptable for this application if field performance data shows the unit to have comparable reliability to non-microprocessor-based control equipment.

6. Deep cycle lead-acid batteries sealed or vented are recommended. Vented batteries should be equipped with recombination caps. Sealed batteries should be considered if their life cycle cost is not greater than 20 percent over comparable vented lead acid batteries. (20 percent is a qualitative value attributable to the elimination or reduction of maintenance).

5.0 CANDIDATE CONCEPTUAL DESIGN

5.1 Design Approach

For the candidate conceptual design, a system configuration was developed based on the loads identified, the equipment technology under consideration, and the design purpose (i.e., development, demonstration, training, lowest cost option). An iterative process was conducted to determine an optimum design between PV, diesel generator, and battery power to operate the ice making plant. Exhibit 5-1 is a block diagram of the process.

The candidate conceptual design of the PV/diesel hybrid energy system assumes a constant average hourly load equal to the total daily kilowatt hours divided by operating hours of the ice maker. The design is based on twenty-four hour operation to maximize capacity, resulting in a constant hourly load representa of flake ice making. A cyclic load, as with plate ice making technology would require a larger capacity diesel generator and battery but would not affect array sizing because array sizing is based on energy per day. With plate ice, PV energy lost during periods when PV output exceeds load can be recovered through battery storage.

5.2 Operating Concept

The operating concept behind a PV/diesel power system is to operate each power system at its highest efficiency compatible with producing the lowest levelized energy cost. This means using a minimum battery capacity and operating the diesel at not less than 40 percent of its rated capacity to achieve good efficiency and to minimize maintenance requirements.

Exhibit 5-2 is a graphical representation of the operation of a PV/ battery/ diesel power system supplying a twenty-four hour daily load. In general, the photovoltaic array operates the load during the day and the diesel operates the load during the night. Points "a" and "b" represent changes in the principal

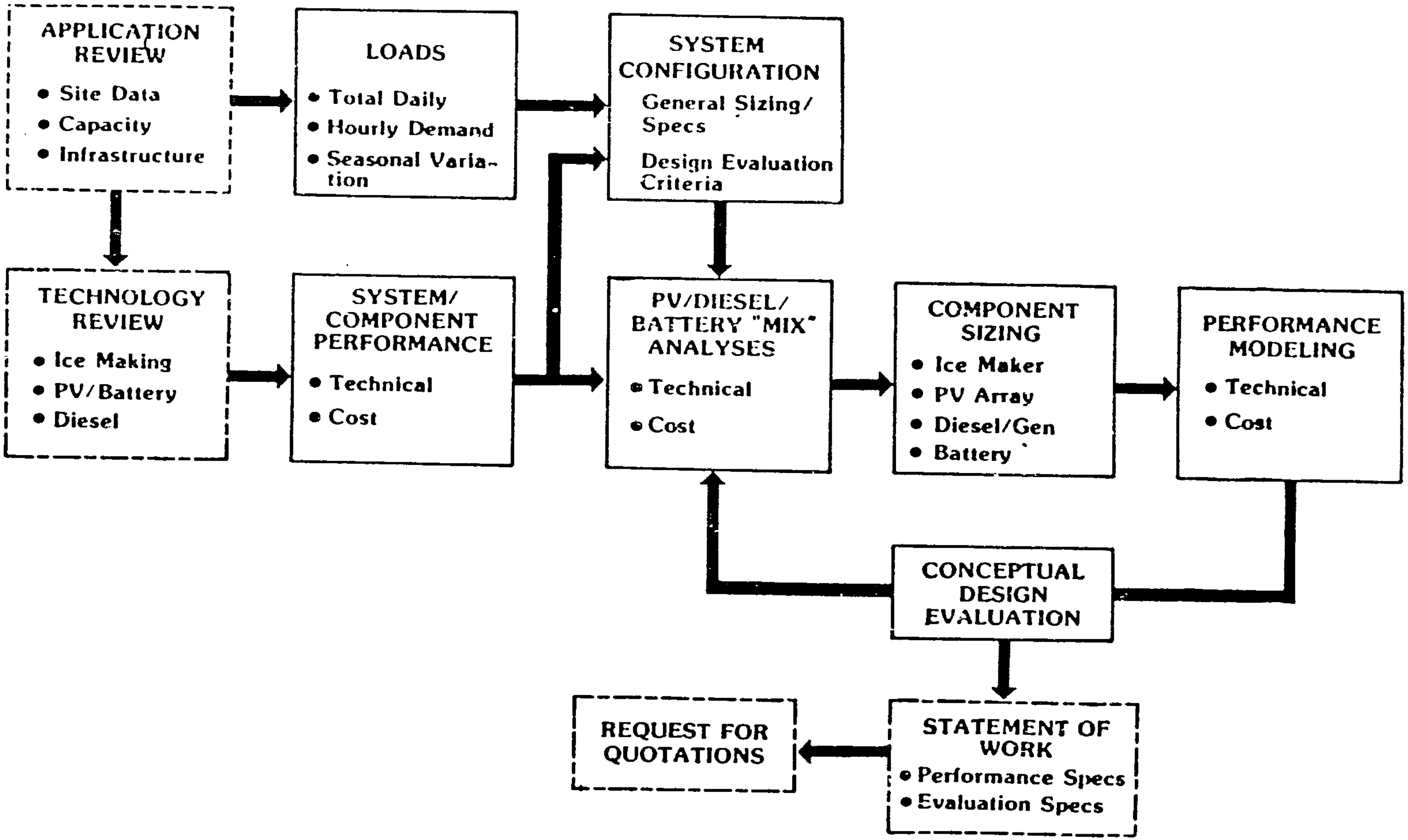
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Figure 5-1

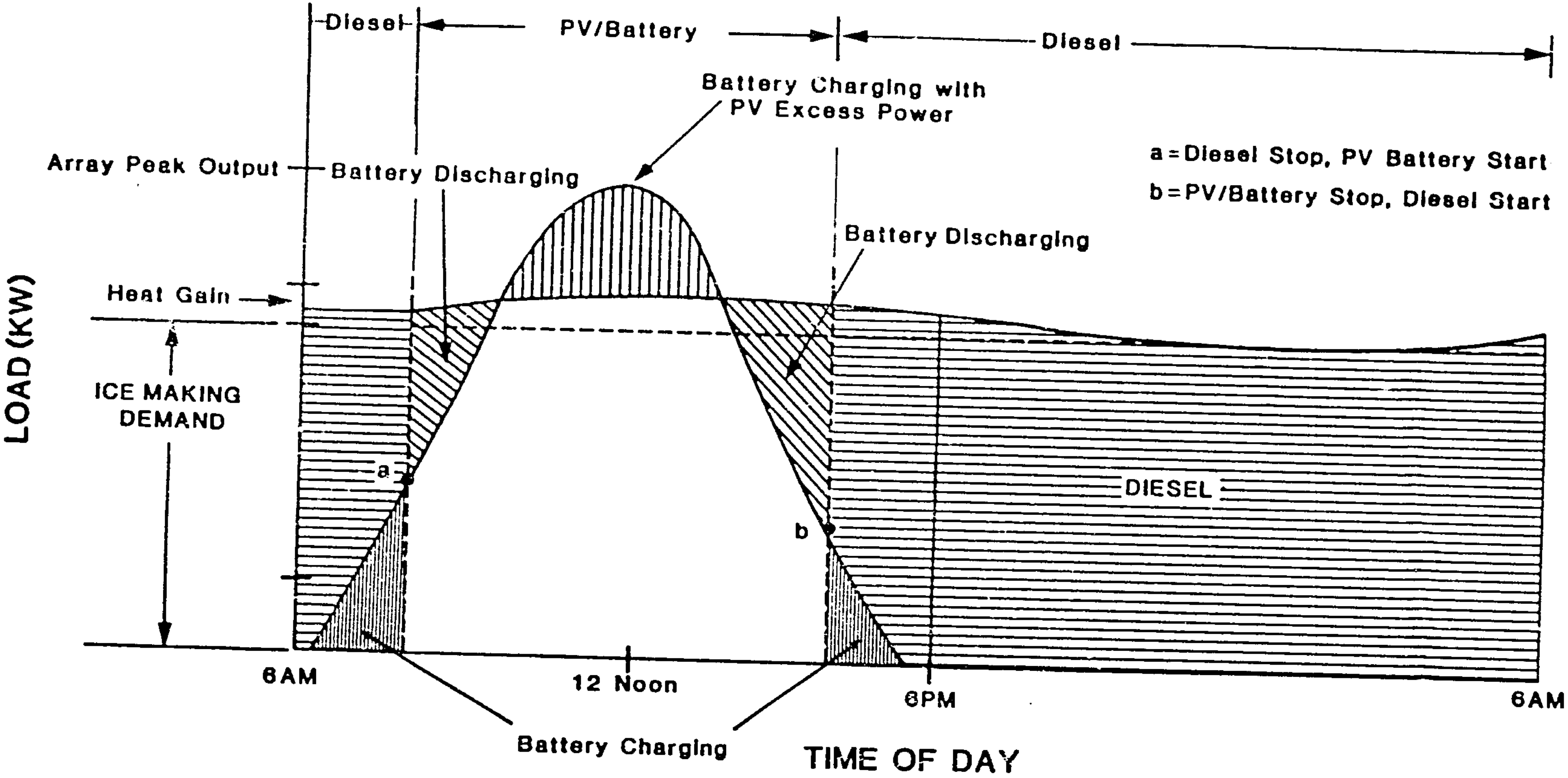


Figure 5-2
PV/DIESEL IDEALIZED OPERATING CURVE

power supply source; from diesel to PV/battery in the morning as array output increases, and from PV/battery to diesel in the evening as array power decreases. The change in power supply can be gradual by "integrating" or combining PV/battery/diesel power to supply the total load, or it can be distinct by effectively operating the equipment as separate power supplies, PV/battery and diesel. Both are reasonable operating methods.

A fully "integrated" power system provides for the maximum flexibility in operating the system. It requires a "smart" power system controller which can identify and compare various operating parameters relative to the PV, battery and diesel power system and determine when to start the diesel, at what power level it should operate, and what is the optimum use of PV power at a given point in time. The availability of such "smart" controllers in the commercial market is relatively recent.

A simpler control method is to operate the PV, battery and diesel as independent power systems. The PV array and battery provide power to the loads for a specific time interval or until a specified minimum battery charge level is reached. At this time the diesel starts and takes over the ice making load. Any remaining array power is used to recharge the battery bank. Diesel power is dedicated to the ice making load and does not concurrently charge the battery bank. Power supply is switched by power relays and can be specified to be manual or automated, to prevent load operation interruption. Commercially available controllers can perform as a "basic" power system controller with the addition of a time, current, or voltage sensor and "remote start" relay.

Issues such as proven reliability, efficiency, cost and maintainability should be considered when evaluating the power controller design. In addition, the Statement-of-Work will provide typical daily power curves to simulate operational concepts specific to the control design.

5.3 System Configuration

The Field Test #6 Application Review discusses the attributes and liabilities of AC versus DC system configurations and plate versus flake ice production. The preliminary conceptual system sizing and design in that document is based on a DC system that produces flake ice. A DC design is encouraged in order to maximize the efficiency and reliabilty of the PV power system. In addition, flake ice presents a continuous load to the power system.

In the final analysis, it is recommended that the system design be left to the bidding contractor, i.e., either an AC or DC power system that drives an ice maker producing flake or plate ice. Evaluation criteria and system acceptance test requirements that specify minimum acceptable system reliability and operational methodology must be clearly stated in the Statement-of-Work.

One possible candidate conceptual design, described in the following paragraphs, includes design and sizing considerations for either an AC or DC system producing plate or flake ice. The system layout with the various equipment options is shown in Exhibit 5-3.

5.3.1 Power System

A sizing analysis for the major components of the PV/Diesel Ice Making plant was performed in the Field Test #6 Application Review. A DC power system and flake ice making loads were used to achieve higher system reliability and energy efficiency over an AC power system design and more conventional AC loads. The principal advantage of a DC power system is the absence of a stand-alone DC-AC inverter. Professional opinion (NASA, Solarex) on the viability of stand-alone inverters supports the conclusion that inverters are to be avoided if at all possible. It is important to realize, however, that a DC system is uncommon, which may prove to be disadvantageous when the realities of the industrial marketplace are considered. It is possible that manufacturers

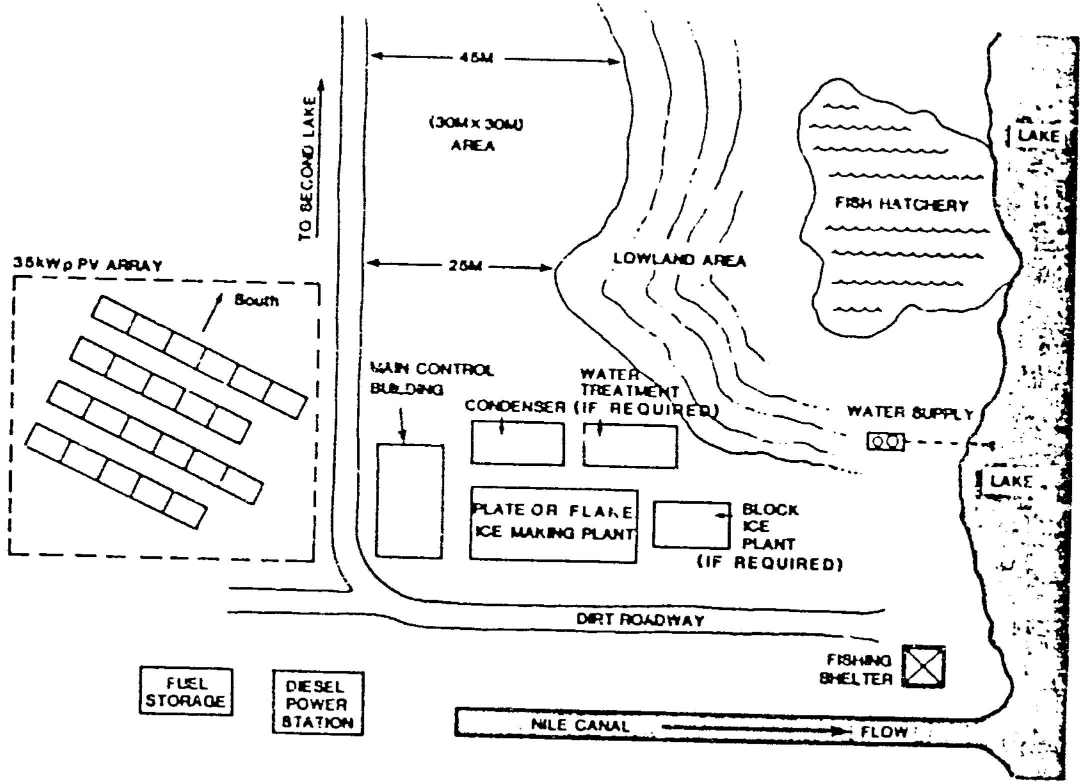


Exhibit 5-3 SITE EQUIPMENT LAYOUT

of ice makers will not replace their conventional (AC) motors with DC motors without a substantial increase in cost. Related issues of spare parts, service and repair, as discussed in the Technology Review for Field Test #6 are important system considerations.

Whether an AC or a DC system is designed, the following components remain the same:

- o Rectifier (Battery Charger) for the diesel gen set.
- o PV Array size---35 kW (peak).
- o Ice maker---6 tons per day (whether plate or flake ice).
- o Storage capacity -- 10 to 12 tons of ice for three days.

For an AC system, the following system component changes are required over those specified in the Field Test #6 Application Review.

1. AC power systems and AC loads instead of DC power systems and DC loads.
2. Addition of a DC/AC inverter (rated at 30-50KW).
3. A nominal 25 kW AC diesel generator set instead of a more specific sizing of 22 kW.
4. Inverters must handle all power (instead of just for the ancillary loads).

Exhibit 5-4 is the revised schematic that shows bidding contractor options (ice maker, AC or DC system) and system options that must be finalized before release of a tender document (water treatment, block ice press, data acquisition system). Differences between AC and DC power flows are also shown.

5.3.2 Photovoltaics Power Subsystem

A typical PV array as shown in Exhibit 5-5 through 5-8, delivers the required peak power. The physical configuration of this array is electrically and functionally similar to that used by several other companies.

The battery bank has the following design characteristics and constraints:

- o Capable of providing 233 kWh of energy.
- o Capable of being charged or discharged at up to 160 amps for short intervals. This current rating comes from the nominal array rating of 35 kilowatts at 220 volts and is the maximum charging or discharging current that the battery will experience.

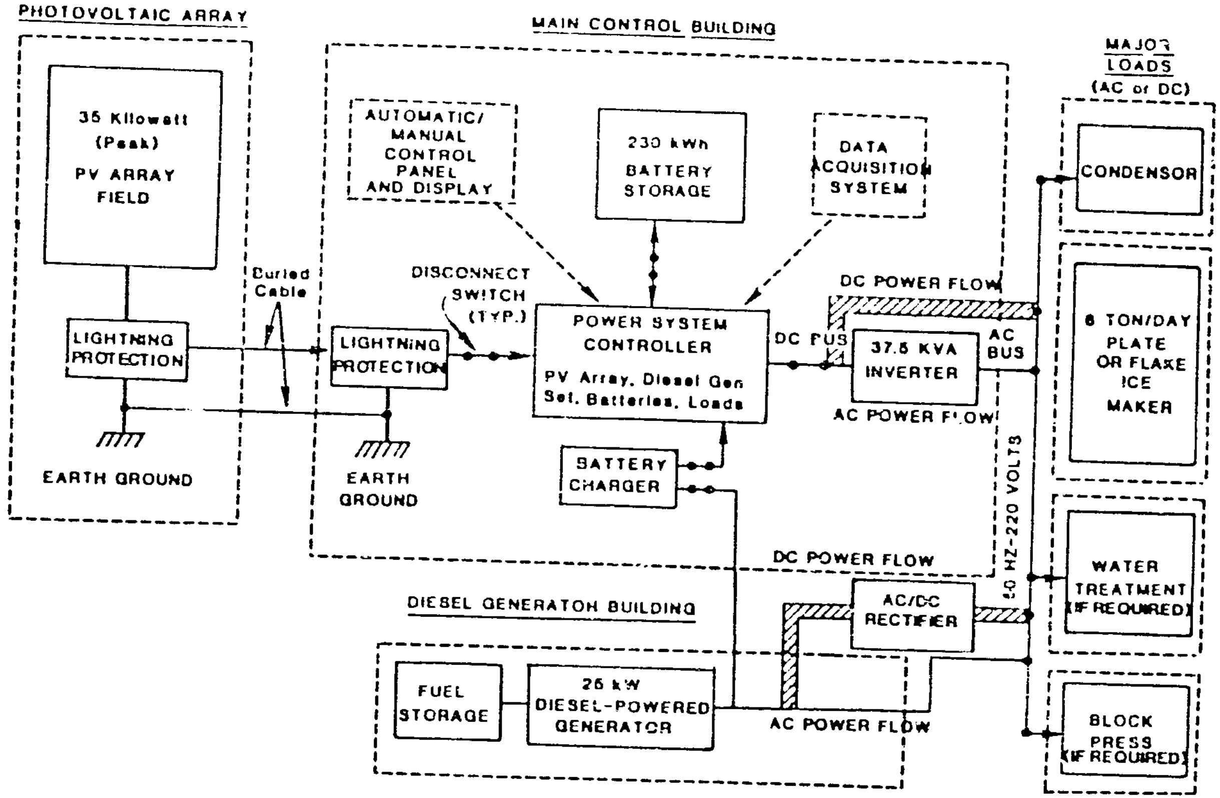


Exhibit 5-4
DIAGRAM OF PV/DIESEL POWER SYSTEM AND LOAD CONFIGURATION

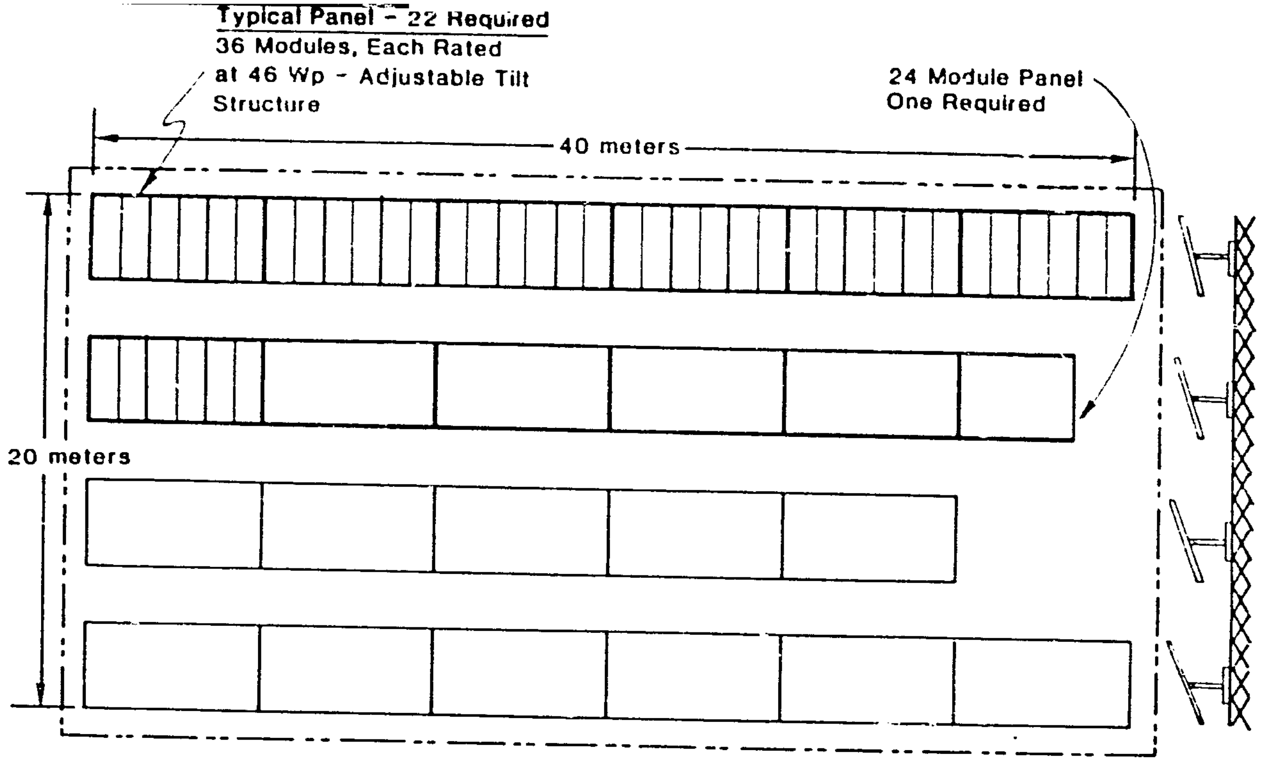
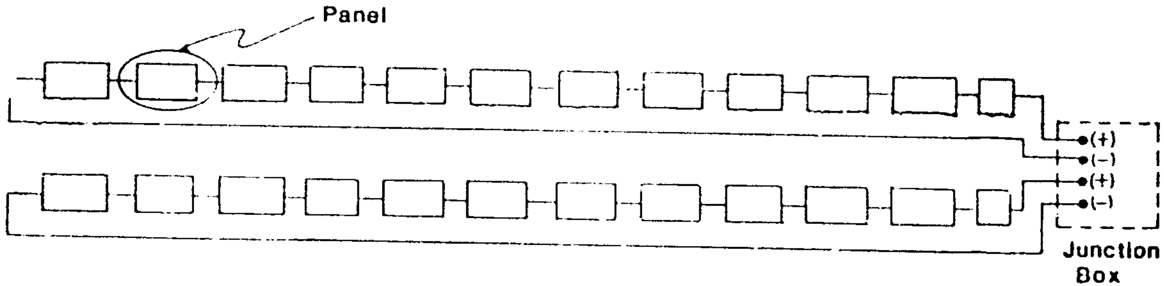


Exhibit 5-5
TYPICAL PV ARRAY PHYSICAL CONFIGURATIONS

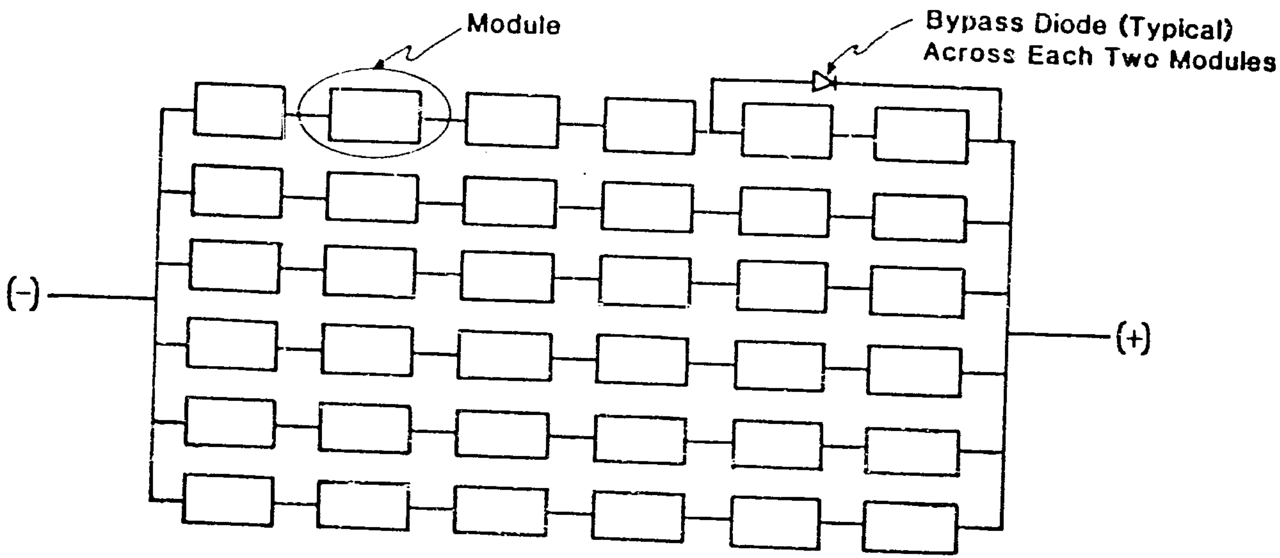


TWO BRANCH CIRCUITS:

- 11 36- Module Panels +1 12-Module Partial Panel per Branch Circuit
- At Standard Conditions Each Branch Circuit Delivers:
  - 17,952 Watts
  - 306 Volts
  - 58.7 Amps
- At 65°C Each Branch Circuit Delivers Approximately:
  - 15,080 Watts
  - 246 Volts
  - 61.3 Amps

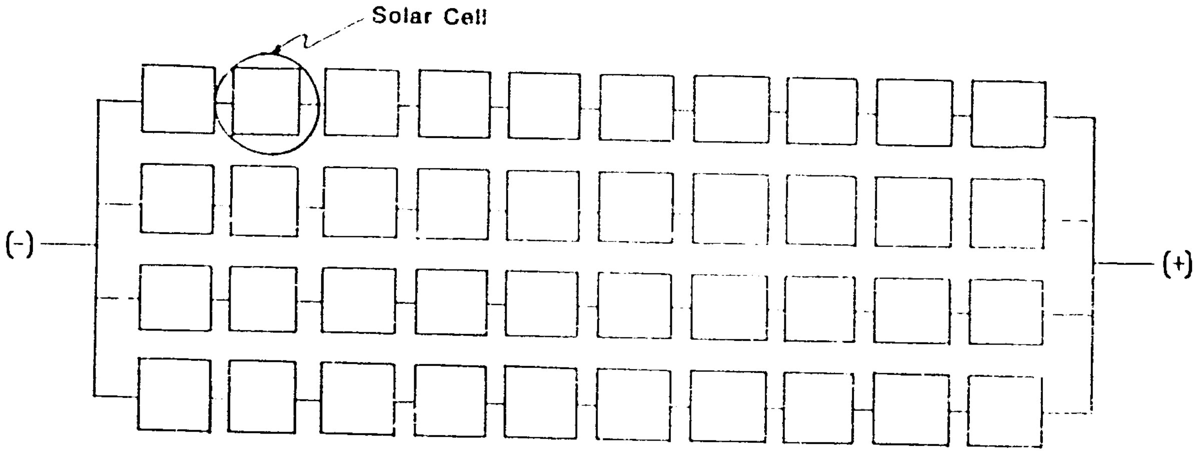
Exhibit 5-6

TYPICAL PV ARRAY ELECTRICAL SCHÉMATIC



- 6 Modules in Series
- 6 Modules in Parallel
- At Standard Conditions
  - 1,584 Watts
  - 27 Volts
  - 58.7 Amps

Exhibit 5-7
TYPICAL PANEL ELECTRICAL SCHEMATIC



- 40 Cells in Module

  10 Cells in Series

  4 Cells in Parallel

Exhibit 5-8

TYPICAL MODULE ELECTRICAL SCHEMATIC

o Deep discharge batteries designed for photovoltaic applications.

The solid state controller is designed to provide efficient power over a wide range of operating conditions. It must be capable of handling voltage between 210 and 260 volts and current between 0 and 110 amps.

5.3.3 Diesel Generator Power Subsystem

The Generator set (Genset) must be at least 25 kW capacity to handle the compressor load for the ice maker. It is fitted with a conventional 50 cycle generator capable of 220 volts. Almost all of the major diesel generator manufacturers have engines in this size class. For a DC power system, or for intermittantly charging the batteries in an AC system, a battery charger is specified for the application.

The size of the diesel fuel storage tank should be determined by the frequency at which resupply can be expected. The fuel consumption of a 25kW diesel is 1.94 gallons per hour. A two-week supply of diesel fuel, permitting 24 hour continuous operation during the period is recommended. This requires a 1230 liter (325 gallon or 1.23 cubic meter) storage tank.

5.3.4 Ice-Making Equipment

A thorough discussion of the attributes of each type of ice (flake, block, and plate) is presented in the Field Test #6 Technology Review. Ice making is a mature industry in which many companies have literally scores of years of experience. The prime operating specification for this application is that the ice maker be able to produce six tons of ice per 24 hour period and have a storage capacity of 10 to 12 tons of ice for three days. The use of flake or plate ice does have implications in the power system design (on-off cycles versus a more continuous load). This will impact system relibility and maintainability.

The ice maker requires a condenser to transfer heat from the refrigerant, thereby condensing the refrigerant (usually freon). The mechanism for this part of the cycle consists of a heat exchanger, plumbing, a fan, and pumps for the refrigerant and water. For this application the loads would consist of:

3 Hp Fan Motor

1/2 Hp Water Pump

1/2 Hp Refrigerant Pump

This possible conceptual system design assumes potable feedwater. However, apart from the question of potability, water must be pumped from the source to a temporary storage facility and then be available for the ice maker. The water supply system should be capable of pumping 8 cubic meters of water per day and have a storage capacity of about 20 cubic meters. The pumping load for this water supply is minimal when compared to the total load demand.

5.3.5 Structures

Structures are required at the site to house system components. A main control building to house the inverter, the battery bank, the instrumentation system, and the controller is required. The batteries will weigh nearly 12,727 kilograms (28,000 pounds) and occupy a volume of nearly 8 cubic meters. This is a floor area of $13.9m^2$ ($150\ ft^2$). Access to the batteries (for maintenance) requires about the same area. Other equipment will require an additional $9.2m^2$ ($100\ ft^2$). The total area of the main control building is therefore approximately $37.2m^2$ ($400\ ft^2$).

The room containing the battery bank must be sealed from the other parts of the building. Venting from the top of the room must be provided so that low density (explosive) hydrogen gas is allowed to escape before it becomes a safety hazard. Sealed batteries are available, but venting is still a good safety precaution.

A diesel generator building with a concrete floor appropriately supported for vibration is required. The location should be downwind from the ice-making plant to avoid fumes and to minimize noise for people who work near the ice plant or the control room. The building must be constructed so that a supply of air is available to the engine and the exhaust can be vented to the atmosphere.

5.4 System Performance

The technical performance of the PV/diesel power system in the field will be measured by an on-site data acquisition system (ODAS). For this document system performance was simulated using the PV F-Chart computer model to determine the expected monthly and annual energy production for the PV array and the resultant diesel energy required to satisfy the 420-kWh per day load demand (for details see the Field Test #6 Application Review and Appendix C of that document).

The major components and assumptions for the performance modeling are as follows:

Components

PV Array	35 kW
Battery Storage	233 kWh
Diesel/Generator	22 kW
Ice Making Plant	6 ton/day (5.5 tonnes/day)

Performance Assumptions

1. Array reference performance data is for poly-crystalline silicon.

2. PV F-Chart is used to determine PV operating efficiency and average daily insolation on a monthly basis.

3. Battery losses are estimated to be 3 percent, based on 15-20 percent of the energy passing through 80 percent efficient batteries.

4. Power conditioning losses are 5 percent.

5. Diesel operating efficiency, i.e., fuel to electricity conversion, is 20 percent.

6. The energy content of diesel fuel is 1.3 kilogram-calories/liter (140,000 Btu/gallon).

To compute the total energy from the PV array, the average daily array operating efficiency is multiplied by the average daily insolation over each month. The result is multiplied by the number of days in a particular month. The diesel generator contribution is the difference between 420 kWh per day and the kilowatt-hours produced by the PV array. Exhibit 5-9 tabulates the resulting values.

The annual energy production values provided in Exhibit 5-9 are calculated based on average daily array efficiency and insolation. PV FCHART predicts a 35 kW array will provide 39.6 percent of the annual energy demand or 60707 kilowatt-hours. The slight difference in total annual energy production shown in Exhibit 5-9 is primarily due to daily average computation versus hourly average.

		Energy Demand	420 kWh/day			ENERGY PRODUCTION (kWh/Day)	
						$354m^2$ (35 kW)	
Month	Days/mo.	PV Oper. Eff.	Battery Losses (1-%)	Power Cond. Eff.	Insolation (kWh/day)	PV Array	Diesel
JAN	31	.08	.97	.95	5.5	143	277
FEB	28	.079	.97	.95	6.4	165	255
MAR	31	.077	.97	.95	6.7	168	252
APR	30	.076	.97	.95	7.6	188	232
MAY	31	.075	.97	.95	7.5	183	237
JUN	30	.074	.97	.95	7.9	191	229
JUL	31	.073	.97	.95	7.9	188	232
AUG	31	.073	.97	.95	7.6	181	239
SEP	30	.074	.97	.95	7.0	169	251
OCT	31	.075	.97	.95	6.5	159	261
NOV	30	.078	.97	.95	5.6	142	278
DEC	31	.080	.97	.95	5.0	130	290
	Yearly Energy Production (kWh)					61089	92211
	Yearly Diesel Fuel (gallons)						11237

Exhibit 5-9
PV/DIESEL ENERGY PRODUCTION DATA

APPENDIX A

Solar, Ambient and Water Temperature Data

APPENDIX A

Insolation (Source: Published research by Dr. Mossallan Shaltout of the Egyptian Meteorological Authority)

Horizontal Global Average Daily Insolation

EL FAIYUM EGYPT LAT=29

	SOLAR (kWh/day)	TEMP °C	REFLEC*
JAN	3.8	15.2	.20
FEB	4.9	16.2	.20
MAR	6.0	18.6	.20
APR	7.4	22.2	.20
MAY	7.6	26.1	.20
JUN	8.1	28.7	.20
JUL	8.1	30.2	.20
AUG	7.5	29.8	.20
SEP	6.7	27.4	.20
OCT	5.2	25.4	.20
NOV	4.0	21.2	.20
DEC	3.4	16.3	.20

* Estimated for sand

Ambient Temperature (Source: El Giza + 2 degrees Centigrade)

MONTH	MAX	MIN	MEAN
JAN	22.2	8.1	15.2
FEB	23.7	8.6	16.2
MAR	26.4	10.7	18.6
APR	30.7	13.7	22.2
MAY	34.7	17.6	26.1
JUN	36.8	20.6	28.7
JUL	37.8	22.5	30.2
AUG	37	22.5	29.8
SEP	34.4	20.4	27.4
OCT	32.6	18.1	25.4
NOV	28.2	14.2	21.2
DEC	22.6	10.1	16.3

Water Temperature (Source: Rafik Georgy, based on FRDA data)

8 - 28 Degrees Centigrade

APPENDIX B

INSTRUMENTATION REQUIREMENTS AND SPECIFICATION

APPENDIX B
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 multiplex 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 each is desired with a range of 0 to ± 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 #6 (PV ice-making)

Parameter	Channel Type	Output Interval
* Array Power (kW)	P	10 min.
Array Voltage (volts)	A	10 min.
Array Current (Amps)	A	10 min.
PV ref. cell temp. (2 or 3) (°C)	A	10 min.
Diesel Fuel Usage (Liters)	A	Daily
Diesel Power (kW)	P	10 min.
Diesel Number of on-off Cycles	P	Daily
Diesel Voltage (volts)	A	10 min.
Diesel Current (Amps)	A	10 min.
Battery Charge and Discharge Current (Amps)	A	10 min.
Battery Voltage (volts)	A	10 min.
Battery Temp. (°C)	A	10 min.
Ice Maker Water Flow (Liters)	P	10 min.
Water Inlet Temp. (°C)	A	30 min.
Ice Maker Power (kW)	P	10 min.
Ice Maker Voltage (volts)	A	10 min.
Ice Maker Current (Amps)	A	10 min.

* Desired but not required.

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 (kgrm/m^2)	A	30 min.
Wind Speed (m/sec)	A	10 min.
Wind Direction (degrees)	A	10 min.