

An Overview of the Goldstone Energy Systems Study

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The primary objective of the Goldstone Energy Systems Study (GESS) was to develop a systems planning methodology for analyzing and synthesizing Deep Space Network (DSN) energy systems. The resultant product, the Deep Space Network Planning and Analysis Methodology (DESPAM), can support DSN energy planning evaluations. It addresses a broad spectrum of tradeoff and dispatching scenarios. It evaluates a variety of energy generation configurations and also includes a capability to evaluate conservation measures.

I. Introduction

In recent years, energy costs have taken increasingly large portions of the Deep Space Network (DSN) annual operations budget. There exists the possibility that energy supplied to the stations could be cut off or reduced during times of world crisis. In response to these factors, several energy goals have been developed by NASA and the DSN. These include reducing energy consumption at all NASA installations by 50% from 1973 levels by 1985, minimizing life-cycle costs in balance with other costs through energy use reductions at the Goldstone Deep Space Communications Complex (DSCC), the attainment of a 90% non-utility, on-site energy generation capability, and an initiative to carry out demonstration projects in order to provide insight and data on existing low-risk technologies. The Office of Telecommunications and Data Acquisition (TDA) implemented a number of studies which evaluated DSN energy consumption as well as future options for alternative energy use. The Goldstone Energy Systems Study (GESS) was one of the TDA energy conservation projects.

The primary objective of GESS was to develop a systems planning methodology for analyzing and synthesizing DSN energy systems. The resultant product can support DSN short and long-term energy planning evaluations. It addresses a broad spectrum of strategic tradeoff and tactical dispatching scenarios. It evaluates a variety of energy generation configurations and also includes a capability to evaluate conservation measures. By implementing the methodology, the user is able to address the following types of issues:

- (1) The definition of optimal energy dispatch strategies for current operations (optimal can be lowest cost or other user-defined attributes such as minimum grid reliance).
- (2) The identification of conservation measures that would have the most favorable impact on operations and costs.
- (3) The determination of the value of new energy generation sources. The identification of the best time for implementing new energy alternatives as well as the

dispatch strategy to be used and the quantity of the new source to use.

- (4) The calculation of the net cost benefits of one energy generation scenario vs another. The calculation of the annual cash flows of varying scenarios.

II. Approach

The tool for assessing the energy planning questions is the DSN Energy System Planning and Analysis Methodology (DESPAM). It consists of several key components. The first is the characterization of new, alternative energy systems that have the potential to be implemented by the DSN in combination with existing generation sources such as grid and diesel. This representation includes performance curves, cost equations, reliability factors, and the selection of a timeframe for implementation which will have the best chance for lowering system costs. The next component relates to energy utilization by the DSN as well as physical conditions at the site. Here, DSN energy loads are characterized, meteorological conditions are specified, and any desired conservation measure is defined. The energy generation data and utilization parameters are then evaluated by implementing the DSN Energy System Simulation Model (DSNX). The next step of the DESPAM methodology is to use the DSNX model to evaluate actual test cases which replicate existing or potential energy generation scenarios of the DSN. The last step is to select those strategies and options which the user deems best for actual implementation.

The remainder of this article focuses on a description of the DSNX simulation model and on an end-to-end application of the DESPAM methodology. For a detailed discussion of the other components of the DESPAM methodology, see the Goldstone Energy Systems Study Final Report (an internal document).

III. DSNX Description

As stated earlier, the main purpose of DSNX is to serve within the overall DESPAM methodology as a tool for analyzing various operating policy scenarios and to perform multi-year generation mix analyses with respect to energy utilization for the DSN. It does this by parametrically evaluating varying quantities of energy generation levels for different sources so that optimum configurations can be determined. In addition, it is possible to evaluate the effects of different timeframes on each scenario evaluated by making multiple runs (the multiple run aspect of the code is covered in the next section). The model has the capability to address new, emerging technologies such as solar thermal, wind, photovoltaics, or solar ponds

in conjunction with conventional utility grid or diesel-generated energy.

When the model addresses these new, emerging technologies, it is usually necessary to know insolation and meteorological data pertinent to a specific geographical location. This input can be provided to DSNX in the form of data tapes. The hourly energy generation level of any new technology selected by the user is then estimated. (A generalized flow chart of the entire model is shown in Fig. 1.)

The user then provides load data for the DSN facility in the form of data tapes, or he can create his own typical day load profile. It is also possible to adjust load data. Additionally, sizing parameters for each energy generation source are required. This includes any new energy technology to be implemented in addition to those sources currently available to the Goldstone DSCC, namely, utility grid and diesel (the diesel capability can also be used to model fuel cells). It is possible to address as many as four new energy technologies in addition to the utility grid and diesel. Grid or diesel or any alternative can also be evaluated individually.

The program then matches demand against energy availability for each source over a 1-year timeframe. The user specifies the dispatch strategy. Varying energy generation sizes and grid penetration levels can be evaluated within a single simulation run. At the user's option, the utility grid maximum usage level can change in accordance with the billing period. Only one diesel size per run is allowed.

The program determines alternative source energy generation, excess alternative generation, grid generation, excess grid capacity, diesel generation, total energy generation, unmet demand, and total demand over the entire period simulated. In addition, utility grid energy and power consumption levels are also determined on a monthly basis according to billing period. All outputs are determined for all configurations evaluated.

These outputs are then combined with user inputs of capital costs, maintenance and operations costs, fuel costs, subsystem replacement and/or rebuild, and utility billing charges, in order to determine one-time and recurring costs for each configuration under evaluation. In addition, inputs of system life, escalation rates, cost of capital, tax parameters, and a time frame for new technologies enable DSNX to determine life-cycle cost and levelized busbar energy cost for each configuration. The model also provides a complete yearly cash flow table. Lastly, a summary table for all configurations is given and a data file is formed which can be accessed from a Hewlett Packard Graphics Terminal for use in creating output plots.

IV. Implementation of DSN Energy System Planning and Analysis Methodology (DESPAM)

In the Approach Section it was explained that the overall methodology that covers all analysis components (characterization of generation systems, characterization of weather and load data, DSNX simulation, interpretation of results) is known as DESPAM. In this section, a typical end-to-end application of DESPAM is given.

Let us suppose we want to evaluate a new technology (solar thermal) for use at the Mars site at the Goldstone DSCC. We want to look at varying penetration levels from 100 kWe to 1500 kWe. We want to integrate the new technology with the currently existing diesel-grid operation. Our criteria for the "best" system will be lowest life cycle cost. A secondary preference is to reduce reliance on grid-generated energy.

The Goldstone Energy Systems Study Final Report provides the following necessary input information:

- (1) The solar thermal system will have a point focusing distributed receiver and a centrally located steam Rankine engine. This system will be assumed to need no major overhauls during a 24-year life and there will be no performance degradation over time.
- (2) The new system will be implemented in 1988. It will be assumed to meet DSN reliability standards at that time.
- (3) Insolation data for Barstow, California, for 1976 will be used.
- (4) The Southern California Edison demand tape for 1980 for the Mars site will be used to characterize the energy load. During those periods when the diesels are in use (0 values on the tape), it will be assumed that 850 kWe of energy is used.
- (5) Diesel efficiency is 12 kWeh/gal. There is no initial capital cost (it is assumed that the diesels are already in place). Diesel M&O cost is \$.003/kWeh. Diesel fuel price is \$.915/gal. Diesel subsystems are overhauled after every 20,000 hours of operation at a cost of \$14,390.
- (6) The electric utility grid cost is based on actual 1982 bills (\$0.069/kWeh). There will be no sell-back of any excess generation of solar thermal energy to the grid (this energy is lost).
- (7) The nominal (including inflation) annual cost escalation rates are:

Inflation rate ¹	10.0%
Capital cost	9.3
M&O	8.9
Discount rate ¹	10.0
Fuel	10.4
Purchased electricity	8.4

We now need to make assumptions regarding the dispatch strategy, baseline cases, and technology size.

The dispatch strategy will be to use solar-generated energy first when available, the utility grid second, and diesel third. In the baseline case (no solar; grid vs diesel only), five different diesel penetration levels will be tested:

Scenario	Grid billing period		
	Off-peak	Mid-peak	On-peak
A	All grid	All grid	All grid
B	All grid	All grid	Grid up to 500 kWe; then diesel
C	All grid	Grid up to 1000 kWe; then diesel	All diesel
D	All grid	Grid up to 500 kWe; then diesel	All diesel
E	All grid	All diesel	All diesel

The current Goldstone DSCC operation of all grid, all grid, all diesel was not tested. However, Scenario C is very similar. These baseline scenarios will be simulated from 1982 to 2011 (Run 1).

The nominal solar thermal sizes tested are 100, 300, 1000, and 1500 kWe. These sizes will be tested in conjunction with the five grid-diesel combinations. It will be assumed that the grid-diesel combinations are used without solar from 1982-1987, and that solar is added in 1988 (construction takes place in 1987). This second case consists of two simulation runs, 1982-1987 (Run 2), and 1988-2011 (Run 3). Each run evaluates performance for a single year separately.

¹When making multiple DSNX runs with differing timeframes, which this case requires, the economic calculations are simplified when inflation equals discount rate.

V. Results

The lowest cost combination in Run 1 (diesel vs grid for 30 years) was Scenario C. Its life cycle cost in 1982 dollars is \$11.64 million. Its annual cash outflow is shown graphically in Fig. 2. This scenario derives 82% of its energy from the grid and 18% from diesel.

In Run 3 the lowest configuration is 300 kWe of solar combined with Scenario C for diesel and grid. Its life cycle cost is \$8.69 million as compared to \$8.98 million for the no-solar case over the same timeframe (1988-2011).² This best case only requires 72% of the energy to be generated by grid (16% comes from diesel and 12% is derived from solar thermal). At large solar penetration levels (1000 and 1500 kWe), reliance on the grid decreases but the monetary savings are lost now since

²The Run 3 costs would have been somewhat lower had we assumed that excess solar generation was sold back to grid.

large portions of solar-generated energy were wasted. (It appears that a solar size of about 500 kWe would give the lowest cost.) Figure 3 shows the results of Run 3 in terms of energy grid displacement as a function of life cycle cost. The cash flow for the lowest cost configuration of Run 3 (300 kWe of solar) is shown in Fig. 4. When the cash flow for the best scenario in Run 2 (Scenario C) is combined with the one from Run 3 and is compared to the baseline (Run 1), we get the net savings shown in Fig. 5. From 1982 to 1987 the net change is 0 since for those six years the baseline is replicated. The solar installation results in a negative net flow of about \$130,000 annually from 1988 to 1992, but turns positive from 1993 to 2011 and results in an overall net life cycle cost savings of about \$300,000. The energy generation breakdown for our optimal case from 1982 to 2011 is given in Fig. 6. We now know that it might be a wise idea to investigate solar thermal systems more fully. Furthermore, if it is possible to acquire a solar system as described, and if the remaining assumptions hold, the DSN may be able to cut grid reliance and reduce net overall operating costs at the same time.

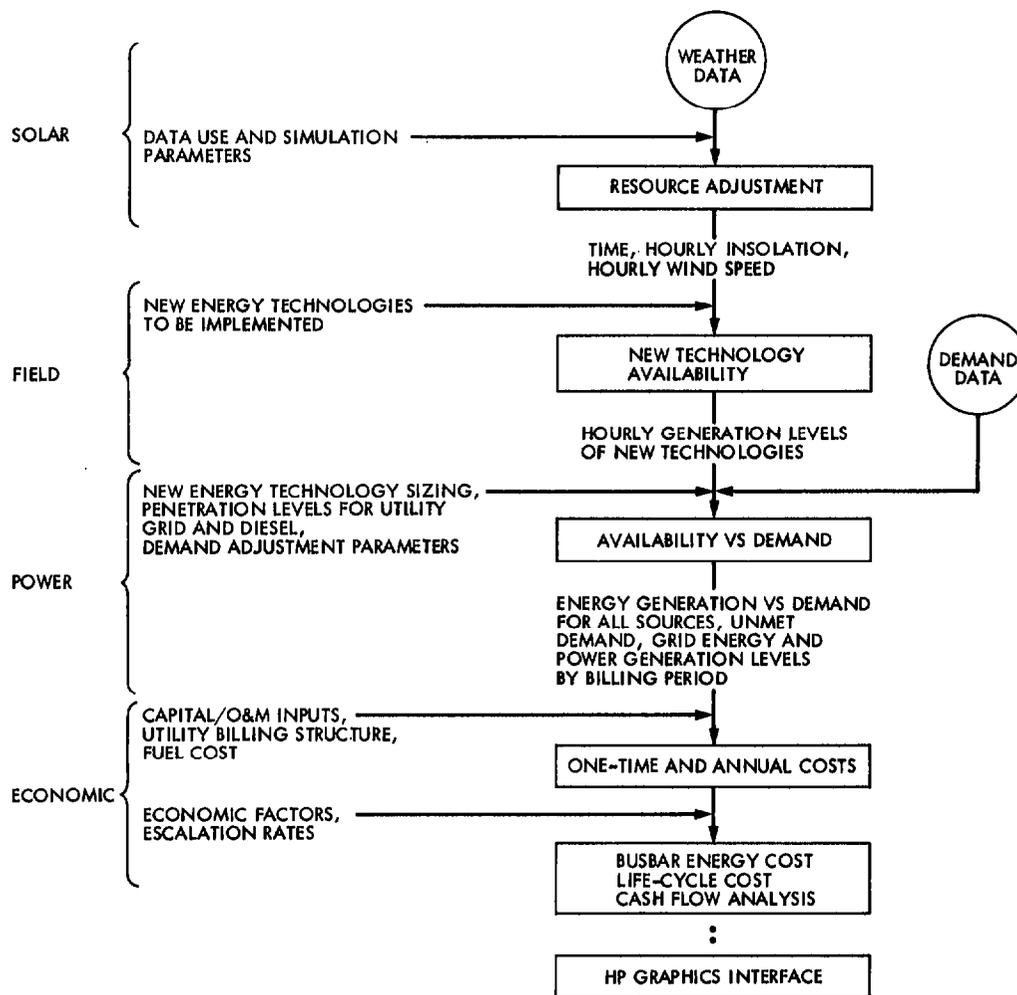


Fig. 1. DSNX simulation sequence

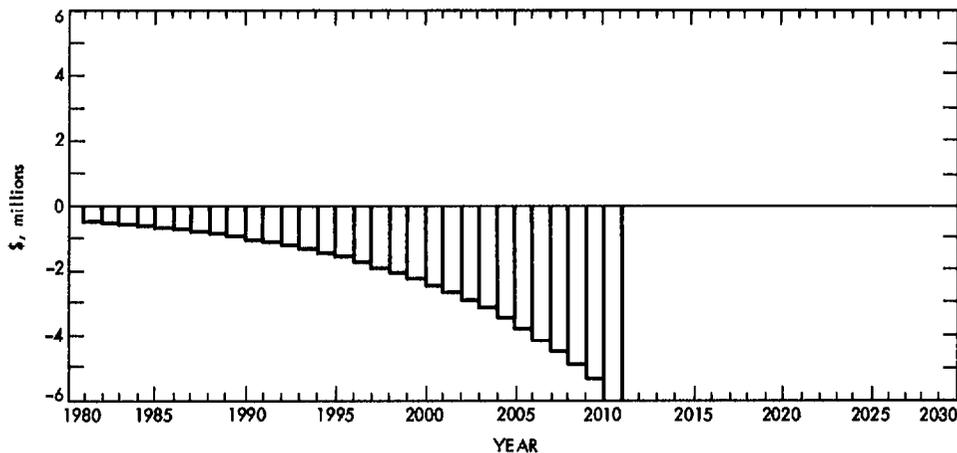


Fig. 2. Net cash flow; diesel vs grid—Run 1, Scenario C

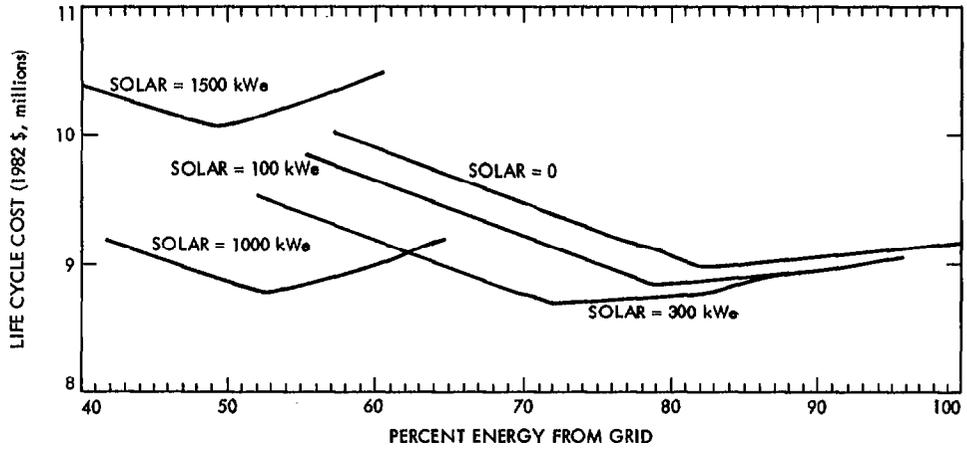


Fig. 3. Grid displacement vs life cycle cost for various solar thermal/grid/diesel scenarios (Run 3)

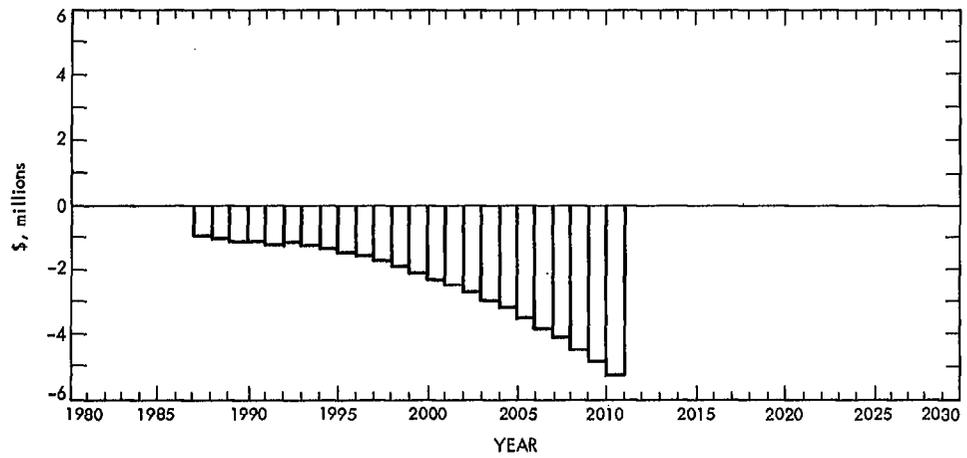


Fig. 4. Net cash flow; Run 3—lowest cost configuration (solar power level = 300 kWe)

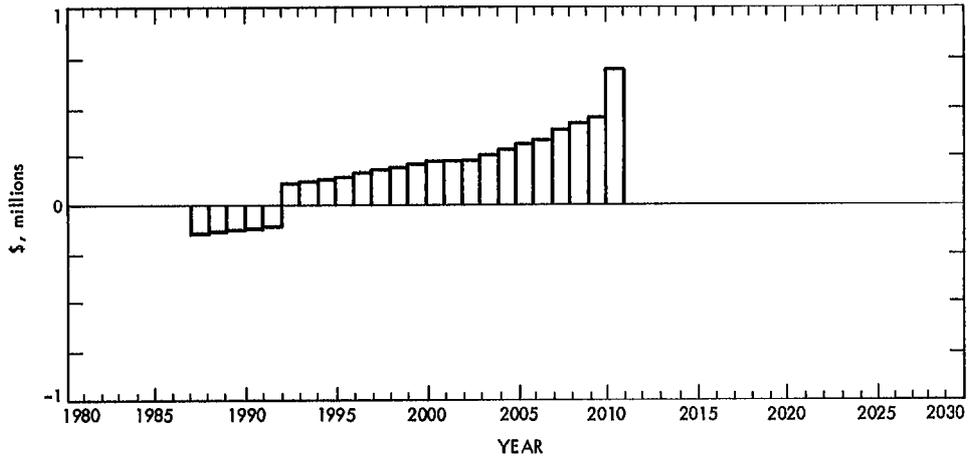


Fig. 5. Net cash flow; solar strategy vs nonsolar

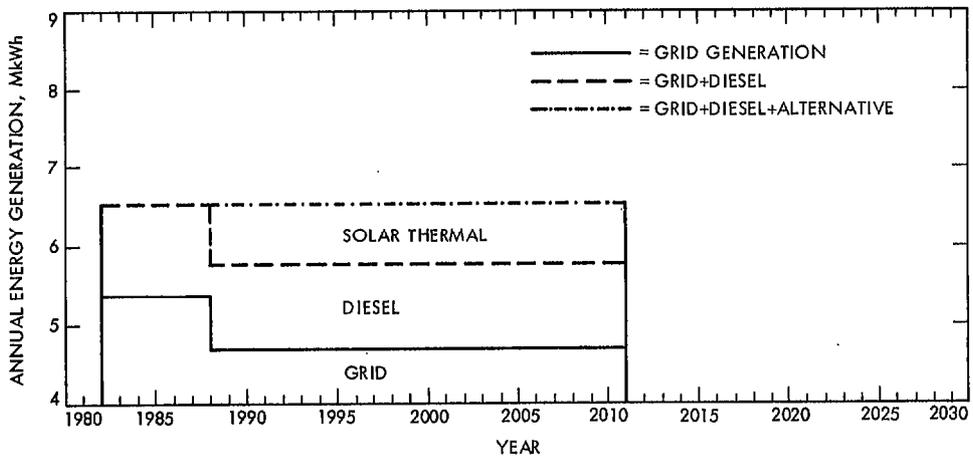


Fig. 6. Energy generation by source (addition of solar to grid and diesel in 1988)