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**Federal Transit
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DEVELOPMENT AND APPLICATION OF A BATTERY ENERGY STORAGE SYSTEM SIMULATION PROGRAM FOR RAIL TRANSIT SYSTEMS

VOLUME III

Prepared By:

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March 1995

FTA TECHNICAL ASSISTANCE PROGRAM

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16. Abstract

Under the Rail Transit Energy Management Program, a computer model was developed to assess the economic feasibility of applying battery energy storage to rail transit systems. This model was applied to the Port Authority of Allegheny County (PAT) (Pittsburgh) light rail system and the Washington Metropolitan Area Transit Authority's (WMATA) MetroRail.

The results indicate that the payback periods for investment into battery energy storage are relatively long; 14 years for WMATA and 10 years for PAT. These payback periods are marginal and with the risk associated with implementing battery storage, it is doubtful whether transit management would be inclined to make such an investment.

The capital cost of battery storage can be reduced by eliminating the power conditioning equipment and allowing the battery to be connected directly to the third rail catenary or trolley system.

The model can easily be modified to assess the economic feasibility of other alternative energy sources such as cogeneration and other storage media, such as superconducting magnetic energy storage.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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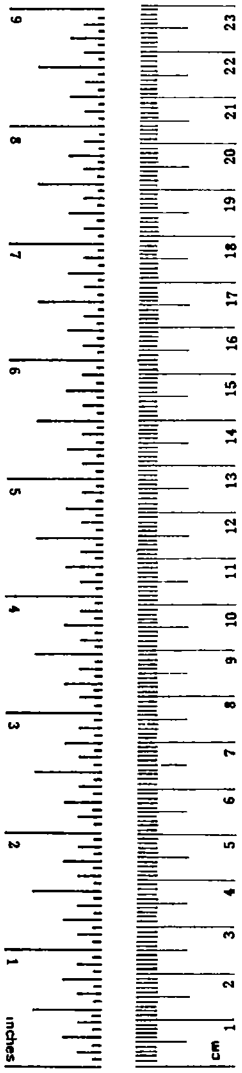
*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.



Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	

MASS (weight)

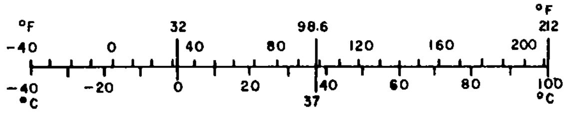
Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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While acknowledging all of this assistance and support, the authors retain responsibility for the materials, analysis, and opinions in this report.

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EXECUTIVE SUMMARY

Introduction

Rail transit electrical energy costs in North America have continued to spiral upward, rising 32% in constant dollars during the decade of the 1980's. This rise in energy cost increases total operating costs.

For nearly 20 years the Rail Systems Center (RSC) at Carnegie Mellon University has been instrumental in the development and application of energy management methodologies to rail transit. The RSC's first work in this area began in 1976 with funding from the U.S. Department of Transportation, Urban Mass Transportation Administration (UMTA), to develop and test a series of computer codes which enabled simulation of an electrified transit system. The RSC was also funded in 1983 by UMTA to develop a set of guidelines for transit energy management. The RSC has subsequently utilized these tools to perform energy studies for a number of transit systems nationwide.

As a continuation of this effort, the RSC was awarded a grant by the Federal Transit Administration in 1990 with the goal of conceiving and evaluating innovative ways for rail transit systems to reduce electrical energy costs. The first phase of this program addressed opportunities associated with alternative energy sources.

This first phase began by establishing a framework for cost reductions through a review of energy costs, usage patterns, rate structures and energy cost reduction strategy results for five representative transit authorities: Washington Metropolitan Area Transit Authority (WMATA), Metropolitan Atlanta Rapid Transit Authority (MARTA), Maryland Mass Transit Administration (MTA), Port Authority of Allegheny County (PAT, Pittsburgh), and Metro-Dade Transit Agency (MIAMI). The report then defined and addressed the issues surrounding each of the forms of alternative energy sources, including energy storage and bypass, which means buying electricity from an entity which is not the local electric utility. The report concluded that energy storage for the PAT and WMATA systems may be economically feasible. One of the recommendations of the report was that computer simulation tools be developed which would enable economic assessment of energy storage schemes.

The purpose of this project (phase II) was to develop a computer model which would simulate the operation of a Battery Energy Storage System (BESS) at a transit system. Additionally, the results of the BESS model will be utilized to establish the economic feasibility of implementing a BESS at two representative transit systems: PAT and WMATA.

BESS Computer Program Description

The BESS model simulates operation of a BESS based on one year's worth of metering load curves. These load curves are generally available from the electric utility which services the rail transit system. The model estimates the annual power bill from the load curves without a BESS in place. It then simulates operation of a BESS modifying the load curves to reflect the use of the BESS. A power bill is then calculated using these modified load curves. An economic model then considers the BESS cost and savings, and provides the user with the BESS Internal Rate of Return, Net Present Value and Payback Period. These parameters provide the user with the information necessary to establish whether use of the BESS is economically sound.

For the purposes of this report, a BESS is a bank of batteries electrically connected through a power conditioning unit to the electrical distribution subsystem of the rail transit system. The BESS provides power to the transit system during its peak-load times, and is recharged during off-peak hours. In this way, the BESS is able to reduce the monthly power requirements from the utility, thus reducing the monthly demand charges (commonly referred to as peak-shaving). For the BESS to be considered economically feasible, the demand savings associated with BESS operation must exceed the sum of the construction finance costs and the operation and maintenance costs.

From discussions with battery manufacturers and from reviewing recent literature, the valve regulated, lead-acid (VRLA) battery was the most attractive from both a cost and performance perspective. Therefore, the BESS model reflects application of a VRLA battery.

The energy capacity of a lead-acid battery varies depending on the rate at which the energy is removed from it. The faster the energy is removed, the lower the amount of energy that can be obtained from the battery for that cycle. The simulation of this phenomena within the BESS model was accomplished through the use of a relationship known as Peukert's equation. This equation, which relates the discharge current to the time the battery will last at the given current, enables the simulator to estimate the capacity for any possible discharge rate history.

Another phenomena modeled within the BESS model is energy recovery, whereby capacity that was lost due to high discharge rates is partially recovered when the battery is idle. The BESS model takes into account a number of other battery characteristics, including its maximum allowable depth-of-discharge, recharge efficiency, battery life and increased battery voltage. The model's handling of each of these battery parameters enables a more realistic simulation of the BESS.

The BESS model simulates the control of battery discharge in two ways. The first, more conventional method, allows discharge of the BESS at a set rate for a specified amount of time, regardless of the demand. The second approach allows discharge of the BESS only when the demand rises above a user-specified value.

Cost estimates were obtained from battery manufacturers and from application studies. The BESS model can use these costs, or case-specific costs can be entered.

The BESS model accepts utility rate structures based on demand and energy charges. The PAT and WMATA rate structures are internally coded into the program, but can easily be replaced by other rate structures.

BESS Application to PAT and WMATA

One year's worth of metering load curves was obtained for both the PAT and WMATA systems, and the BESS computer program utilized this information to determine the economic feasibility of a BESS application at these facilities.

Using the BESS computer program with the conventional discharge method (i.e. BESS constant discharge for set times), both the PAT and the WMATA systems were not economically feasible. For both systems, the payback period was more than 3-4 years, which is considered reasonable.

However, considering a discharge methodology, whereby the BESS is utilized only when the demand exceeds a set value, the payback period results are over 14 and 10 years for WMATA and PAT, respectively. Both of these payback periods are marginal. Since a battery system has never been applied under strict controlled conditions on a rail transit system, there is a degree of risk associated with application. With this risk, it is doubtful whether transit management would be inclined to make such an investment.

Recommendations for Future Work

The capital cost of BESS can be reduced by eliminating the power conditioning system and allowing the battery to be connected directly to the third rail (of course, with appropriate circuit protection). In order to assess this potential, a model must be developed which will simulate this type of operation.

The BESS model can easily be modified to assess the economic feasibility of other alternative energy sources such as cogeneration. This should also be done as part of the future development on this computer program.

1.0 INTRODUCTION

1.1 Background

During the decade of the 1980's, the rates which utilities charged transit authorities for electrical energy rose over 32% in constant dollars.[1] This spiraling energy cost has put pressure on transit authorities. And for this reason, authorities have been actively pursuing methods to reduce their energy bills. The Rail Systems Center (RSC) has been working in the transit system energy management field since 1976, when it was first responsible for development of the Energy Management Model, which is a computer simulation tool that simulates operation of electrified transit systems. Since 1976 the RSC has applied this simulation package to a number of transit authorities while performing energy management studies on their systems. The use of this simulation package has enabled the RSC, at a cumulative one-time cost of less than $2M, to develop energy management programs for transit authorities which save over $10M annually.

One of the methods that has been simulated is the use of Battery Energy Storage Systems (BESS) to shave the peak demand, resulting in reduced monthly demand costs.

There is lack of generic models which can evaluate BESS performance and address economic feasibility. Engineering firms which have such models are generally in the construction business and use these models to perform specific application studies which usually yield positive results.

As part of the work performed under the Rail Transportation Energy Management Program (FTA Grant PA-26-0008), a computer model was developed by the RSC which would effectively and realistically simulate BESS performance, and which would be flexible enough to be applied to all electrified transit systems with minor changes.

1.2 Objectives

The objectives of this portion of the work were to develop a computer model which would assess BESS performance and economic feasibility, and to apply this model to two rail transit systems.

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[1] *113th Edition Statistical Abstracts of the US*, (US Department of Commerce, 1993), p.954.

1.3 Report Description

Chapter 1 presents the background and objectives of the work.

Chapter 2 covers the BESS model methodology. It also details the relationships and equations used by the model to simulate various battery system properties related to battery cost, life and performance. The relationships which highlight energy storage economic feasibility are also stated in this chapter.

Chapter 3 describes the application of the BESS model to two rail transit systems; namely, the Port Authority of Allegheny County (PAT) Light Rail Transit System in Pittsburgh, PA and the Washington Metropolitan Transit Authority's (WMATA) Heavy Rail System in Washington D.C. In the early part of this chapter all input values which are non-transit specific, such as BESS cost, BESS discharge characteristics and options are detailed. This is followed by brief descriptions of the PAT and WMATA BESS related characteristics.

Chapter 4 highlights the conclusions and recommendations of the work.

Appendices are included which provide the BESS model computer source codes and a user's manual.

2.0 BATTERY MODEL METHODOLOGY

To enable simulation of a battery energy storage system (BESS), relationships had to be identified which enabled modeling of pertinent battery properties. This chapter describes the various battery characteristics that were modeled within the BESS computer model, and also explains the power rate structures and economic parameters used.

The specifications associated with development of the BESS computer code are shown in Table 2-1.

The specifications for the simulation of the two separate transit authorities are shown in Table 2-2.

2.1 Battery Characteristics

This report will be dealing with the application of secondary (as opposed to primary) batteries. Primary batteries cannot be recharged and are, therefore, limited to providing only that capacity that is initially stored within the battery. Secondary batteries, on the other hand, are capable of being electrically recharged to full capacity after discharge simply by reversing the current flow.

Most secondary batteries typically offer high power densities and good low-temperature performance, while suffering poor, long-term energy retention when idle.

A discussion of some of the more important battery characteristics, along with how they are modeled within the model are covered in this section.

2.1.1 Battery Capacity

The capacity of a battery is the amount of energy it can provide. Most battery capacities are related to an amount of time that the battery can be discharged to a final voltage, such as a 5-hour 500 Ampere-hour (A-h) capacity battery to a final voltage of 1.75 volts per cell. What this means is that the battery can provide a current of 100 Amps for 5 hours until reaching the cutoff voltage. A number of factors affect the capacity of a given battery, such as temperature, previous history and discharge rate. These are discussed below.

The capacity of a battery will increase with increasing temperature. However, at elevated temperatures the lifetime of the battery is significantly reduced. Therefore, most manufacturers recommend keeping a battery at a set temperature which yields a high capacity while not seriously impacting

TABLE 2-1
BESS COMPUTER CODE SPECIFICATIONS

1) Software Requirements:

   - Written in FORTRAN
   - Stand-alone, requiring no other software to operate

2) Hardware Requirements:

   - Source code able to compile on any PC using MicroSoft™ FORTRAN version 5.1 or higher

3) Model Structural Requirements:

   - Modular architecture, simplifying future modifications and upgrades
   - Easy-to-understand input
   - Ability to evaluate ranges or specific BESS sizes
   - Organized to facilitate incorporation of a future Self-Generation Model

4) Applicability Requirements:

   - Ability to model potential BESS facilities ranging from 100KW to 10MW
   - Able to evaluate BESS economics for both non-conjunctive or conjunctive metering

5) Data Requirements:

   - Utility or monitored metering load curves
   - Technical and cost data reflective of valve-regulated lead-acid batteries will be available internal to the model
   - User can utilize the available internal battery technical/cost data or specify characteristics of their own battery
   - General and specific utility rate structures
   - User-defined inflation rates
   - Project duration

6) Output Requirements:

   - Demand and energy costs without BESS
   - Capital required (including replacement battery capital)
   - Annual operation costs
   - Net present value, internal rate of return and payback period
   - Cash flow for life of project
   - When model being run for a range of BESS sizes, the optimum size based on economics

TABLE 2-2
SPECIFIC TRANSIT SYSTEM SIMULATION SPECIFICATIONS

- Evaluate both an individual and conjunctively-metered transit system
- For the two systems chosen, obtain one year's worth of metering load curve information
- Use this data within the BESS computer program to simulate operation of a BESS considering best-estimate input values
- Perform a parametric study for both of the systems evaluated by looking at a range of values for the key input items.
- Use these results to establish the economic feasibility of installing a BESS at these transit authorities

its lifetime (this temperature is typically 77° F). For the model developed here, temperature effects will not be considered.

Battery capacity is a function of its discharge history. As the battery is discharged and recharged, it's capacity varies based on the method and amount of energy removed.

A high-discharge rate will reduce the amount of energy which is available from a battery. For example, the 5-hour 500 A-h battery previously discussed will only have an available capacity of 300 A-h at the 1-hour rate before reaching the cutoff voltage. Therefore, the same battery can be used to provide 100 Amps for 5 hours, or 300 Amps for 1 hour. The available battery capacity will vary throughout the possible discharge times (i.e. this same battery would provide 600 A-h at the 10-hour rate). The primary causes of this phenomena are a closing of the pores due to sulphation on the surface of the plates, a limited amount of time for diffusion of the electrolyte, and the loss of voltage due to the internal resistance of the cells. It should be noted that while the **available** battery capacity varies with discharge rate, the **actual** capacity of the battery does not vary significantly. A value close to the theoretical actual energy can be obtained from the battery by successive discharges at lower and lower currents.

An equation has been developed which estimates the battery capacity based on a given discharge rate.[2] This relationship, known as Peukert's equation, is able to closely predict the available capacity for a wide range of discharge rates for many batteries. This equation is shown below:

$$\mathbf{I^n * t = C}$$

Where:

I - Discharge current (Amps)
t - Discharge duration (Hours)
n - Equation exponent (slope of log-log line)
C - Equation constant

This equation is used within the computer model to simulate the capacity for a given battery. Figure 2-1 is a graphical representation of the relationship between battery capacity and discharge duration using Peukert's equation. To apply this equation to a particular battery, two capacity versus discharge rate points must be obtained for the battery being evaluated. This enables

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[2] Linden, David, ed., *The Handbook of Batteries and Fuel Cells* (New York: McGraw-Hill, 1984), p.3-9.

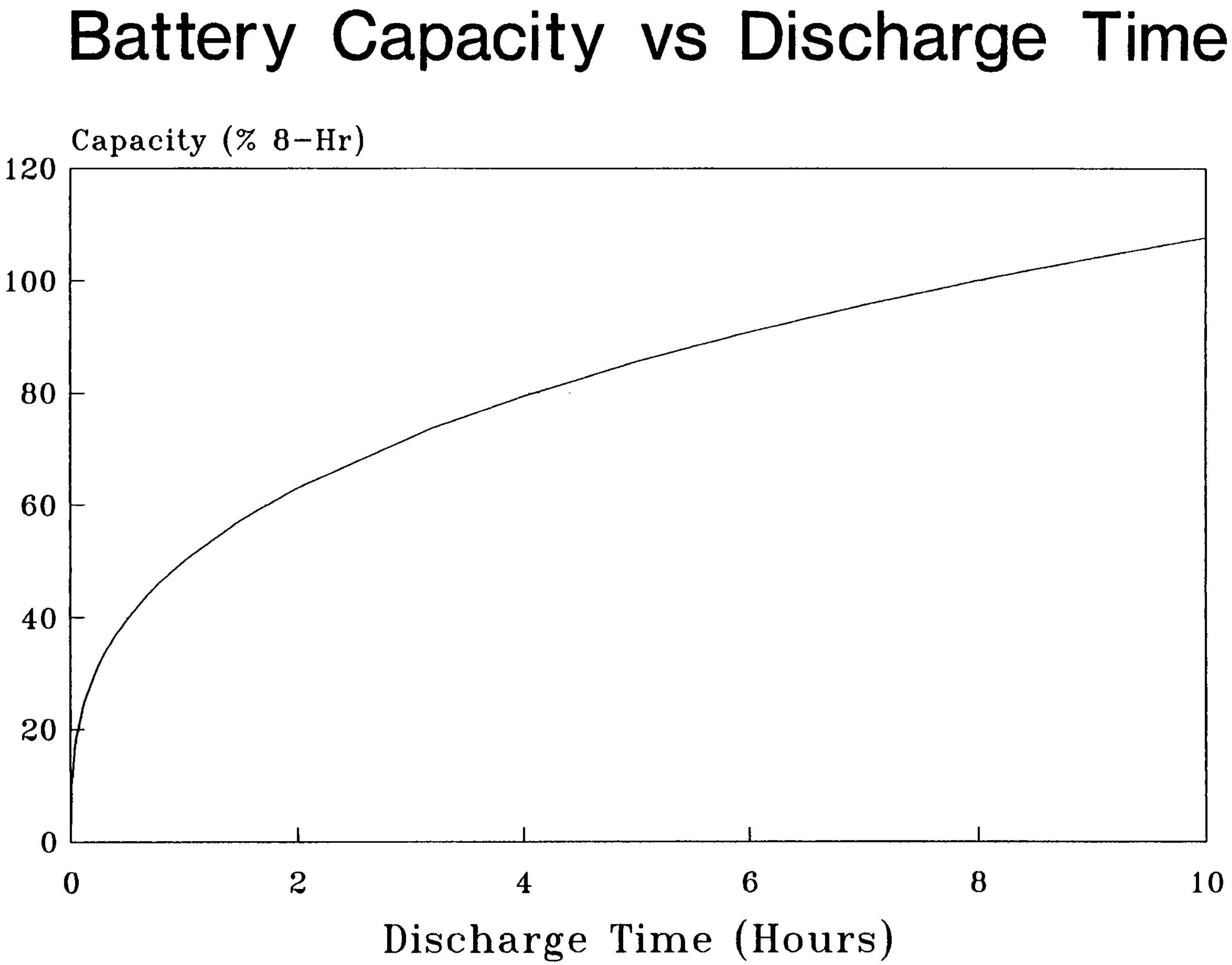
Battery Capacity vs Discharge Time
Capacity (% 8-Hr)
120
100
80
60
40
20
0
0
2
4
6
8
10
Discharge Time (Hours)

Figure 2-1

determination of the two coefficients. Once these are defined, the equation can be rearranged as follows to enable calculation of the amount of time the battery can operate at the given current before reaching the cutoff voltage:

$$t_{peuk} = C / I^{n}$$

Where:

t_{peuk} - Time to cutoff voltage for given current (Hours)

Metering information is used to establish the current being drawn from the battery. This information, in conjunction with the previously calculated battery coefficients, is entered in the above equation, and yields the amount of time the battery can provide the given current until it reaches the cutoff voltage. Dividing the time associated with the meter pulse interval by the amount of time the battery can last at the specified meter discharge rate (obtained from the Peukert equation), and multiplying this number by the battery capacity (the model arbitrarily uses the 8-hour capacity) will yield the Peukert equation's estimate of the apparent energy removed during the meter interval, as shown below:

$$E_{app} = (t_{met} / t_{peuk}) * E_{8hr}$$

Where:

E_{app} - Apparent Energy to be removed (KWh)
E_{8hr} - Full charge 8-Hour battery Energy Capacity (KWh)
t_{met} - Meter time interval (Hrs)[3]

The real amount of energy removed is simply the power recorded by the meter multiplied by the meter time interval:

$$E_{real} = P_{met} * t_{met}$$

Where:

E_{real} - Real amount of energy removed from battery (KWh)

After being recharged, the actual and the available energy rates are both set to the same value, which is the 8-Hour battery capacity. But as the battery is discharged, these values are revised using the following equations:

---

[3] Metered energy is recorded in the number of meter pulses in a fixed time interval. Each pulse, which usually is one revolution of the disk inside of the meter, is of fixed energy. The fixed time interval is referred to as the meter time interval. The number of pulses in that time interval multiplied by the energy per pulse and divided by the time interval is P_{met}.

$$E_{actual} = E_{actual} - E_{real}$$

$$E_{avail} = E_{avail} - E_{app}$$

Where:

E_{actual} - Actual amount of energy remaining in battery (KWh)
E_{avail} - Amount of battery energy available for use (KWh)

The model tracks both the actual and the available energy, and ensures that the actual never goes below a user-defined Depth-of-Discharge (DOD), and that the available cannot go below zero.

2.1.2 Energy Recovery

Another phenomena exhibited by batteries is their ability to gain back capacity that was lost due to high discharge rates. Studies of lead-acid batteries have shown an ability to recover as much as 10% of their lost capacity.[4] This property is also simulated within the computer model.

When the model establishes that the battery will be idle for a particular meter time interval, it checks to see if there is more available than actual energy. If there is, the model attempts to restore some of the lost available energy. This is regulated by two user-input values: the maximum amount of recoverable capacity (as a percent of the difference between the actual and available capacities), and the rate at which energy is restored (in percent per hour). If the battery is idle, and the amount of available energy is greater than the actual, then the following equation is used to determine the maximum amount of recoverable energy for this meter time interval:

$$E_{PulRecov} = (E_{avail} - E_{actual}) * (\mathbf{Rate}_{recov} /100) * t_{met}$$

Where:

$E_{PulRecov}$ - Maximum amount of recoverable energy (KWh)
$\mathbf{Rate}_{recov}$ - Rate at which energy is recovered (%/Hour)

A counter monitors the amount of energy previously recovered for the day. The model checks to see if the sum of the previously recovered energy plus the maximum recoverable energy for the interval is less than the user-input maximum percent of recoverable capacity times the difference of the available minus the actual energy. If it is, then all of the maximum recoverable energy for the interval will be restored. If not, only that amount

---

[4] Marcel G. Jayne, "The Behaviour of Lead-Acid Batteries Under Pulsed Discharge Conditions," in Power Sources Volume 6, ed. D. H. Collins (London: Academic Press, 1977), p.40.

of the maximum recoverable energy which is below the maximum total recoverable energy will be restored. These relationships are presented in the equations below:

$$\textbf{IF } (E_{RecovDay} + E_{PulRecov}) < (E_{avail} - E_{actual}) * (\textbf{Pcnt}_{recov}/100)$$

$$\textbf{THEN } E_{avail} = E_{avail} + E_{PulRecov}$$

$$\textbf{ELSE } E_{avail} = (E_{avail} - E_{actual}) * (\textbf{Pcnt}_{recov}/100) - (E_{RecovDay} + E_{PulRecov})$$

Where:

$E_{RecovDay}$ - Energy previously recovered for the day (KWh)
$\textbf{Pcnt}_{recov}$ - Recoverable portion of lost energy (%)

2.1.3 Battery Recharge

Recharging of the battery refers to the process by which chemicals are returned to their high-energy state by the reversal of the electric current. For a lead-acid battery this involves the conversion of the positive electrode's lead sulfate to lead oxide, the negative electrode's lead sulfate to metallic lead, and the electrolyte's sulfuric acid solution to a higher concentration.

During development of the computer model, the benefits of a realistic simulation of the recharging phenomena were evaluated. Upon consideration, it was decided that the inefficiencies associated with the battery system was the only critical battery recharge characteristic in terms of it's impact on an economic assessment.

Therefore, the recharge module within the program simply places an amount of power equal to the sum of the energy provided over the last discharge period plus the extra energy necessary to overcome electrical losses and energy conversion inefficiencies into a set of user-defined pulses (typically these pulses would be during off-peak times, such as midnight to 5AM). This is modeled within the program as follows:

$$P_{PulRech} = ((E_{Discharge} * (1 + \textbf{Effic}_{RT}/100)) / \textbf{Pulses}) / t_{met}$$

Where:

$P_{PulRech}$ - Amount of power to add to recharge pulses (KW)
$E_{Discharge}$ - Sum of E_{actual} over prior discharge period (KWh)
$\textbf{Effic}_{RT}$ - Round-trip efficiency of the battery system (%)
Pulses - Number of user-defined recharge meter time intervals per day

This energy is then converted to average power by multiplying it by the meter time interval, and this value is then added to each of the user-defined recharge meter time intervals within the model to properly account for the recharged energy.

2.1.4 Depth of Discharge

The Depth-of-Discharge, or DOD, is a measure of how much energy has been removed in comparison to its rated capacity. This value is expressed as the difference between 1 and the ratio of the actual energy removed to the battery system's rated capacity, all multiplied by 100 to get the value into percent. This equation is shown below:

$$\mathbf{DOD} = (1 - (E_{actual} / E_{8hr})) * 100$$

Where:

DOD - Depth of Discharge of battery (%)

Within the computer model, the user is asked to supply a specific DOD that the battery is never to exceed. Each time the computer model encounters a meter time interval which meets the criteria for shaving, the program verifies that removing the desired amount of energy for the specified time interval will not cause the battery to fall below the user-defined DOD.

2.1.5 Battery Life

The useful life of a battery is tied to it's retained capacity. The long-term capacity is related to the method and amount of energy removed from it previously. In the beginning, new batteries will exhibit an increase in capacity over the first few cycles, until reaching their maximum capacity. After reaching this maximum, the capacity will begin to drop off slightly until the plate capacity is around 80% of its rated capacity. Any further cycling after reaching the 80% capacity mark will cause a significant loss of capacity. Therefore, most batteries are discarded when their capacity has dropped to 80% of the original value.

An evaluation of the performance of many batteries has shown that their life in terms of the total number of discharge cycles can be related to the DOD via the following equation[5]:

---

[5] Frank Robinson, Thomas P. Prouty and Dr. Rathbun B. Squires, "Technical and Economic Analysis of a Rapid Transit Battery Storage Substation Project", New York State Energy Research and Development Authority, NYSERDA Report 83-7 (April 1983), p.3-10.

$$\mathbf{Life}_{cycles} = \mathbf{C} * 10^{(m * DODAvg)}$$

Where:

$\mathbf{Life}_{cycles}$- Battery life until reaches 80% capacity (cycles)
DODAvg - Average annual DOD of the battery
C, m - Constant and slope of equation

The model calculates the constant and the slope via two user-input values of cycle life vs DOD for the specific battery to be used. Once these values are determined, then the program can estimate the number of cycles that the battery can provide for any average DOD. An example of this relationship is shown in Figure 2-2.

Each time that the model evaluates a specific BESS, it keeps track of the amount of energy discharged from the battery. At the end of the year, it uses this value to determine the average DOD. Using this value in the above equation, the anticipated cycle life can be calculated. Since the model has also identified the number of times the battery has been cycled within a year, it can then determine the number of years that the battery will last by dividing the projected cycle life by the number of cycles per year, as follows:

$$\mathbf{Life}_{years} = \mathbf{Life}_{cycles} / \mathbf{Cycles}_{Act}$$

$\mathbf{Cycles}_{Act}$ - Actual number of times battery is cycled per year

Inside the model this value is compared to a user-defined maximum battery life, and the smaller of the two is then used to determine how often the batteries must be replaced over the duration of the BESS lifetime.

2.1.6 Increased Battery Voltage

In most applications of a BESS, the stored energy is used to shave off a portion of the demand seen at the substation and associated meter where it is located. Therefore, under these conditions, the size of a BESS would be limited by the capacity of that substation. There are situations, however, where it may be advantageous to utilize a BESS whose capacity ratings exceed those of the substation.

Such an occasion occurs when a transit authority has a number of substations that are billed conjunctively. When this happens, the individual meters' energy pulses are added together before the demand calculation is performed. This can save a significant portion of the demand cost, since it is common for individual meter peaks to occur on different days and at different times than the other meters of the system.

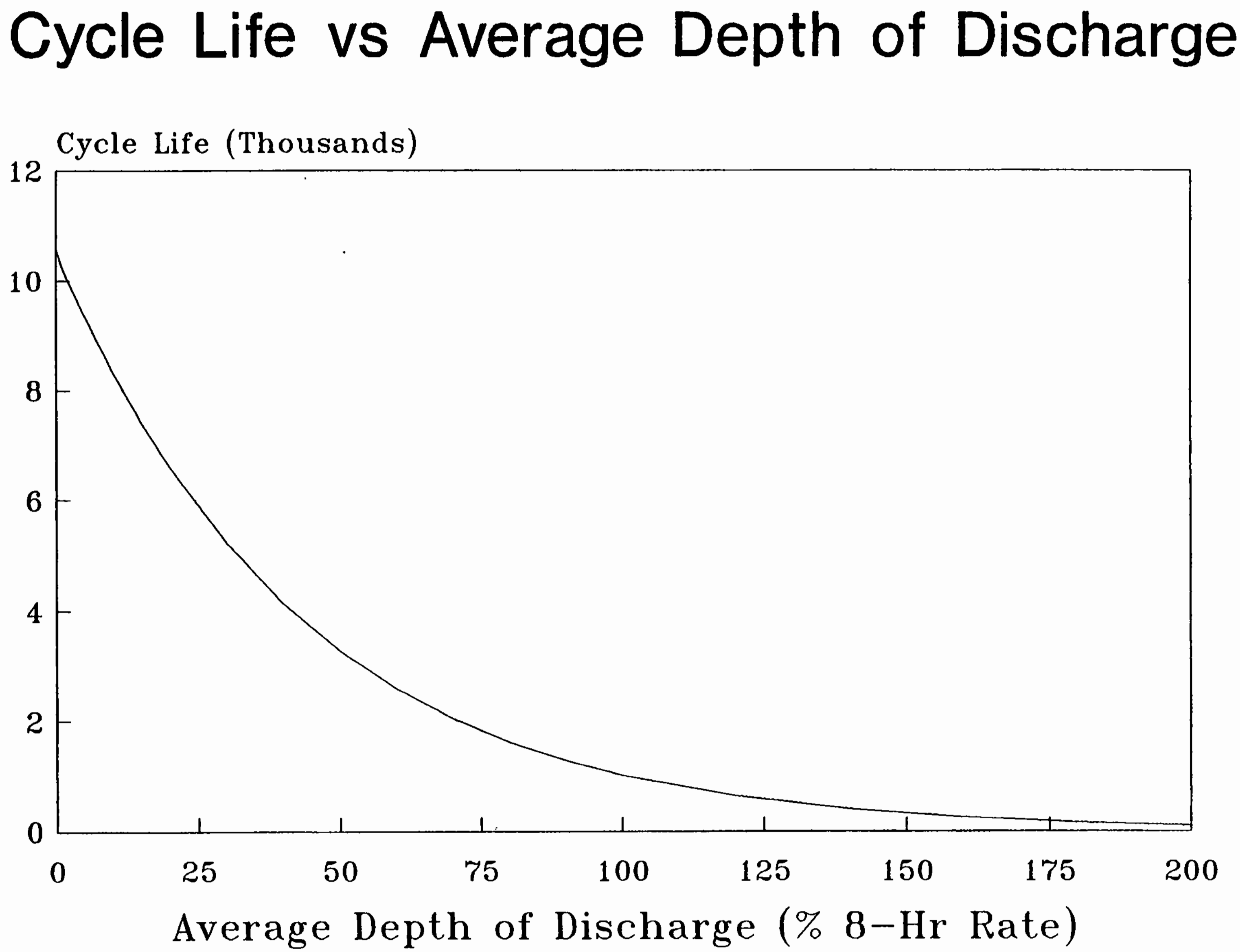
Cycle Life vs Average Depth of Discharge
Cycle Life (Thousands)
12
10
8
6
4
2
0
0
25
50
75
100
125
150
175
200
Average Depth of Discharge (% 8-Hr Rate)

Figure 2-2

In a conjunctively billed system, it may be that the optimum amount of power to shave is greater than the largest demand seen at any one meter. Under these conditions, it may be beneficial to install a BESS at a substation that could shave all of it's substations energy, as well as shaving energy from adjacent substations. This could be accomplished by installing a BESS that has a voltage which is greater than the system voltage. Raising the BESS voltage will cause more energy to come from the BESS than from the substation, if no BESS were present.

To quantify the effect of installing a BESS at a substation with an increased voltage, the Rail Transit Energy Management Model (EMM) was used. The EMM is a computer simulation tool which has been proven to accurately predict the energy consumption of many transit systems, and has been used extensively both domestically and abroad[6].

The Washington, DC Metro (WMATA) Red Line without a BESS was simulated using the EMM, and then the EMM was used several more times assuming a BESS was located at the Farragut North substation with the voltage increased up to 8% over the nominal[7]. The results of these runs are shown in Table 2-3.

Evaluation of this data showed that a strong linear relationship exists between the increased voltage and the amount of energy provided by the battery. The following equation presents this relationship, and is shown graphically in Figure 2-3:

$$\mathbf{Energy}_{\text{Increase}} = 34.98 * \mathbf{Volt}_{\text{Raised}} + 3.84$$

Where:

$\mathbf{Energy}_{\text{Increase}}$ - Energy increase due to raised voltage (%)
$\mathbf{Volt}_{\text{Raised}}$ - Amount battery voltage above system voltage (%)

Therefore, an option was included within the computer model which enables the user to choose an increased voltage for those substations which are conjunctively billed. When the increased battery voltage option is chosen within the computer model, the individual meter energy values will all be escalated using the above relationship. Since this equation will increase the individual meter energy values, it will ultimately enable sheering of a much larger amount of energy (almost 300% more energy at a raised voltage of 8% above nominal).

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[6] Uher, Richard A. *Rail Traction Energy Management Model*, Rail Systems Center, Carnegie Mellon University, Pittsburgh, PA USA.

[7] 10% above nominal is the limit of the specification.

TABLE 2-3
EMM RAISED BATTERY VOLTAGE SIMULATION OF WMATA SYSTEM

Amount over System Voltage (%)	Battery Energy (kWh)	Increase in Energy Provided (%)
0.0	323	0.0
2.0	566	75.2
4.0	802	148.3
6.0	1020	215.8
8.0	1226	279.6

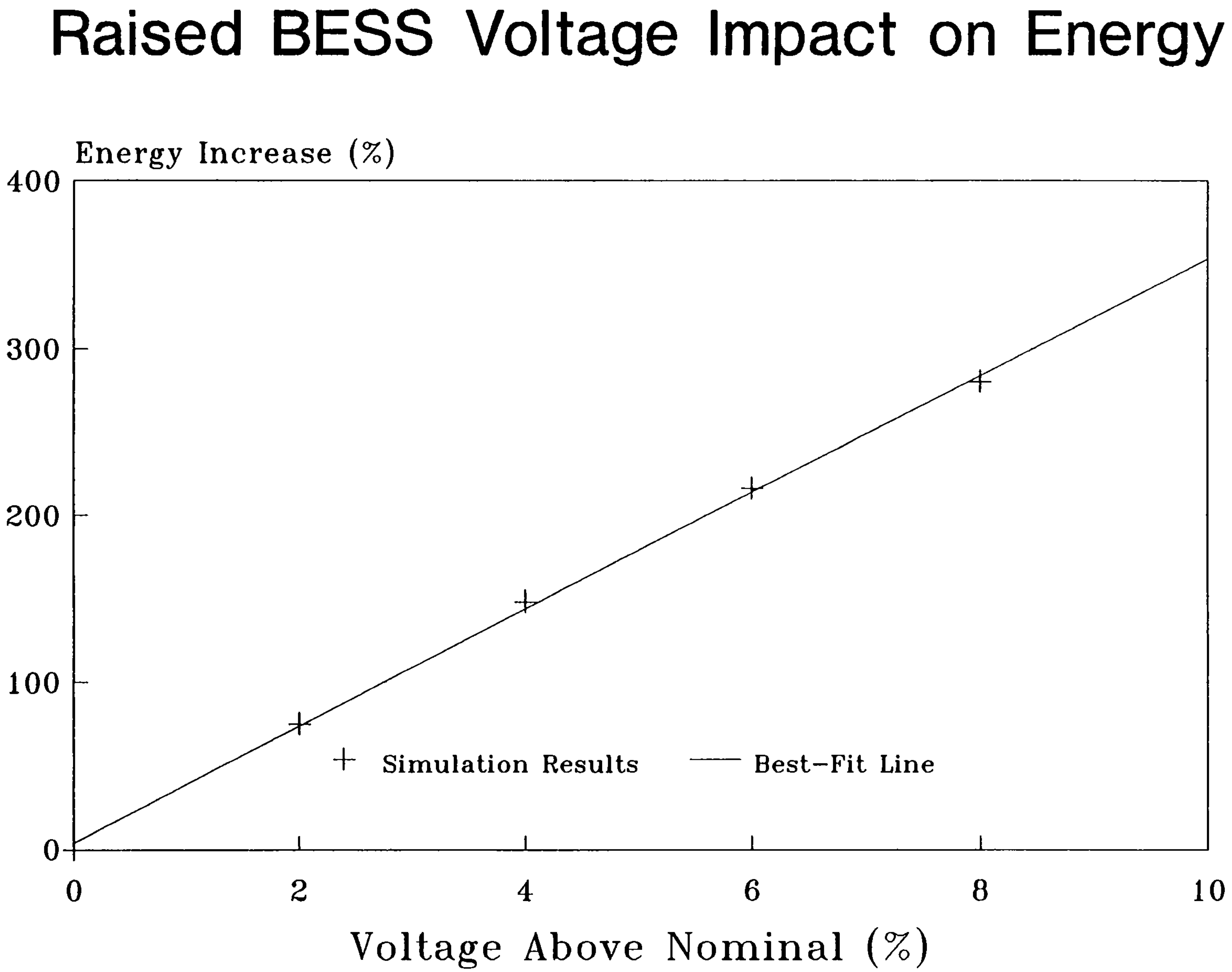
Raised BESS Voltage Impact on Energy
Energy Increase (%)
400
300
200
100
0
0
2
4
6
8
10
Voltage Above Nominal (%)
Simulation Results
Best-Fit Line

Figure 2-3

2.1.7 Cell Voltage Drop

As lead-acid batteries are discharged, their cell voltages drop from a nominal value typically around 2.1 volts to a cut-off voltage around 1.75 volts. This reflects a voltage drop of about 17%. For the simulation package developed within this study, it is assumed that the power conditioning system will ensure that the output battery voltage maintains a specific value. As was discussed in the previous section, this value could be chosen as something other than the system voltage.

2.2 BESS Cost Model

The costs associated with a BESS will vary based on the type of battery used, it's power and energy ratings, the power requirements of the power conditions system, and the installation requirements. For this reason the model was developed to be flexible enough to allow the user to either apply costs that were obtained from the manufacturer and application studies (which are built into the model), or to enter costs based on prices quoted for a specific BESS.

For the purpose of this report, it was assumed that VRLA (Valve-Regulated Lead Acid) batteries would be used. VRLA batteries are sealed, and therefore do not require any addition of water or checking of specific gravity, and are essentially maintenance free. Since any premature failure of the batteries (if operated within the constraints of the manufacturer's specifications) are covered by a warranty, this also should not result in any additional maintenance costs. While occasional inspection of the batteries is recommended, the associated cost was considered minimal. Therefore, it was not considered necessary to add any costs for maintenance of the BESS.

Table 2-4 shows the costs associated with various components of a BESS. These costs were all normalized to 1993 dollars. Specific options within the model enable the user to utilize costs reflective of the Metro-North BESS project[8], an EPRI report[9] which developed battery costs, an average value as shown in Table 2-4, or user-specified costs.

These costs, given in $ per kW or $ per kWh, are multiplied by the BESS demand or capacity values being evaluated to determine each component's specific cost.

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[8] Walter J. Stolte, "Assessment of a Battery Storage System for the Metro-North Commuter Railroad 126th Street Traction Rectifier Substation", Bechtel Corporation (April 1993), p.3-28.

[9] Walter J. Stolte, "Characterization of Energy Storage for Transportation", Bechtel Group, Inc. (May 1993), p.2-16)

TABLE 2-4
BESS Component Cost Estimates

	Source ==>	Metro North	NY City	Test Case	Average <== of 3	San Diego	EPRI Report	Manufacturer Costs Traction Batteries	
	Date ==>	1993	1983	1990		1992	1993	1993	1993
	Company ==>	Bechtel	Garrett	Univ of Missouri		Bechtel	Bechtel	GNB	Exide
Demand (kW)		1000	6905	1000		210			
Daily Use (Hrs)		0.5	1	2		2			
Energy @ Discharge (kWh)		500	6905	2000		420			
Energy @ 8 Hr Rate (kWh)		1471	13810	2985		627			
Battery:	Cost ('93 $K's)	506	2612	575		235			
	Cost ('93 $/kWh)	344	189	193	242	375	220 - 250	150 - 180	250
PCS :	Cost ('93 $K's)	149	1962	326		497			
	Cost ('93 $/kW)	149	284	326	253	2368	100 - 400		
BOP :	Cost ('93 $K's)	361	1962	286		750			
	Cost ('93 $/kWh)	246	142	96	161	1197	55		
	Cost ('93 $/kW)						165		
	Base Cost ('93 $K's)						500000		

2.3 Transit Power Rate Structure Model

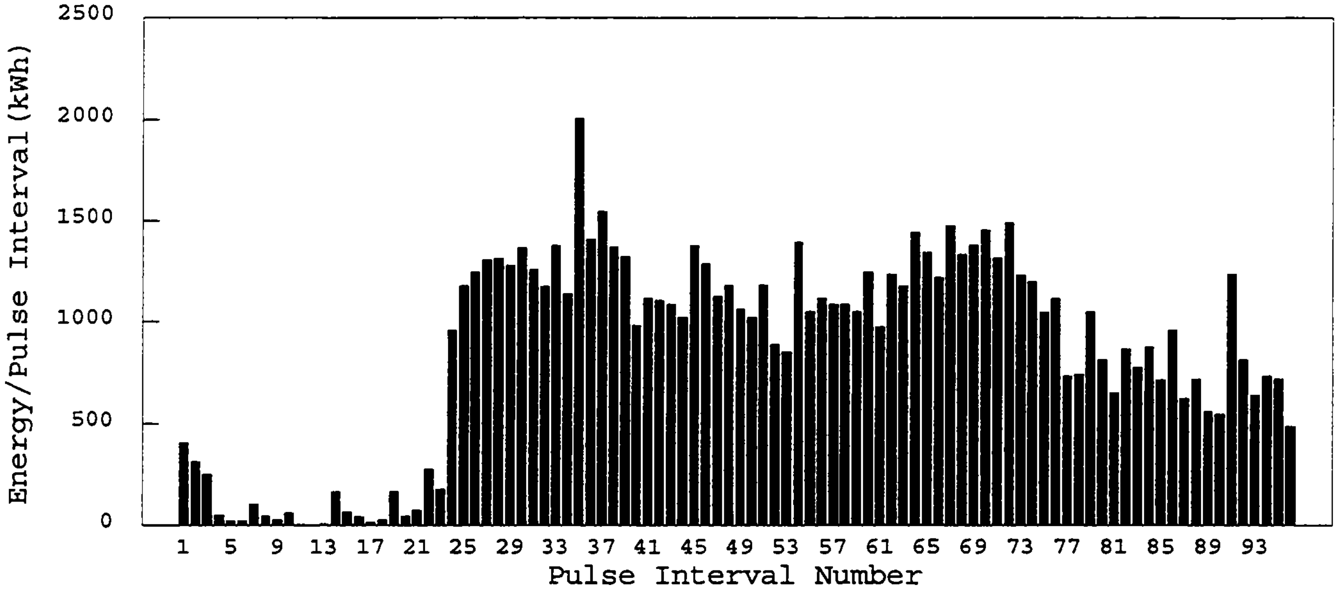
The model requires one year's worth of meter pulse (kW) data to enable an accurate simulation of battery performance. An example of one day's data for the WMATA rail operation is shown in Figure 2-4. The model first uses these data to apply a power rate structure to establish the power bill without the battery. It then modifies the meter data to reflect implementation of a BESS, recalculates a new power bill, and establishes the annual savings. Therefore, in order to utilize the model, the substation meter data must be obtained. The factors which determine electricity cost in rail transit systems are dependent on the energy use pattern in conjunction with the power rate structure imposed by the electric utility that serves the system. The power rate structure sets the schedule of electricity charges for energy consumption, power demand and facilities charges. Energy consumption is the actual use of power integrated over time, and is measured in units of kilowatt-hours (kWh). Power demand is measured and recorded by meters, and is a reflection of the average power over a time interval (demand interval) seen at the meter and measured in kilowatts (kW). Facilities charges are generally fixed costs that the utility passes on to the transit authority to offset non-energy related costs incurred by the utility.

Energy and facilities charges are relatively straight-forward calculations. To determine the energy charge the monthly energy is summed together and multiplied by the cost per kWh. Facilities charges are typically just flat monthly charges. However, the method used to calculate the demand costs varies significantly from transit authority to transit authority. Some of the variations include use of an average of a certain number of power readings, use of a demand ratchet, and use of a conjunctive (also known as coincident) demand.

When rate schedules make use of an average demand, an agreed-upon number of adjacent power readings are averaged together to establish the demand value, which is then multiplied by the demand charge (in $/kW) to get the demand cost. In a conjunctive demand (also known as a coincident demand), a group of meters that are all under the same utility jurisdiction have their individual meter energy values added together before the demand charges are applied. Conjunctive demand can enable substantial reductions in demand costs since individual peak demands frequently occur on different days and different times. The summed energy values are divided by the demand time interval and then multiplied by the demand charge to determine the demand cost. A demand ratchet refers to a minimum amount of demand that the transit authority will be charged, and is typically tied to a peak demand that the transit authority has experienced over a prior number of months (such as a transit authority being responsible for paying a demand cost for the highest demand experienced over the past 3 months). The model incorporates an average demand calculation for one of the specific transit authority power rate structures (described below).

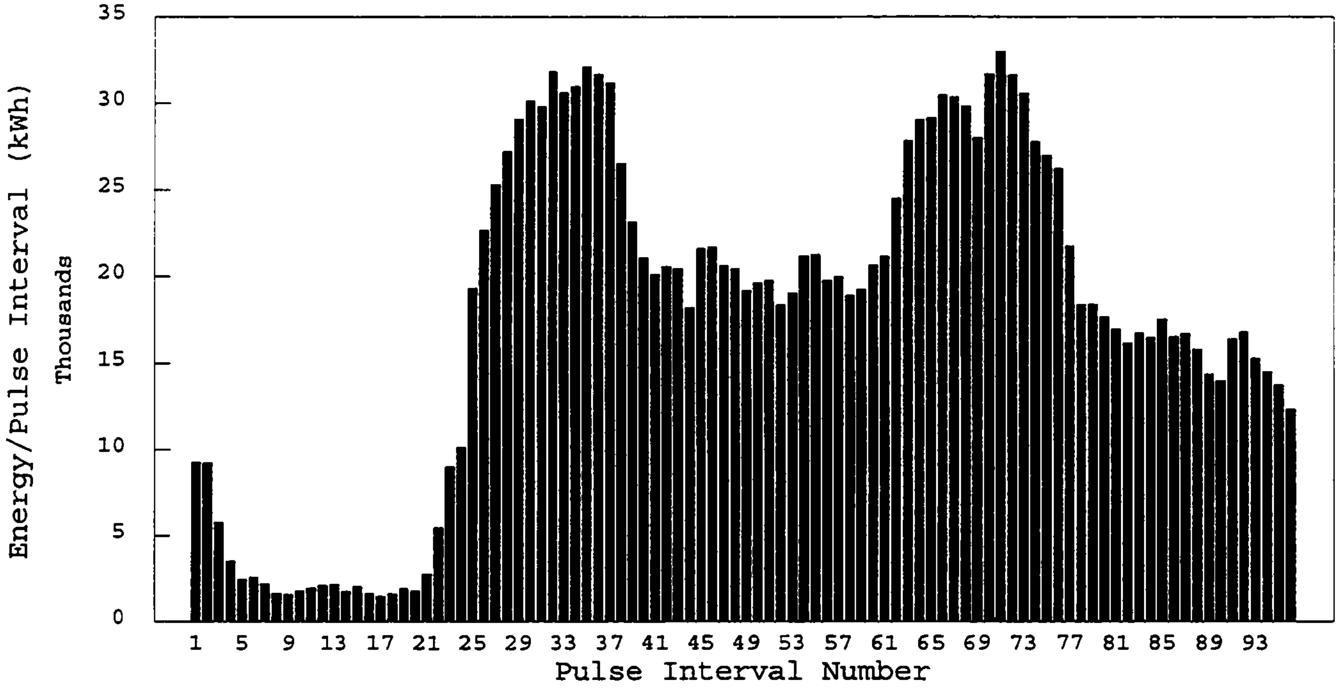
WMATA Meter Pulse Data

Meter at Farragut North Substation



Date: January 2, 1985

DC PEPCO Conjunctive Demand



kwpulse.wk3 /range:graphs

FIGURE 2-4

The model also has the ability to handle conjunctively-billed transit authorities. This capability requires that the user obtain pulse information for both the individual meter where the BESS will be located, as well as pulse information reflective of the sum of all the meters. This is the case for WMATA. The model will simulate operation of the BESS at the individual meter, and will modify the energy value summations to obtain a new conjunctively-billed demand cost.

No demand ratchet capability was included within the power rate structure model.

The model was programmed with three different power rate structure options. These options reflect power rate structures for the two specific systems that will be evaluated using the model (PEPCO-DC for the WMATA red-line in Washington, DC and Duquesne Light for the PAT system in Pittsburgh, PA), as well as a generic power rate structure which should enable a reasonably accurate calculation of the electric bill for most transit authorities. The WMATA and PAT systems were chosen to enable evaluation of a conjunctive (WMATA) and non-conjunctive (PAT) power rate structure. The various power rate options available within the model will be discussed in the sections below.

2.3.1 Duquesne Light (PAT, Pittsburgh, PA) Rate Structure

As will be described in a subsequent chapter, a meter within the Duquesne Light utility power rate jurisdiction was chosen as the location to analyze with the application of a BESS.

The Duquesne Light power rate structure is given in Table 2-5. This power rate structure applies a straight energy charge of $.0378/kWh. It also charges $5,493 for the first 300 kW (which works out to $18.31/kW), and adds an additional $13.90/kW for any additional demand. The Duquesne Light power rate structure does not include a conjunctive demand calculation, nor does it utilize any equations to calculate the demand to which it applies these charges. It simply uses the 15-minute energy readings monitored at the meters. There is also no demand ratchet involved with the Duquesne Light rate structure.

2.3.2 PEPCO-DC (WMATA, Washington, DC) Rate Structure

A meter on the WMATA red line was chosen for application and evaluation of a BESS.

TABLE 2-5
Duquesne Light Rate Structure

Duquesne Light - Rate GL (General Service 7300 kW)

Energy:	
All kWh	$.0378/kWh
Demand:	
First 300 kW or less	$5,493
Additional kW	$13.90/kW

Billing Demand: The monthly billing demand will be the maximum fifteen (15) minute individual meter demand reading recorded during the billing month.

The PEPCO-DC power rate structure is shown in Table 2-6. This power rate structure includes a straight energy charge of \$.0356/kWh, a monthly delivery charge of \$233.35 per month for each delivery point, and a demand charge of \$11.26/kW. The PEPCO-DC structure includes a conjunctive calculation of demand, and therefore adds the 12 individual traction meter pulses together. Before applying the demand charge, these energy values are then used to calculate a one-half hour average demand using the 15-minute conjunctive energy data. Each month the maximum demand value calculated following this procedure is multiplied by the demand charge of \$11.26/kW to obtain the monthly demand cost.

2.3.3 Generic Power Rate Structure

A general power rate structure was also incorporated into the model to enable a reasonably good estimate of an electric bill for most transit authorities. This model included a user-defined energy charge (\$/kWh), demand charge (\$/kW), base demand charge (\$) and a base demand below which the demand charge is not applied (kW).

The conjunctive demand capability is still accessible with this general power rate structure.

2.4 Economic Analysis Model

Once all the costs and energy savings associated with a particular BESS size have been established for each year of the project, these values are used within the computer model to generate several gauges of it's economic viability. These economic indicators will be discussed in the sections below.

2.4.1 Net Present Value

The Net Present Value (NPV) expresses the economic attractiveness of a proposed capital expenditure in dollar terms. A NPV is always associated with a specific discount rate. The discount rate chosen is often interpreted as a figure that represents the minimum return below which an investment is considered unattractive. The NPV can be thought of as a means to determine the present value of a project considering the assumed discount rate. The equation used to calculate the NPV is shown below:

$$NPV = \sum_{t=1}^{Years} \frac{CashFlow_t}{(1+DiscRate)^t} - Capital_{Init}$$

TABLE 2-6
PEPCO DC Rate Structure

PEPCO DC Schedule RT

Energy:	
All kWh	$.0356/kWh
Demand:	
Monthly Peak	$11.26/kW
Customer Charge:	
Monthly	$233.35/metering point

Billing Demand: The monthly billing demand will be the maximum thirty (30) minute integrated conjunctive demand of all delivery points recorded during the billing month.

Where:

Years - Active project life (years)
$CashFlow_t$ - Cash flow for specific year being evaluated ($)
DiscRate - Discount rate being considered (fraction)
$Capital_{Init}$ - Initial capital required to construct BESS ($)

The cash flow for a particular year is just the energy cost savings inflated to that particular year less battery equipment costs also inflated to that year. Thus, the initial NPV is the capital investment and is negative.

Given that the chosen discount rate reflects the rate that must be met in order for the project to be considered attractive, then a positive NPV would indicate that the BESS is economically attractive, while a negative value would signify that it is not.

2.4.2 Internal Rate of Return

The Internal Rate of Return (IRR) is another economic barometer which is calculated within the computer model. The IRR is the discount rate which equates the discounted present value of the cash inflows with the initial investment. The following equation defines the IRR:

$$\sum_{t=1}^{Years} \frac{CashFlow_t}{(1+IRR)^t} = Capital_{Init}$$

Where:

IRR - Internal Rate of Return (fraction)

The IRR is basically an indication of the earning power of an investment. This means that, for an IRR of .1 (i.e. 10%), enough money will be received to repay the initial investment with a 10% internal earning on the initial investment. If a BESS IRR is above the horizon rate of return for a transit authority, then the project is economically attractive. The IRR must be at least higher than the discount rate to be attractive.

2.4.3 Payback Period

The PayBack Period (PB) is the final method employed by the model to determine it's economic viability. This method involves calculating the time required to recover the capital investment given the anticipated cash flow. This relationship is shown in the following equation:

$$\sum_{t=1}^{PB} \frac{CashFlow_t}{(1 + DiscRate)^t} - Capital_{init} = 0$$

Where:

PB - Time required to payback the initial capital (Years)

If the resulting PB is less than the transit authority's desired payback period, the project is economically attractive.

2.4.4 Preferred Economic Index

The NPV was chosen as the economic index to maximize. There are two reasons for this choice:

1. Any project returning more than it costs is contributing to value added.
2. It allows maximization of dollars and not percents[10].

The other two indices, namely, IRR and PB are also considered.

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[10] George F. Pinches, *Essentials of Financial Management*, 2nd ed., (1987), p. 246.

3.0 BESS SIMULATION OF WMATA AND PAT

Recent energy management studies were completed on several rail transit systems including

- Washington Metropolitan Area Transit Authority (WMATA)
- Metropolitan Atlanta Rapid Transit Authority (MARTA)
- Mass Transit Administration of Maryland (MTA-MD)
- New Jersey Transit Corporation (NJ Transit) Morris-Essex Line
- Port Authority of Allegheny County (PATransit) Pittsburgh

The best opportunities for power demand shaving would be with rail transit authorities who have large demand rates in their power rate structures. PAT, which has a demand rate of $13.90/kW under Duquesne Light and WMATA, which has a demand rate of $19.26/kW under the Potomac Electric Power Company in the DC jurisdiction (PEPCO-DC) were chosen on this basis for BESS modeling. This chapter contains a description of this modeling including the results.

The chapter begins with a discussion of BESS input values for the base case and variations from the base case, which are rail transit system independent. This is followed by discussion of the simulations carried out on PAT and then on WMATA. A survey of rail transit was conducted on acceptable payback periods for capital investments which reduce operating costs. The results of that survey are summarized here.

3.1 BESS Input Values Independent of Rail Transit System Specifics

There are a number of input requirements for the BESS model which are not rail transit system specific. These values are used for both WMATA and PAT.

Discharge Option

The model allows two battery discharge options; namely, partial discharge and full discharge.

For the partial discharge option, the BESS will attempt to shave power demand only when the demand is above some threshold value, which is defined as the maximum meter demand less the BESS rated power. For example, if the maximum meter demand for the year or month was 2000 kW and the BESS rated power is 1250 kW, then the threshold demand is 750 kW. Thus, the BESS will discharge enough energy to keep the new meter demand equal to the threshold demand of 750 kW. The BESS will be turned on only during pulse intervals when maximum demand is expected to occur. The partial discharge option is taken as the base case for BESS operation.

Under the partial discharge option, if the meter demand exceeds the threshold, the BESS will begin discharging at full rated power. If there is insufficient BESS capacity remaining, the BESS discharge power is regulated to just meet capacity.

In practice, this is accomplished in the following manner. Each rotation of the meter represents a pulse of energy in a particular time period. The number of meter rotations since the beginning of the pulse interval is monitored. When this value exceeds the threshold demand the battery is switched on and will discharge up to full power. If the meter demand exceeds the full power of the BESS, the meter will still feed the rail transit system at some value of power less the battery discharge power. The energy remaining in the battery is also monitored. If the remaining energy can not support the discharge, the battery is simply turned off for the remainder of the interval.

The full discharge option is different from partial discharge. For each pulse interval in which the BESS is operating, the BESS will try to discharge its rated power. Thus, a BESS rated at 1250 kW will make available 1250 kW. In addition, the BESS will not operate on weekends and holidays, when train movement is light.

It is clear that battery capacities and, thus, BESS costs, to meet the full discharge mode of operation, will be higher than the partial discharge mode of operation. However, meter power monitoring is not required for this case. This case is treated as a variation on the base case for both WMATA and PAT.

Maximum Depth of Discharge

The Depth of Discharge (DOD) is a measure of how much energy has been removed from the battery in comparison to its rated capacity. It is measured in terms of percent of rated energy. The base case sets the maximum DOD at 80%. This means that the battery will not be allowed to discharge energy if the DOD is greater than or equal to 80%. This value is relatively standard industry-wide, and enables access to the bulk of the battery's energy while minimally impacting the life of the battery.

To test the sensitivity of the BESS to maximum DOD, a variation of the base case, in which the maximum depth of discharge is set at 60%, was simulated.

Battery Lost Energy Recovery

The base case for lost energy recovery was considered to be a 10% maximum recovery of lost energy, returned at a rate of 2% per hour. This means that only 10% of the capacity of the battery could be recovered over a five hour time period.

No variation on the base case was completed, because variation within reasonable industrial values was found to have a negligible impact on the results.

Round Trip BESS Efficiency

The base case for RT BESS efficiency was set at 80%. This takes into account the average losses in the PCS and the battery. Two variations of the base case were considered; namely, 70% and 90%.

Recharge Periods

Recharge periods should be chosen so that replacing the discharge energy plus energy losses in the BESS does not exceed the threshold demand, which is the peak demand less the BESS discharge rate. For both PAT and WMATA, the recharge intervals were chosen from 10:15 PM to 5:00 AM, periods when transit service is light or not operating.

BESS Voltage

The base case for BESS voltage was taken to be system voltage. The PCS will provide the voltage necessary to discharge the power. Alternate cases are investigated where the voltages will vary 2%, 4% and 6% above the base case voltage. This was only done on WMATA for which demand is conjunctively billed.

BESS Project Life

The project life refers to the lifetime of the BESS system from the financial point of view. Batteries will have to be replaced several times during the project life. The base case for BESS project life is set at 35 years. Variations on the base case include 25 and 45 years.

Discount Rate

The discount rate was taken to be 5%. This is typical of discount rates presently being used for large electrical equipment. No variation in the discount rate was considered.

Energy Inflation Rate

The energy inflation rate for the base case was set at zero. Variations of 3%, 5% and 7% were also considered.

Battery Cost Inflation Rate

For the purposes of the financial analysis, the battery cost inflation rate was taken as zero. Historical experience, however, shows an annual inflation rate of 3%. This number, together with 5% and 7% were used for variations on the base case.

Capital Costs

The PAT and WMATA capital costs for BESS were estimated using various reports on applications of these systems and manufacturer's data. These values are shown in Table 3-1. Observation of this table shows a breakdown of capital cost into two categories (points). One point shows the breakdown for a small BESS (point 1), while the other shows the breakdown for a large BESS (point 2).

Costs are expressed per capacity (kWh) and per rated power (kW). Battery cost only depends on kWh (8 hour discharge). PCS costs depend only on kW. The BOP depends on both kWh and kW.

Linear interpolation is used between the points defined in Table 3-1.

Peaking Options

The threshold power can be set monthly or yearly. Historical experience can be used to set the threshold monthly. This would account for variations in air conditioning and heating loads, as well as demand and response for transit service. Thus, for the monthly option, the threshold setting is just the monthly demand less the BESS rated power.

If the threshold is set yearly, its value is just the yearly peak demand (maximum of the monthly demands) less the BESS rated power.

Battery Technical Characteristics

There are two technical characteristics of the battery that are relevant to the BESS model. These are the discharge rate vs. time to cut-off voltage and the average DOD vs. cycle life.

The values for discharge rate vs. time to cut-off voltage reflect specific

TABLE 3-1
BESS MAJOR SUBSYSTEM CAPITAL COSTS

SubSystem		Point 1	Point 2
Batteries	$/kWh	250	180
	@ kWh	100	15000
Power Conditioning	$/kW	420	220
	@ kW	100	1000
Balance-of-Plant	$/kWh	50	30
	@ kWh	100	15000
	$/kW	150	120
	@ kW	100	2000

information obtained from manufacturer's data[11]. These values are shown in Table 3-2 and reflect the two points necessary to find the coefficients in the Peukert equations.

The values for projected cycle life to average DOD were taken from an application study[12] and are also shown in the table. These points are used to fit the life cycle equation.

3.2 BESS Simulation of the PAT System

3.2.1 Brief Description of the PAT System

The Pittsburgh, PA PAT Light Rail Transit System, known as the 'T', services 82 stops along 25 route miles of operation. PAT operates both PCCs and Siemens-Duewag Light Rail Vehicles (LRVs). Service is provided seven days a week, with lighter operation on weekends.

The T receives power from six different substations that are provided power from two separate utilities: West Penn Power and Duquesne Light. Neither of these utilities allow PAT to use conjunctive billing for their respective traction substations. The T electric bill for 1991 was $2.1M.[13]

3.2.2 Substation Selection

The following criteria were used to select a PAT substation for modeling with the BESS:

1) For systems being supplied power under different rate structures, first choose all the substations from the system that are billed at the highest demand charge.

2) From this group, choose those substations which have demands that reflect large peaks during the AM and PM peak traffic periods (i.e., maintenance yards are typically poor places to locate a BESS since they frequently have no distinguishable peaks to shave).

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[11] Personal Correspondence with Sanjay Deshpande of Gould National Batteries, December 16, 1992.

[12] Frank Robinson and Thomas P. Prouty, "Technical and Economic Analysis of a Rapid Transit Battery Storage Substation Project", (New York State Energy Research and Development Authority, April, 1983), p. 3-10.

[13] Richard A. Uher and John Howard, "Alternative Electric Energy Sources for Rail Transit", (Report for the US Department of Transportation, January, 1993), p.97.

TABLE 3-2

BATTERY TECHNICAL CHARACTERISTICS

DISCHARGE RATE VS TIME TO CUT-OFF VOLTAGE

Discharge Rate (Amps)	Time to Cut-Off Voltage (Hours)
19.23	8
76.92	1

AVERAGE DEPTH-OF-DISCHARGE VS CYCLE LIFE

Average Depth-of-Discharge (% 8-hr capacity)	Projected Number of Cycles
170	200
24	6000

3) Finally, from this subset choose the substation which has the largest demand.

After evaluating the PAT system, consideration of the first criteria above indicates that the substation chosen should be from one of the four Duquesne Light traction substations, since Duquesne Light charges $13.90/kW versus the $3.49/kW charged by West Penn Power. Since all of these meters reflect standard operation substations, the one with the largest magnitude was chosen. This was found to be the South Hills Junction substation.[14]

Pulse data for this meter extending from July of 1987 to June of 1988 was obtained during the previously referenced report.

3.2.3 BESS Model Results for PAT

Table 3-3 summarizes the BESS simulation results for the PAT light rail system.

All of the simulations are optimized BESS designs for the conditions stated in the summary.

The base case has the following input parameters:

- Partial Discharge Option
- Maximum DOD - 80%
- Lost Energy Recovery, maximum 10% @ 2%/hr
- RT BESS Efficiency 80%
- BESS Project Life - 35 years
- Energy Inflation Rate - 0%
- Battery Cost Inflation Rate - 0%
- Capital Cost - Computed by linear interpolation with fixed point indicated in Table 3-1
- Threshold Power Selected Monthly

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[14] Rail Systems Center, "Energy Usage and Cost Reduction Study of the Port Authority of Allegheny County Transit System", (January, 1990), p.41.

TABLE 3-3

PAT BESS Economic Results

(Optimized BESS Design for Each Condition)

BESS Partial Discharge

BESS Variation	BESS Power (kW)	BESS Capacity (kWh)	Actual DOD(%)	Maximum Available DOD(%)	Annual Savings	BESS Initial Cost	Net Present Value	Internal Rate of Return(%)	Payback Period(yrs)
Base Case	506	1,009	65	100	$83,689	$504,869	$454,963	12.46	10.5
Base Case - IRR Optimization	210	240	43	100	$34,796	$174,543	$296,179	17.62	5.9
Battery Cost -10%	506	1,009	65	100	$83,689	$480,063	$520,820	13.75	6.9
Battery Cost +10%	475	911	63	99	$78,717	$488,521	$391,984	11.76	11.0
PCS Cost -10%	506	1,009	65	100	$83,689	$491,383	$468,449	12.89	10.3
PCS Cost +10%	506	1,009	65	100	$83,689	$518,355	$441,477	12.07	10.8
BOP Cost -10%	506	1,009	65	100	$83,689	$492,674	$467,158	12.85	10.3
BOP Cost +10%	506	1,009	65	100	$83,689	$517,064	$442,768	12.11	10.8
BESS Cost -10%	570	1,239	68	100	$93,477	$532,014	$547,195	13.48	6.9
BESS Cost +10%	475	911	63	99	$78,717	$512,692	$367,812	11.05	11.6
Energy Cost Inflation 3%	680	1,735	75	100	$110,871	$766,118	$1,335,051	14.34	10.6
Energy Cost Inflation 5%	731	1,986	79	100	$119,876	$851,251	$2,551,774	16.76	9.8
Energy Cost Inflation 7%	791	2,403	80	93	$123,374	$983,364	$4,240,715	17.62	10.0
Battery Cost Inflation Rate 3%	316	406	55	100	$49,679	$263,521	$271,299	14.73	6.3
Battery Cost Inflation Rate 5%	234	269	45	100	$38,290	$192,638	$165,763	15.16	5.9
Battery Cost Inflation Rate 7%	*******	No Net Present Value		*******					
BESS Lifetime 25 yrs	475	911	63	99	$78,717	$466,084	$319,142	12.34	10.2
BESS Lifetime 45 yrs	506	1,009	65	100	$83,689	$504,869	$536,882	12.62	10.5
Battery DOD 60%	396	663	60	99	$64,972	$366,967	$425,627	14.24	6.8
BESS RT Efficiency 70%	506	1,009	65	100	$83,280	$504,869	$448,259	12.38	10.6
BESS RT Efficiency 90%	506	1,009	65	100	$84,008	$504,869	$460,176	12.54	10.5
Threshold Demand Value Yearly (rather than Monthly)	680	829	64	100	$58,189	$507,686	$106,814	6.88	20.7

BESS Full Discharge

BESS Variation	BESS Power (kW)	BESS Capacity (kWh)	Actual DOD(%)	Maximum Available DOD(%)	Annual Savings	BESS Initial Cost	Net Present Value	Internal Rate of Return(%)	Payback Period(yrs)
Base Case	*******	No Net Present Value		*******					
BESS Cost -10%	*******	No Net Present Value		*******					
BESS Cost +10%	*******	No Net Present Value		*******					
Energy Cost Inflation 5%	*******	No Net Present Value		*******					
Energy Cost Inflation 7%	273	1598	80	90	$42,395	$591,612	$662,903	8.68	23.4
Battery Cost Inflation Rate 3%	*******	No Net Present Value		*******					
BESS Lifetime 25 yrs	*******	No Net Present Value		*******					
BESS Lifetime 45 yrs	*******	No Net Present Value		*******					
BESS RT Efficiency 70%	*******	No Net Present Value		*******					
BESS RT Efficiency 90%	*******	No Net Present Value		*******					
Threshold Demand Value Yearly (rather than Monthly)	*******	No Net Present Value		*******					

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The base case BESS simulation yields an optimum size of 506 kW discharge power rating with a capacity of 1009 kWh. The DOD is 65%. Although the battery replacement life would be much larger than 8 years, it was assumed to be 8 years in the financial calculations. The BESS capital cost is $505,000. The annual energy cost savings are $89,000. This produces an NPV of $455,000 with an IRR of 12.46% and a payback period of 10.5 years.

The next entry in Table 3-3 is a BESS design selected to optimize IRR. This design is quite different, yielding a smaller BESS whose discharge power rating is 210 kW and whose capacity is 240 kWh. The capital cost is $174,500 with an annual energy cost savings of $34,800. This yields an NPV of $296,000 and an IRR of 17.62% with a payback period of 5.9 years.

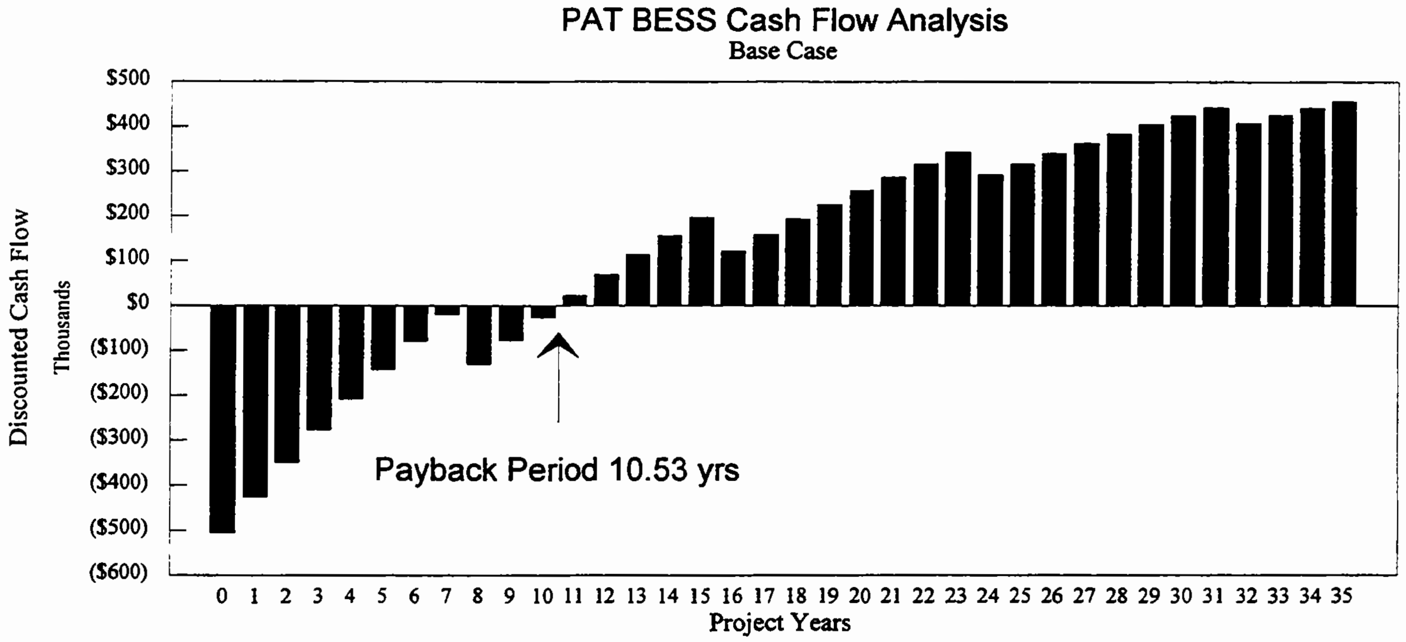
The next eight entries in the table show the financial results with variable BESS component capital cost changes.

Reducing the battery cost of the BESS by 10% reduces the capital cost of the BESS by 5%. This variation shows a dramatic decrease in the payback period from 10.5 years in the base case to 6.9 years. This is explained with the help of Figure 3-1. For the base case cash flow analysis, the cash flow becomes positive only once at 10.5 years. However, when the battery cost is reduced by 10%, the cash flow becomes positive at 6.9 years; but yet because of battery replacement costs in the eighth year, becomes negative again and then becomes positive once again in the tenth year. This is termed the battery replacement effect.

Five of the eight cases of capital cost variation in Table 3-3 result in the same optimized BESS design (506 kW x 1009 kWh). The case in which battery cost is increased by 10% does not. This case yields a new optimized BESS (475 kW x 911 kWh).

The next set of variations in Table 3-3 represent the inclusion of energy cost inflation in the NPV estimates. This means that both the demand and energy rates of the electric utilities are inflated on an annual basis. Three inflation rates were considered; namely, 3%, 5% and 7%. The base case had no energy cost inflation. The optimized BESS increases in size as energy cost inflation increases. So does the capital cost, NPV and IRR. The payback period does not significantly change.

Battery cost inflation increases the cost of battery replacement in future years. Three battery cost inflation rates were considered, 3%, 5% and 7%. For inflation rates of 3% and 5%, the optimized BESS has a smaller size than the base case (0% battery cost inflation). The capital cost and NPV are smaller, while the IRR increased. The payback period decreased substantially. This is reflective of the battery replacement effect seen when battery cost was increased by 10%. In the case of 7% battery inflation rate, no return could be made on the capital invested.



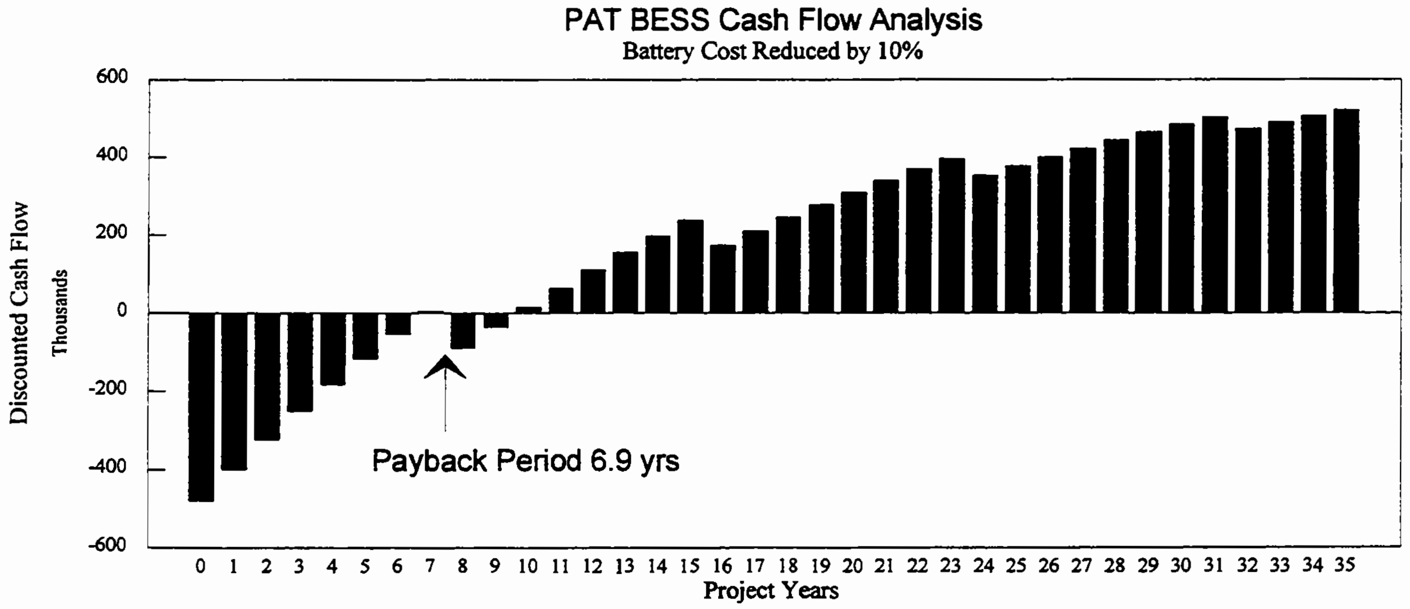


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FIGURE 3-1

The next two cases in Table 3-3 show the effect of BESS (project) lifetime. The base case was set at 35 years. The variations considered were 25 years (shorter) and 45 years (longer). For the case of 25 years, a different optimized BESS (475 kW x 911 kWh) was found. This produced a smaller capital cost and NPV with IRR and payback period remaining about the same. For the 45 year lifetime case, the optimized BESS was the same as the base case, while NPV increased, reflective of the 10 additional years the project would be operating. The IRR and payback periods remain about the same.

Reducing the maximum DOD from 80% to 60% also reduces the size of the optimum BESS. Although the initial capital cost required is smaller, the NPV and IRR are larger. The payback period is 6.8 years, again reflective of the battery replacement effect.

Varying the round trip (RT) efficiency of the BESS by + 10% does not change the optimum BESS, which has a RT efficiency of 80%. The NPV and IRR vary slightly in the plus direction with increasing efficiency and in the minus direction with decreasing efficiency as would be expected.

If the threshold demand for the BESS is selected yearly instead of monthly, a different optimized BESS was found, with about the same capital cost expenditure. The IRR is substantially lower and the payback period is much higher as would be expected.

For all but one of the cases of full BESS discharge, no return on capital invested was found for all BESS simulation. The only case that resulted in an optimized BESS being found was for an energy cost inflation rate of 7%, which is highly unlikely.

Table 3-4 presents the results of the economic analysis from a different perspective. The base case optimized BESS is used for all of the variation studies, in contrast to finding a new optimized BESS for each variable condition. The variations can easily be understood.

- Increased (decreased) capital costs increase (decrease) NPV and IRR.
- Energy cost inflation increases NPV and IRR.
- Battery cost inflation decreases NPV and IRR.
- Decreased (increased) BESS project lifetime decreases (increases) NPV and IRR.
- Decreasing BESS battery maximum DOD reduces NPV and IRR.
- Decreased (increased) BESS RT efficiency increases (decreases) NPV and IRR.

TABLE 3-4

PAT BESS Economic Results

(Base Case Optimized)

BESS Partial Discharge

BESS Variation	BESS Power (kW)	BESS Capacity (kWh)	Actual DOD(%)	Maximum Available DOD(%)	Annual Savings	BESS Initial Cost	Net Present Value	Internal Rate of Return(%)	Payback Period(yrs)
Base Case	506	1,009	65	100	$83,689	$504,869	$454,963	12.46	10.5
Battery Cost -10%	506	1,009	65	100	$83,689	$480,063	$520,820	13.75	6.9
Battery Cost +10%	506	1,009	65	100	$83,702	$529,400	$389,799	11.29	11.4 *
PCS Cost -10%	506	1,009	65	100	$83,689	$491,383	$468,449	12.89	10.3
PCS Cost +10%	506	1,009	65	100	$83,689	$518,355	$441,477	12.07	10.8
BOP Cost -10%	506	1,009	65	100	$83,689	$492,674	$467,158	12.85	10.3
BOP Cost +10%	506	1,009	65	100	$83,689	$517,064	$442,768	12.11	10.8
BESS Cost -10%	506	1,009	65	100	$83,702	$454,145	$547,117	14.71	6.5 *
BESS Cost +10%	506	1,009	65	100	$83,702	$555,066	$364,133	10.59	12.0 *
Energy Cost Inflation 3%	506	1,009	65	100	$83,702	$504,606	$1,196,745	17.19	6.5 *
Energy Cost Inflation 5%	506	1,009	65	100	$83,702	$504,606	$2,014,633	20.04	6.0 *
Energy Cost Inflation 7%	506	1,009	65	100	$83,702	$504,606	$3,274,549	22.73	5.7 *
Battery Cost Inflation Rate 3%	506	1,009	65	100	$83,702	$504,606	$180,813	9.57	11.5 *
Battery Cost Inflation Rate 5%	506	1,009	*******	No Net Present Value		*******			*
Battery Cost Inflation Rate 7%	506	1,009	*******	No Net Present Value		*******			
BESS Lifetime 25 yrs	506	1,009	60	94	$78,765	$504,606	$374,797	11.27	11.4 *
BESS Lifetime 45 yrs	506	1,009	65	100	$83,689	$504,869	$536,882	12.62	10.5
Battery DOD 60%	506	1,009	60	94	$78,765	$504,606	$374,797	11.27	11.4 *
BESS RT Efficiency 70%	506	1,009	65	100	$83,280	$504,869	$448,259	12.38	10.6
BESS RT Efficiency 90%	506	1,009	65	100	$84,008	$504,869	$460,176	12.54	10.5
Threshold Demand Value Yearly (rather than Monthly)	506	1,009	*******	No Net Present Value		*******			*

BESS Full Discharge

BESS Variation	BESS Power (kW)	BESS Capacity (kWh)	Actual DOD(%)	Maximum Available DOD(%)	Annual Savings	BESS Initial Cost	Net Present Value	Internal Rate of Return(%)	Payback Period(yrs)
All Cases	506	1,009	*******	No Net Present Value		*******			

* Non optimized values

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3.3 BESS Simulation of the WMATA System

3.3.1 Brief Description of the WMATA System

The Washington Metropolitan Area Transit Authority (WMATA) Metrorail system serves 79 stops along 89.5 route miles of operation. The system utilizes 764 rail cars, with 390 of these being chopper cars, and the remainder are cam-operated resistor-control cars. The system has service seven days a week, with lighter operation on weekends.

WMATA traction power is supplied through 130 metering points using three different rate structures: VEPCO, PEPCO DC and PEPCO MD. WMATA spent $28.2M for electricity in 1990.[15]

3.3.2 Substation Selection

The following guidelines were used in the selection of a WMATA substation for modeling with the BESS:

1) For systems being supplied power under different rate structures, first choose all the substations from the system that are billed at the highest demand charge.

2) If the highest rate structure reflects conjunctive billing, then choose all substations within a conjunctive group.

3) From within this group, choose the substation whose energy consumption reflects the largest peak.

After evaluating the WMATA system, consideration of the first criteria above indicates that the PEPCO DC rate structure has the highest demand structure, charging $11.26/kW compared to $6.90/kW for PEPCO MD and $9.325/kW for VEPCO. The PEPCO DC rate structure incorporates conjunctive billing. The WMATA Red Line has a group of meters that are billed using the PEPCO DC rate structure. Therefore, the WMATA Red Line meters were chosen to be evaluated. From evaluation of WMATA data, it appears that the Farragut North meter reflects the largest demand for any of these substations.[16]

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[15] Richard A. Uher and John Howard, "Alternative Electric Energy Sources for Rail Transit", (Report for the US Department of Transportation, January, 1993), pp.18-36.

[16] Richard A. Uher, Neena Sathi and Arvind Sathi, "Energy Cost Reduction Study of the Washington Metropolitan Area Transit Authority Metrorail System", (US Department of Transportation, May, 1992), p.76.

Pulse data for all the Red Line substations was obtained for the period extending from December of 1984 to June of 1986 during a previous energy update for the WMATA system.[17]

3.3.3 BESS Model Results for WMATA

Table 3-5 summarizes the BESS simulation results for the WMATA heavy rail system.

All of the simulations are optimized BESS designs for the conditions stated in the summaries.

The base case has the following inputs:

- Partial Discharge Option
- Maximum DOD - 80%
- BESS Voltage at System Voltage
- Lost Energy Recovery Maximum 10% @ 2%/hr
- RT BESS Efficiency 80%
- BESS Project Life - 35 years
- Energy Inflation Rate - 0%
- Battery Cost Inflation Rate - 0%
- Capital Cost - computed by linear interpolation with fixed points indicated in Table 3-1
- Threshold Power Selected Monthly

The base case BESS simulation yields an optimum size of 2160 kW discharge power rating with a capacity of 2613 kWh. The DOD is 54%. The BESS capital cost is $1,386,000 with an annual energy cost savings of $181,000. This yields an NPV of $545,000 with an IRR of 8.44%. The payback period is 14.2 years.

The next entry in the table is a BESS which is optimized for IRR. The BESS in this case is slightly different from the base case with an optimum size of 1900 kW rated discharge power and 2200 kWh capacity. The BESS capital cost is $1,212,000 with an energy cost savings of $159,000 annually. The

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[17] Charles Ball, Joe Castellani and Richard A. Uher, "Update of Energy Cost Reduction Study of the Washington Metropolitan Area Transit Authority Metrorail System", (Prepared for WMATA, January, 1987), p.5-1.

TABLE 3-5

WMATA BESS Economic Results

(Optimized BESS Design for Each Condition)

BESS Partial Discharge

BESS Variation	BESS Power (kW)	BESS Capacity (kWh)	Actual DOD(%)	Maximum Available DOD(%)	Annual Savings	BESS Initial Cost	Net Present Value	Internal Rate of Return(%)	Payback Period(yrs)
Base Case	2,160	2,613	54	100	$180,828	$1,386,182	$544,777	8.44	14.2
Base Case - IRR Optimization	1,900	2,200	46	100	$158,683	$1,212,150	$511,888	8.65	14.0
Battery Cost -10%	2,160	2,613	54	100	$180,828	$1,323,944	$710,009	9.53	13.1
Battery Cost +10%	1,979	2,317	47	100	$164,604	$1,317,070	$367,798	7.50	19.3
PCS Cost -10%	2,160	2,613	54	100	$180,828	$1,347,904	$583,055	8.77	13.8
PCS Cost +10%	2,160	2,613	54	100	$180,828	$1,424,460	$506,498	8.11	14.6
BOP Cost -10%	2,160	2,613	54	100	$180,828	$1,348,079	$582,879	8.77	13.8
BOP Cost +10%	2,160	2,613	54	100	$180,828	$1,424,284	$506,674	8.13	14.6
BESS Cost -10%	2,168	2,706	56	100	$183,552	$1,271,842	$775,303	10.16	12.4
BESS Cost +10%	1,885	2,178	46	100	$157,188	$1,322,917	$298,514	7.03	20.3
Energy Cost Inflation 3%	2,356	2,706	56	100	$185,861	$1,459,491	$2,164,650	13.01	11.5
Energy Cost Inflation 5%	2,356	2,706	56	100	$185,861	$1,459,491	$3,980,788	15.82	10.2
Energy Cost Inflation 7%	2,356	2,706	56	100	$185,861	$1,459,491	$6,778,459	18.50	9.2
Battery Cost Inflation Rate 3%	********	No Net Present Value		********					
Battery Cost Inflation Rate 5%	********	No Net Present Value		********					
Battery Cost Inflation Rate 7%	********	No Net Present Value		********					
BESS Voltage +2%	3,276	5,233	55	100	$336,186	$2,317,150	$1,231,513	9.65	12.8
BESS Voltage +4%	4,582	8,268	60	100	$490,955	$3,279,699	$1,863,588	9.98	12.4
BESS Voltage +6%	5,913	12,176	75	100	$641,705	$4,264,032	$2,348,953	9.88	12.5
BESS Lifetime 25 yrs	1,885	2,178	46	100	$157,188	$1,202,652	$256,732	7.50	14.0
BESS Lifetime 45 yrs	2,168	2,706	56	100	$183,552	$1,413,158	$693,051	8.65	14.4
Battery DOD 60%	2,160	2,613	54	100	$180,828	$1,386,182	$544,777	8.44	14.2
BESS RT Efficiency 70%	2,160	2,613	54	100	$180,691	$1,386,182	$542,533	8.42	14.2
BESS RT Efficiency 90%	2,160	2,613	54	100	$180,934	$1,386,182	$546,512	8.44	14.2
Threshold Demand Value Yearly (rather than Monthly)	********	No Net Present Value		********					

BESS Full Discharge

BESS Variation	BESS Power (kW)	BESS Capacity (kWh)	Actual DOD(%)	Maximum Available DOD(%)	Annual Savings	BESS Initial Cost	Net Present Value	Internal Rate of Return(%)	Payback Period(yrs)
Base Case	********	No Net Present Value		********					
BESS Cost -10%	********	No Net Present Value		********					
BESS Cost +10%	********	No Net Present Value		********					
Energy Cost Inflation 5%	2,356	10,389	80	100	$255,324	$3,161,179	$2,308,116	8.41	21.7
Energy Cost Inflation 7%	2,356	10,389	80	100	$255,324	$3,161,179	$6,151,376	11.52	18.0
Battery Cost Inflation Rate 3%	********	No Net Present Value		********					
BESS Lifetime 25 yrs	********	No Net Present Value		********					
BESS Lifetime 45 yrs	********	No Net Present Value		********					
BESS RT Efficiency 70%	********	No Net Present Value		********					
BESS RT Efficiency 90%	********	No Net Present Value		********					
Threshold Demand Value Yearly (rather than Monthly)	********	No Net Present Value		********					

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NPV is $512,000 with an IRR of 8.65% and a payback period of 14.0 years.

The next 8 entries in Table 3-5 show the financial results with variable BESS component capital cost variations.

Reducing component costs in all cases increases NPV and IRR and decreases the payback period while increasing component costs decreases NPV and IRR and increases the payback period. Five of the eight variations result in the same optimized BESS (2,160 kW x 2,613 kWh).

The next set of variations in Table 3-5 represents the inclusion of energy cost inflation in the NPV estimates. This means that the demand and energy rates of the utilities are inflated in future years on an annual basis. The inflation rates were 3%, 5% and 7%. For all three cases the optimized BESS (2,356 kW x 2,706 kWh) was different from the base case. The NPV and IRR were substantially higher, as a direct consequence of the inflation rate.

Variations from the base case which included a battery cost inflation rate of 3%, 5% and 7% resulted in no return on the capital invested for any BESS.

Increasing the average BESS voltage, which resulted in capturing more stored energy and power did not improve IRR and the payback period substantially. The NPV increased roughly in the same proportion as the capital investment required for the larger BESS sizes.

As expected, decreasing (increasing) BESS lifetime decreased (increased) NPV and IRR while increasing (decreasing) the payback period. New optimized BESS were found for these conditions.

Since the DOD of the base case was already 54%, decreasing the maximum DOD from 80% to 60% had no effect.

Changes in the RT efficiency of the BESS had only slight effects on the NPV and IRR. A decrease in the RT efficiency by + 10% decreased the IRR from 8.44 to 8.42.

If the threshold demand for the BESS is selected yearly instead of monthly, no BESS can be found that will yield a positive NPV.

For all but two of the cases of full BESS discharge, no return on capital invested was found for all BESS simulation. The only case that resulted in an optimized BESS being found was for an energy cost inflation rate of 5% and 7%.

Table 3-6 presents the results of the economic analysis from a different perspective. The base case optimized BESS is used for all of the variation studies, in contrast to finding a new optimized BESS for each variable condition. The variations can easily be understood.

TABLE 3-6

WMATA BESS Economic Results

(Base Case Optimized)

BESS Partial Discharge

BESS Variation	BESS Power (kW)	BESS Capacity (kWh)	Actual DOD(%)	Maximum Available DOD(%)	Annual Savings	BESS Initial Cost	Net Present Value	Internal Rate of Return(%)	Payback Period(yrs)
Base Case	2,160	2,613	54	100	$180,828	$1,386,182	$544,777	8 44	14.2
Battery Cost -10%	2,160	2,613	54	100	$180,828	$1,323,944	$710,009	9.53	13.1
Battery Cost +10%	2,160	2,613	54	100	$180,831	$1,448,460	$379,500	7.36	19.6 *
PCS Cost -10%	2,160	2,613	54	100	$180,828	$1,347,904	$583,055	8.77	13.8
PCS Cost +10%	2,160	2,613	54	100	$180,828	$1,424,460	$506,498	8.11	14.6
BOP Cost -10%	2,160	2,613	54	100	$180,828	$1,348,079	$582,879	8.77	13.8
BOP Cost +10%	2,160	2,613	54	100	$180,828	$1,424,284	$506,674	8.13	14.6
BESS Cost -10%	2,160	2,613	54	100	$180,831	$1,247,598	$786,362	10.31	12.3 *
BESS Cost +10%	2,160	2,613	54	100	$180,831	$1,524,842	$303,118	6.80	20.7 *
Energy Cost Inflation 3%	2,160	2,613	54	100	$180,831	$1,386,220	$2,145,876	13.32	11.2 *
Energy Cost Inflation 5%	2,160	2,613	54	100	$180,831	$1,386,220	$3,912,863	16.15	10.0 *
Energy Cost Inflation 7%	2,160	2,613	54	100	$180,831	$1,386,220	$6,634,819	18.83	9.1 *
Battery Cost Inflation Rate 3%	2,160	2,613	********	No Net Present Value		********			
Battery Cost Inflation Rate 5%	2,160	2,613	********	No Net Present Value		********			
Battery Cost Inflation Rate 7%	2,160	2,613	********	No Net Present Value		********			
BESS Voltage +2%	2,160	2,613	48	100	$186,688	$1,386,220	$640,644	8.98	13.6 *
BESS Voltage +4%	2,160	2,613	48	100	$186,688	$1,386,220	$640,644	8.98	13.6 *
BESS Voltage +6%	2,160	2,613	48	100	$186,688	$1,386,220	$640,644	8.98	13.6 *
BESS Lifetime 25 yrs	2,160	2,613	54	100	$180,831	$1,386,220	$263,021	7.25	14.2 *
BESS Lifetime 45 yrs	2,160	2,613	54	100	$180,831	$1,386,220	$709,472	8.79	14.2 *
Battery DOD 60%	2,160	2,613	54	100	$180,828	$1,386,182	$544,777	8.44	14.2
BESS RT Efficiency 70%	2,160	2,613	54	100	$180,691	$1,386,182	$542,533	8.42	14.2
BESS RT Efficiency 90%	2,160	2,613	54	100	$180,934	$1,386,182	$546,512	8.44	14.2
Threshold Demand Value Yearly (rather than Monthly)	********	No Net Present Value		********					

BESS Full Discharge

BESS Variation	BESS Power (kW)	BESS Capacity (kWh)	Actual DOD(%)	Maximum Available DOD(%)	Annual Savings	BESS Initial Cost	Net Present Value	Internal Rate of Return(%)	Payback Period(yrs)
All Cases	2,160	2,613	********	No Net Present Value		********			

* Non optimized values

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- Increased (decreased) capital costs increase (decrease) NPV and IRR.

- Energy cost inflation increases NPV and IRR.

- Battery cost inflation decreases NPV and IRR.

- Decreased (increased) BESS project lifetime decreases (increases) NPV and IRR.

- Decreasing BESS battery maximum DOD reduces NPV and IRR.

- Decreased (increased) BESS RT efficiency increases (decreases) NPV and IRR.

3.4 Transit System Payback Period Survey

Many transit authorities have economic guidelines which must be met before a new capital investment, which reduces operating cost, can be approved. Frequently, one of the economic gauges utilized is the payback period. As discussed in section 2.4.3, the payback period is the required amount of time it takes for the savings associated with a new project to pay back the initial capital investment.

A survey of a number of existing rail transit authorities was made attempting to establish what is considered a reasonable payback period. The results of this survey are shown in Table 3-7.

Table 3-7
Rail Transit Capital Payback Requirements

Transit Authority	Required Payback (Years)
Vancouver, BC	2.0
Montreal, QU	3.0
Toronto, ON	3.0
Chicago, IL	3.5
Miami, FL	4.0
Sacramento, CA	5.0
Long Island, NY	5.0
Baltimore, MD	7.0
Washington, DC	8.0
Hamilton, ON	10.0
Buffalo, NY	10.0
New York, NY	10.0
Dallas, TX	10.0
Cleveland, OH	15.0

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

A computer program has been developed which can evaluate the effectiveness of operating a Battery Energy Storage System (BESS) at transit traction substations. By using one year's worth of substation metering data, the model can simulate operation of a BESS. The program uses the BESS simulation results to determine energy bill savings, all costs associated with a BESS, and the resultant cash flow for the project based on the input discount rate. The results are used to calculate several economic parameters which gauge the economic attractiveness of installing the BESS.

The computer code was programmed to enable simulation of most rail transit systems. All that is needed is one year's worth of metering data for the substation where the BESS is to be located, and a file which defines the other required input data for several key BESS technical items, economic variables, and utility-bill parameters (costs, rate structures, battery characteristics, etc). The program can simulate any transit authority which monitors the meter pulse data every 15 minutes or longer (i.e. 96 pulses per day). It also has a generic rate structure routine which allows the user to define the energy and demand charges. The program can handle either individually or conjunctively billed substations.

Once the program was developed, it was then used to simulate operation of a BESS at PAT's Light Rail system and at the WMATA Metrorail system.

The base case payback period for the optimum BESS on WMATA is over 14 years, while on the PAT light rail system, it is over 10 years. In both cases, these payback periods are too long for a positive assessment of such a project. Payback periods of less than 3-4 years are more appropriate to projects of this kind. Such a system is, in essence, a capital investment made to reduce operating cost.

4.2 Recommendations

A large cost of the BESS is the power conditioning subsystem (PCS). The PCS controls the amount of power discharged as well as charging the battery. If the battery were connected directly to the third rail (circuit protection provided), the PCS could be eliminated with a substantial capital cost reduction (40%). Under these circumstances, the battery would charge and discharge only as third rail voltage varied above and below battery voltage. Simulation of such a battery substation is beyond the BESS model. A model should be developed to simulate the battery substation, without the PCS. This model could be applied to WMATA and PAT.

Modifications should be made to the BESS model which would enable simulation of other forms of alternative energy, such as generators, superconducting magnetic energy storage systems, pumped fluid energy storage systems, etc. Due to the computer codes modular nature, inclusion of these other forms of alternative energy into the model should only require development of the routines necessary to simulate their operation. These routines can make use of the existing cost model, rate-structure model, and economic model to reduce the coding required to analyze these options.

Several years ago, a survey was concluded on the power rate structures of most electric rail transit systems. This survey included the demand and energy rates as well as all different methods for measuring demand and billing electric power (time of day rates, seasonal rates, etc.). It is clear that payback periods for BESS become shorter as demand rates go up. By updating this survey, other potential candidate transit systems for BESS projects could be identified.

Appendix A

BESS Program User's Manual

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A. BESS COMPUTER SIMULATION

The BESS computer simulation program was written in the scientific programming language known as FORTRAN, and was written with each major function contained in a separate subroutine within the FORTRAN program. Keeping different functions of the program in separate subroutines simplifies understanding, and also facilitates any future modifications that may be desired or required.

The remainder of this chapter will be used to describe the approach of the program, the computer requirements for running the code, and will also present a user's manual which describes the input, output and gives directions and examples showing how to run the program.

A.1 BESS Computer Simulation Methodology

The approach taken by the BESS program is to simulate operation of a BESS at a traction substation meter. This is accomplished by utilizing the substation's meter demand data and simulating the performance of a particular size BESS against this data using the Peukert equation described in section 2.1.1.

The flow of the BESS program is shown in Figure A-1. The program first reads in the user input (described in section A.4.1), and then utilizes the user-defined battery current vs time to cutoff voltage to calculate the exponent associated with the Peukert Equation. If the user is running a conjunctive case, and has chosen the option to increase the battery voltage to enable shedding of adjacent substation demand, then the program modifies the individual meter pulses via the routine described in section 2.1.6. It then calculates what the annual utility bill would be without a BESS. This value is used later to establish the annual costs savings associated with application of a BESS.

The program then evaluates the pulse data read in to determine the maximum monthly and yearly values. If the user has chosen to shave the demand from each monthly peak, the program calculates a KW adjustment value for each month.

If the user is making a single run, then the specific battery capacity, demand, and discharge intervals being evaluated have been defined within the input. However, if the user has chosen either the option to run multiple cases or to run until the economics are optimized, the program will iterate through a range of user-defined minimum and maximum percentages on the demand and capacity. It first chooses a demand value within the user-specified range, and then applies the Peukert equation to the meter pulses to determine the amount of capacity required to enable shaving of all the pulses

Figure A-1

BESS Simulator Flow Chart

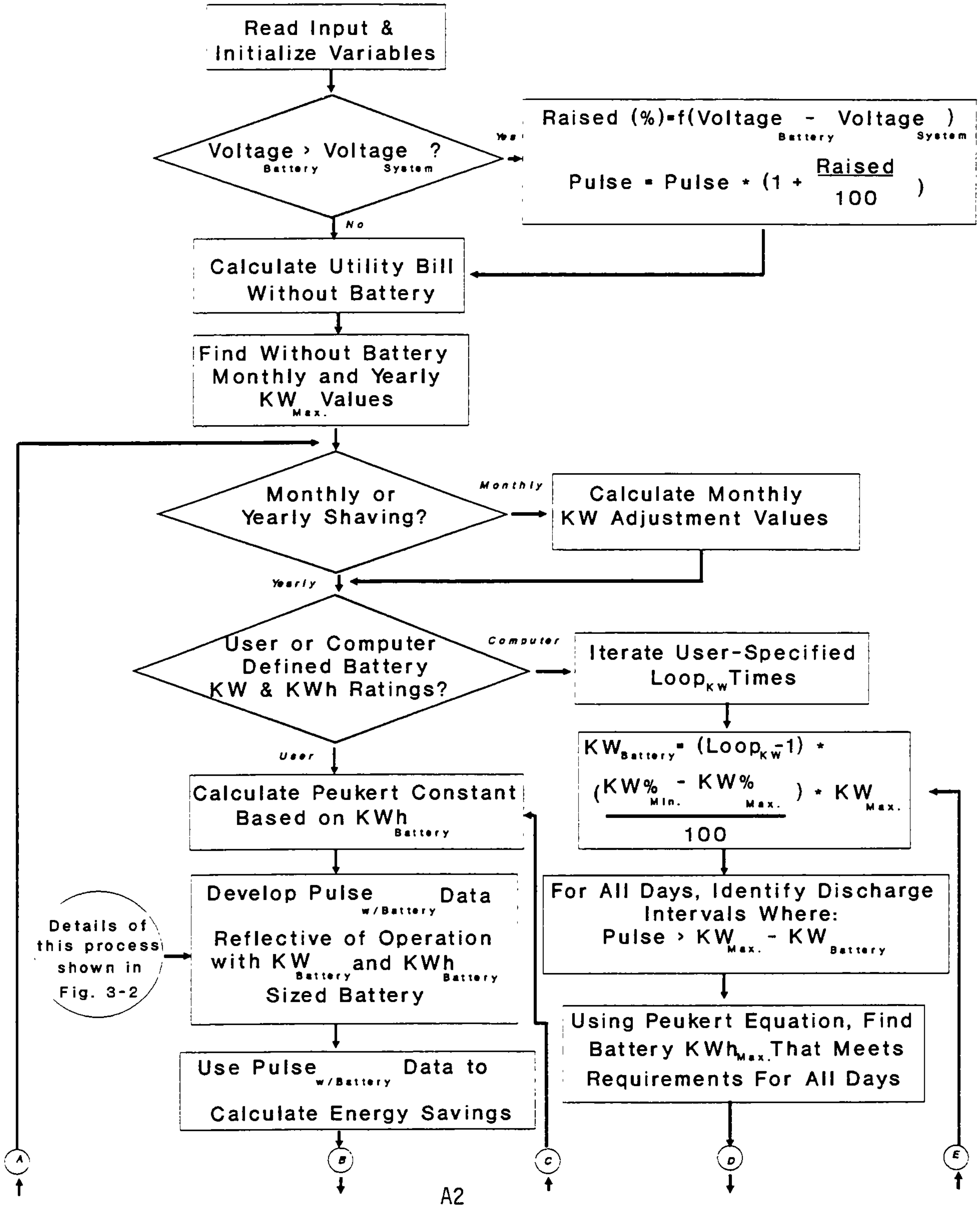
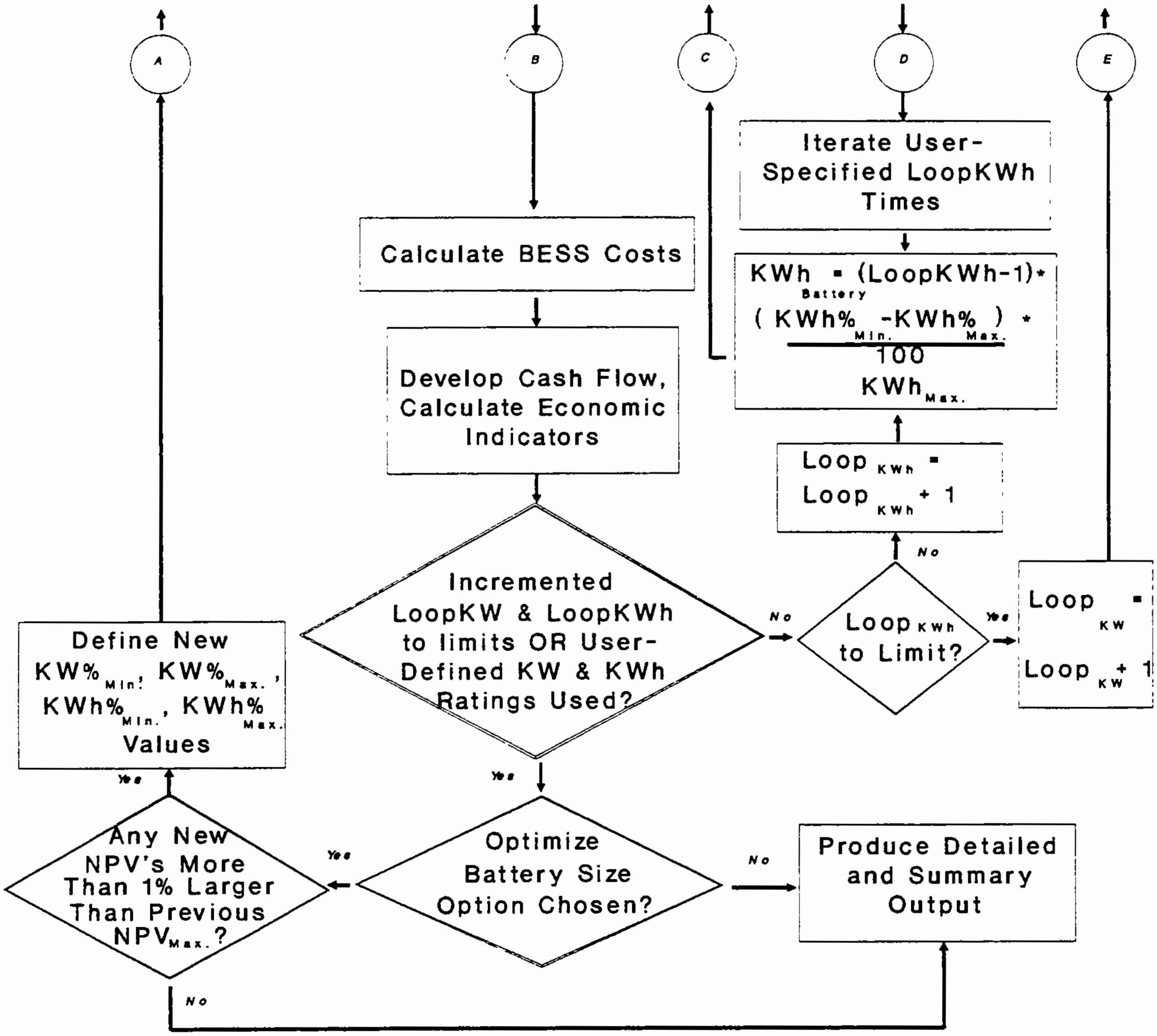


Figure A-1(Cont'd)

BESS Simulator Flow Chart



that meet the shaving criteria. It then iterates from the user-defined minimum to maximum percentages of this capacity.

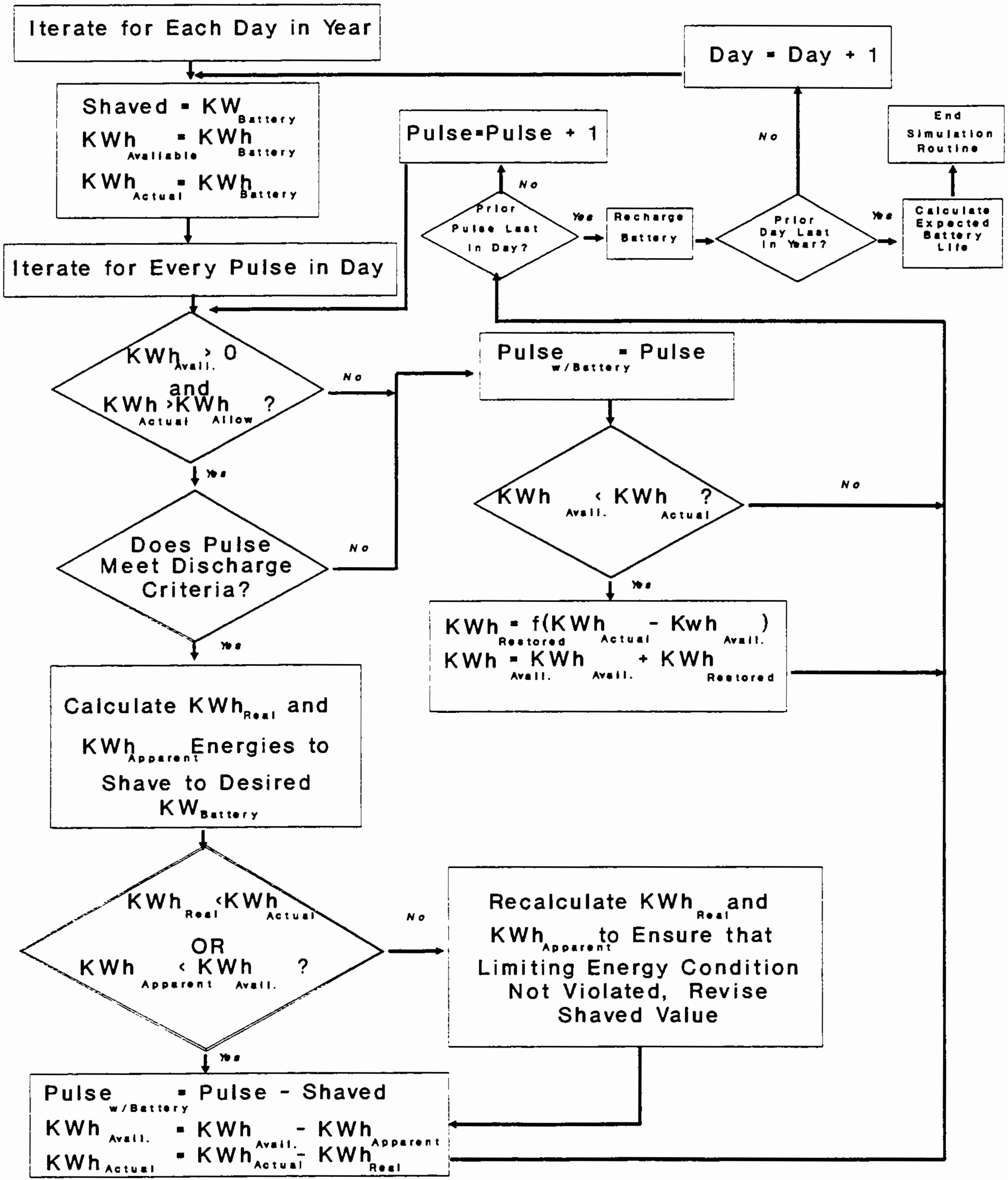
At this point a specific battery demand and capacity have been chosen, as have the battery discharge intervals. Given the chosen battery capacity, the constant associated with the Peukert Equation is calculated. Now the Peukert equation has both it's exponent and constant, and is ready to simulate operation of the specific battery chosen.

Figure A-2 shows the battery discharge simulation routine flow chart. Following this figure, the program will evaluate all the meter pulse data starting with the first pulse on the first day of the year, and finishing with the last pulse on the last day of the year. The routine checks to see if the current pulse is the first of a new day, and if so sets both the amount of available and actual energies to the battery capacity for the specific case being evaluated. The routine then checks to see that both the actual and the available energy counters are above their minimum values. If either value has reached it's limit, the program restores a portion of any energy that may have been lost due to high-discharge rates, and then increments to the next pulse. If both the actual and available still have energy, then the program checks to see if the current pulse meets the shaving criteria. If the pulse does not meet this criteria, then again the program restores part of any lost high-discharge energy, and increments to the next pulse value. If the pulse does meet the criteria, then the amount of apparent and real energies desired to remove from the battery are calculated. If both of these values are less than the remaining available and actual energies, then the apparent and real values just calculated are subtracted from the available and actual energy counters, and a new meter pulse is generated which is less than the original by an amount equal to the actual energy provided by the battery divided by the pulse duration. If either the desired to withdraw apparent or real energies are greater than their respective available or actual energy counters, then new values of apparent and real energies are calculated which keep the respective energy counter from violating it's defined minimum condition. After evaluating the final pulse of a day, the routine simulates recharging of the battery by adding an appropriate amount of demand to each of the user-defined recharge intervals' pulse data for that day. Once the battery has been simulated against the entire year's meter data, then the expected life of the battery is determined based on it's history for the year. This value is used to establish how often the batteries must be replaced. Once the life expectancy of the battery is completed, the discharge simulation routine is completed.

The new pulse data just generated is then used to calculate a new utility bill based on use of the battery. The energy savings associated with the BESS can then be calculated by subtracting the BESS energy costs from the energy costs of the substation without a battery system.

Figure A-2

Battery Discharge Routine Flow Chart



The program then calculates the costs associated with the specific BESS being evaluated.

Given the costs and the savings for the BESS being evaluated, the program calculates a number of economic gauges, including the Net Present Value (NPV), the Internal Rate of Return (IRR), and the Payback Period (PB - see section 2.4 for descriptions of these parameters).

This process is repeated for the multiple-run options until each of the capacity and demand values within the specified ranges are completed. Once they are completed, the single and multiple non-optimizing runs print out the results to whatever output files the user has defined.

For the optimizing option, the program evaluates the NPV's calculated during the last completed range of capacity and demands, and determines whether any new NPV's are more than 1% larger than the biggest prior NPV. If there is a NPV with a >1% larger NPV, then the program resets the demand and capacity range to be a finer mesh around the demand and capacity values which resulted in the largest NPV, and the entire process is then repeated. If no new NPV's exceed the old maximum NPV by the required 1%, then the optimizing option is completed and the results are printed to the desired output files.

A.2 Computer Requirements

The program was written in Microsoft™ FORTRAN version 5.1, and was compiled (using the Microsoft™ extensions) on a 486 personal computer which contained a math coprocessor. A version was also compiled without the math coprocessor.

Due to the extreme amount of data that must be used, the program requires nearly 600K of free RAM in order to run. The user can check the amount of free RAM available on their machine by typing the DOS command 'MEM' at the DOS prompt. If the output of this command states that the largest executable program size is smaller than 600K, then the user may need to alter their configuration files (AUTOEXEC.BAT and/or CONFIG.SYS) to remove some memory-resident programs to free up enough memory for the program to run.

A.3 FORTRAN Data Description

While there are numerous format types available within the FORTRAN language, for simplicity the BESS program uses only three: Integers, Real Fixed Format, and Alphanumeric Character Strings.

For any field, regardless of type, there is a specified column width. This column width defines how many numbers or alphanumerics can be included in the definition of the particular variable.

When an Integer format is specified, the user can only enter numbers within the specified fields. There can be no periods, commas, or any other alphanumeric.

Another aspect of FORTRAN integer fields is that numbers separated by spaces within a single Integer variable column width are concatenated. FORTRAN Integers are also not left or right justified. Lastly, any numbers outside of the field width are ignored. Therefore, the 5-column Integers shown below are all interpreted by the program as 101:

```
column #  12345
          101
           101
          1 01
          10  1
            10162345
```

Note that in the last case the '62345' all occur outside of the 5-column field width.

When a variable is defined as a FORTRAN Real fixed format, then the field will accept numbers with an optional decimal place. As with Integers, blanks between numbers in a Real statement are concatenated, there is no justification, and characters outside of the column width are ignored. The following 10-column Real fixed format values are all interpreted as 123.45.

```
column #  1234567890
              123.45
          1 2 3. 45
           12 3.4 5
          123.45    67890
```

Also, a Real fixed format value that does not have a fractional part can be represented without using a decimal.

In FORTRAN, an Alphanumeric Character string can be any character. However, within the BESS program many of the Alphanumeric Characters have been confined to a certain group of characters. When a user tries to enter a character outside of this group, they are prompted to re-enter an appropriate character.

While in Integer and Real data strings spaces are eliminated, in Alphanumeric Character strings spaces are interpreted as just that - spaces. There is no concatenation of Alphanumerics. Therefore, only enter spaces if they are desired.

A sometimes confusing aspect of FORTRAN data is it's ability to string together data on the same line. Since each variable has a specific column width, it is possible to put many variables on the same line. For example, the sample below shows a 15-column Alphanumeric filename followed by a 5-column Integer and a 10-column Real. Several examples have been included for clarity:

```
Column #  123456789012345678901234567890
          C:\Test.dat    101   123.45
             c:\test.dat  1 01 12  3. 45
          C:\TEST.DAT    1 0 11 2 3 . 45
```

Some of the entries shown above have been intentionally made difficult for the user to visually interpret, but once you understand the rules governing FORTRAN input it becomes clear what the program is expecting.

The following section addresses the various FORTRAN input variables used by the BESS program. Each of the variables defined in that section will be one of the three data types described above, and will follow the rules just given.

A.4 BESS User's Manual

This section will provide the necessary information to enable a user to run the BESS program. It begins by describing the required input, with a separate section dedicated to explaining the purpose and use of each of the program's options. The section then discusses each of the potential output files, and explains to the user what information is contained in each of these optional files. The section then steps the reader through creation of a sample input file for the BESS program, shows how to run the program, and finishes by showing the output for the sample run.

A.4.1 BESS Input

The crucial information necessary to make use of the program is meter pulse data which reflect one-year's worth of operation at the traction substation(s) to be modeled. This data must be obtained from the prospective utility. Each utility must monitor and register the substation demand intermittently in order to bill the transit authority. Most utilities keep records of this data for at least one year, and frequently for much longer. This data should be available to the transit authority by simply requesting it from the utility.

During prior energy management studies performed by the Rail Systems Center on the New Jersey Transit, Port Authority Transit, and Washington Metro systems, this data was obtained from the prospective utility with little difficulty. Depending on the utility, this data will be provided in either computer disk or paper-dump form. This data will need to be put in the proper form for the program, the format of which is described later in this chapter, using either a text editor, word processor or spreadsheet program.

Once the substation data has been obtained and put in the proper form, the user needs to generate another data file which will define all the variable values and options to be chosen by the user. A complete list of all the possible input items that need to be entered within this file are described in the following section.

A.4.1.1 BESS Input Description

Shown in Table A-1 is a complete list of all the possible input items for the BESS computer program. For each of the inputs, the variable type (Integer, Real or Alphanumeric) and column width are shown, along with limits on the range of input values, their units and a brief description of the purpose of the variable.

Table A-2 shows the format for the substation meter data file. Note that for this file, all the data for a particular day is contained on one contiguous line (note that in FORTRAN culmination of a data line is done with a carriage return, and therefore data lines can and are often significantly larger than the standard 80 characters terminal width).

A.4.1.2 BESS Program Options

The previous section gave brief descriptions of each of the possible BESS program input variables. Most of these variables represent properties that simply require number values, and are fairly straight-forward. However, a number of the variables reflect options within the program which may need more detailed descriptions. Therefore, the following sections are included to clarify use of the BESS options.

A.4.1.2.1 Mode of Operation Option (Mode)

The Mode variable determines the type of run that the BESS program is going to be making. There are 3 possible values for Mode:

TABLE A-1
BESS COMPUTER PROGRAM INPUT

Variable	Format	Limits	Units	Description
Mode	A1	1/2/3		Option to establish type of run to make (1-single run, 2-multiple runs, 3-optimization)
Title	A80			Title for the run
OutputYN(1)	A1	Y/N		Summary Output Desired Option
OutputFile(1)	A45			Summary Output File Name
OutputYN(2)	A1	Y/N		Detailed Output Desired Option
OutputFile(2)	A45			Detailed Output File Name
OutputYN(3)	A1	Y/N		Meter Output Desired Option
OutputFile(3)	A45			Meter Output File Name
NumDays	I3	1->365		Number of days worth of data
PulsPerDay	I3	1->96		Number of kW pulses per day
DischrgMethod	A1	F/P		Full or Partial Discharge Method option
DischrgAddKW	F10	>=0		For Full Discharge option, extra amount pulses must be over to be shaved
ConjYN	A1	Y/N		Will current evaluation be of a conjunctively-billed system
InputFile(1)	A45			File Name containing sum of kW meter data for conjunctive, individual meter File Name for non-conjunctive
InputFile(2)	A45			For conjunctive case, File Name for individual meter data
TransitNominal Voltage	F10	>0	(Volts)	Transit System Nominal Voltage
DepthOf Discharge	F10	<=100	(%)	Depth of Discharge that the battery system is allowed to attain
KWhIdleRcvry Rate	F10	0->10	(%/Hr)	Rate at which high-discharge lost kWh restored up to defined maximum
PcntLostKWh Recoverable	F10	0->10	(%)	Maximum portion of high-discharge lost kWh restorable
RoundTripEff	F10	<=100	(%)	BESS round trip efficiency
NumRechrg	I3	<=5		Number of recharge intervals for the day
BegRechrg Puls(i)	I3			Beginning recharge pulse for ith interval

Variable	Format	Limits	Units	Description
EndRechrg Puls(i)	I3			Ending recharge pulse for ith interval
RaiseKW2YN	A1	Y/N		For conjunctive evaluations, option to simulate raised battery voltage
BatVolt	F10	0-10%	(Volts)	If RaiseKW2YN=Y, voltage of the BESS
BillType	A1	W/P/S		Option which defines rate structure to be imposed (W-WMATA, P-PAT, S-Standard)
ProjectYears	I3		(Years)	Number of years BESS assumed to be used
DiscountRate	F10		(%)	Discount rate that Net Present Value calculated at
Energy InflationRate	F10		(%)	Anticipated inflation rate for utility energy costs
ElectEqu InflatRat	F10		(%)	Anticipated battery inflation rate
StartKWPcnt OfMax	F10	<=100	(%)	For Mode equal to 2 or 3, percent of maximum kW to use as starting point in iteration
EndKWPcnt OfMax	F10	<=100	(%)	For Mode equal to 2 or 3, percent of maximum kW to use as ending point in iteration
StartKWhPcnt	F10	<=100	(%)	For Mode equal to 2 or 3, percent of maximum kWh to use as starting point in iteration
EndKWhPcnt	F10	<=100	(%)	For Mode equal to 2 or 3, use as ending point in iteration
KWIter	I2	<=10		For Mode equal to 2 or 3, number of iterations between the minimum and maximum demand identified above
KWhIter	I2	<=10		For Mode equal to 2 or 3, number of iterations between the minimum and maximum capacity identified above
Shaved	F10	>=0	(kW)	For Mode equal to 1, demand capability of the BESS
ShaveKWh	F10	>=0	(kWh)	For Mode equal to 1, capacity of the BESS

Variable	Format	Limits	Units	Description
NumOvr	I2			For Mode equal to 1, number of intervals that battery will be discharging for
PulOvr(i)	I2(1X)*			For Mode equal to 1, the i = 1 to NumOvr interval during which the battery is to discharge
CstTyp	A1	E/M/A/ U/V		Option to determine what type of cost data will be used (E-EPRI,M-Metro North, A-Avg, U-User defined constant, V-User defined variable)
BatDolPerKWh	F10		($/kWh)	For CstTyp equal to U, constant battery cost
PCSDolPerKW	F10		($/kW)	For CstTyp equal to U, constant power conditioning cost
BOPDolPerKW	F10		($/kW)	For CstTyp equal to U, constant balance of plant demand cost
BOPDolPerKWh	F10		($/kW)	For CstTyp equal to U, constant balance of plant energy cost
BOPBaseCost	F10		($)	For CstTyp equal to U, base balance of plant cost
BatLinCost PerKWh(i) BatLinKWh(i)	F10 F10		($/kWh) (kWh)	For CstTyp equal to V, battery costs vs energy for i = 2 values which program uses to develop linear battery costs
PCSLogCost PerKW(i) PCSLogKW(i)	F10 F10		($/kW) (kW)	For CstTyp equal to V, PCS costs vs demand for i = 2 values which program uses to develop logarithmic PCS costs
BOPLinCost PerKWh(i) BOPLinKWh(i)	F10 F10		($/kWh) (kWh)	For CstTyp equal to V, BOP costs vs energy for i = 2 values which program uses to develop linear BOP costs
BOPLinCost PerKW(i) BOPLinKW(i)	F10 F10		($/kW) (kW)	For CstTyp equal to V, BOP costs vs demand for i = 2 values which program uses to develop linear BOP costs

---

* For mode = 1, when using an input file, all PulOvr #s are on 1 line separated by a space.

Variable	Format	Limits	Units	Description
KWMonthYN	A1	Y/N		Option which when equal to Y shaves the battery demand from monthly peaks, when N shaves from yearly peak
Amp(i)	F10		(Amps)	Discharge current vs time to
Time(i)	F10		(Hours)	cutoff voltage at that current for i = 2 values, which the program uses as the base for all future discharge calculations
Depltd(i)	F10		(%)	Average Depth of Discharge vs
CycLif(i)	F10		(Cycle)	Cycle Life for i = 2 points, which the program uses to model the useful life of the battery with

TABLE A-2[*]
SUBSTATION METER PULSE DATA INPUT DESCRIPTION

Nine spaces are used at the beginning of each day's data, and the following formats are to be repeated i = 1 to NumDays times:

Variable	Format	Limits	Units	Description
	9X			9 spaces begin each day's data
Day(i)	I3	< = 365		Day of the year
Year(i)	I2			Last two digits in the year
DayType(i)	I2	1/2/3/4		Number which indicates the type of day (1 = Saturday, 2 = Sunday, 3 = Holiday, 4 = Weekday)
KW(m,i,j)	F6		(kW)	This represents the substation pulse data for j = 1 to PulsPerDay.

---

[*] Note that all data items for a particular day are contained on one contiguous line.

Mode Value	**Mode Choice Description**
1	Single BESS run option
2	Multiple BESS simulation option
3	Search for Optimum BESS size

Mode = 1

Using Mode = 1 indicates that the program is to evaluate only one BESS demand and capacity size. For this option the user must specify the precise BESS demand and capacity, as well as defining the pulse intervals during which the battery will is to be considered 'ON'. For example:

```
1500.                 <== Shaved, indicates BESS demand (kW)
10000.                <== ShaveKWh, the BESS capacity (kWh)
6                     <== NumOvr, # intervals battery 'ON'
32 33 34 63 64 65     <== PulOvr(i), specific intervals 'ON'
```

Mode = 2

Using Mode = 2 indicates that the program will be evaluating a range of BESS demand and capacity sizes. For this option, the user will select limiting percentage values for both the demand and capacity (these percentages are of the maximum possible demand and capacity), as well as how many discreet demand and capacity intervals within these limits that the program will be evaluating. For example:

```
50.           <== StartKWPcntOfMax, Starting demand (% of
                  maximum)
100.          <== EndKWPcntOfMax, Ending demand (% of maximum)
80.           <== StartKWhPcnt, Starting capacity (% of maximum)
100.          <== EndKWhPcnt, Ending capacity (% of maximum)
5             <== KWIter, # of demand iterations
5             <== KWhIter, # of capacity iterations
```

The program evaluates the meter pulse data provided by the user, and establishes what the absolute maximum demand pulse is for the entire year. Let's assume that for a fictitious meter, the program has searched the data and determined that 2000kW is the maximum pulse seen. Then the user-defined input above indicates that the program will evaluate from 50% of this maximum, or 1000kW, up to 100%, or 2000kW, with 5 intervals. Therefore, it will consider BESS's with demand ratings of 1000, 1250, 1500, 1750 and 2000kW. Now, for each of the BESS demand sizes, the program will evaluate the pulse data again to first identify all the pulse intervals that fall above the Threshold Demand (Threshold Demand = Maximum Demand - Battery Demand). Once these have been identified the program determines the maximum battery capacity required using the

Peukert Equation and the user-input battery data. Continuing with the prior example, let's assume that we are on the second demand iteration with the BESS equipment rated at 1250kW. The program will search through all the meter pulse data and note all pulses which have a value greater than 750kW (= 2000kW - 1250kW). The BESS will be considered turned 'ON' for all these pulses. Then, the program will iterate on the BESS capacity until it finds a value that is able to meet the worst consumption day's energy needs. Assume that for the 1250kW case a maximum battery capacity of 5000kWh was calculated. Then based on the above Mode=2 data, the program would model battery capacities from 80% of this maximum, or 4000kWh, up to 100%, or 5000kWh. Therefore, for the 1000kW demand, capacities of 4000, 4250, 4500, 4750 and 5000kWh would be evaluated. The battery capacities evaluated would change for each new demand rating.

Mode=3

Setting Mode=3 utilizes the program's economic optimization routine. This option evaluates the meter data within the user-specified demand and capacity limits, and finds the demand and capacity values which results in the largest positive Net Present Value. The input for Mode=3 is identical to Mode=2, with the user needing to specify the limiting demand and capacity percentages, as well as the number of discreet intervals to be evaluated (see Mode=2 above for sample input).

The difference with Mode=3 is that after the program has completed the initial simulations for the user-defined range of BESS sizes, it then searches for the demand and capacity which yielded the highest positive Net Present Value (NPV). The program will then begin another range of calculations, with the limits on demand and capacity reset to the values one iteration on either side of the previous best case. Basically, the program is developing a finer and finer mesh around the best BESS size. This process continues until the new NPV is less than 1% larger than the previous NPV. When this occurs, the program prints out the optimum demand and capacity size.

Should the initial iteration not yield a positive NPV, then the program prints out a message stating that the optimum search was aborted.

A.4.1.2.2 Discharge Method Option (DischrgMethod)

The DischrgMethod option allows the user to define how the BESS will be used: Full or Partial discharge. Both the Full and Partial options require the meter pulse to be 'ON' (ie PulOvr(i) = 1). Given this, the Full option attempts to discharge the Full BESS rated demand. The Partial option only discharges enough energy to keep the demand below a specific pre-set value.

The advantages of the Partial over the Full discharge option are twofold:

1) The Partial can shave an identical amount of demand to the Full with a significantly smaller BESS capacity.

2) The Full shaves demand that does not help reduce the energy bill, and when this energy is replaced an additional 20% must be purchased from the utility to account for round-trip inefficiencies.

Most studies which have evaluated application of a BESS have opted for the Full discharge method, primarily due to it's straightforward Power Conditioning System (PCS) design. Although a thorough analysis of the ability to develop a system which enables Partial discharge was not completed, several discussions were held with PCS experts[2,3]. From these discussions, it was indicated that a PCS design coupling a thyristor rectifier with a microprocessor which monitors the current and switches the rectifier gate on when the demand goes above a specified limit could perform this function. Therefore, to gain an understanding of the impact a Partial discharge method would yield, it was decided to simulate this capability within the BESS model.

These two methods are discussed below:

<u>DischrgMethod = F</u>

When the Full option is chosen (DischrgMethod = F), then for each pulse interval during which the BESS is to be 'ON' the program will try to provide the full rated demand. Therefore, a BESS rated at 1000kW will attempt to provide all of this 1000kW to the system when it is turned 'ON' (ie when the pulse interval is chosen for discharge). The criteria below outline for the Full discharge option how the program operates when certain conditions occur:

1) The BESS will not be used for weekends or holidays, and will only be utilized for weekdays (Day(i) = 4).
2) The pulse interval must be 'ON' (ie PulOvr(i) = 1) for the BESS to be used.
3) Given the above two conditions are met, the BESS will provide the Full rated demand as long as:

    (a) The meter demand for the interval and day being evaluated is equal to or larger than the BESS demand rating. (If it is not, the

---

[2] Telephone conversations with AEG-Westinghouse Transportation Systems, Inc. representative William Hodgeson, September 7, 1993 and January 13, 1994.

[3] Telephone conversation with Control Power Limited representative Tom Edmunds, September 13, 1993.

BESS will only attempt to provide the demand seen by the meter for that interval.)

(b) There is sufficient capacity within the BESS to provide the Full discharge. This is determined via the Peukert Equation. If there is insufficient capacity, then the demand taken from the BESS is scaled back to meet the available capacity.

When the Full discharge method is chosen, there is another variable available to the user utilizing the multiple simulations option (ie Mode = 2 or 3). This variable, DischrgAddKW, defines an extra amount that the meter pulses must be above the threshold value in order for the pulse to be turned 'ON'. To understand the usefulness of this variable, it is important to once again recognize that when the Full discharge option has been chosen and all the necessary conditions have been met, the BESS discharges at it's full demand rating regardless of the magnitude of the current pulse. So in a situation where the BESS is rated at 1000kW and the maximum meter pulse demand is 2250kW (thus leading to a Threshold Demand of 1250kW), a specific meter pulse registering a maximum yearly value of 1260kW would be turned 'ON' every weekday. This would cause the BESS to discharge it's full 1000kW for this interval, even though inclusion of this interval will require a larger BESS capacity (and therefore a higher initial capital cost), extra energy inefficiency charges, and will result in insignificant energy cost savings.

However, when the program is evaluating the meter data to establish which pulses to turn on with the DischrgAddKW variable equal to 100kW, it will cause the program to not turn this meter pulse 'ON' since 1260kW is less than 1250 + 100 = 1350kW.

DischrgMethod = P

For the Partial discharge method, when the pulse interval is 'ON' (ie PulOvr(i) = 1) the BESS attempts to shave only that amount of demand which is above the Threshold Demand (Threshold Demand = Maximum Meter Demand - BESS Demand Rating). For example, if the maximum meter demand for the year is 2000kW, and the BESS rated demand is 1250kW, then for those pulses which are 'ON' the BESS will always try to shave enough off to keep the new meter demand equal to the Threshold Demand of 750kW. The following criteria explain how the program deals with the various conditions it could be confronted with when the Partial discharge method is chosen:

1) The BESS will only attempt to discharge for intervals which are considered 'ON' (ie PulOvr(i) = 1).

2) If the pulse meter demand is greater than the Threshold Demand, then the program will attempt to shave this amount of demand, up to

the BESS rated demand.

3) If there is insufficient BESS capacity, then the demand taken from the BESS is scaled back to meet the available capacity.

A.4.1.2.3 Conjunctive vs Individual Meter Option (ConjYN)

Conjunctive billing refers to the process whereby a group of substation meter pulses are added together before they are evaluated for demand charges. Since from substation to substation the peak can occur on different days and at different times of the day, use of conjunctive billing can frequently save 10-20% of the demand charges when compared to the individual meter demand charges.

ConjYN = Y

Turning the Conjunctive option on enables the program to evaluate the feasibility of installing a BESS at a substation that is conjunctively billed. When this option is chosen, the program will expect to read in two meter pulse files: (1) the summation of all the meters' pulses for the year, and (2) the individual meter pulses for the substation where the BESS will be housed.

For this case, the program utilizes the meter summations to determine whether a pulse is to be shaved, and uses the individual meter pulses to determine the maximum amount of demand that can be shaved. For example, a fictitious conjunctive system has a maximum meter pulse summation of 50,000kW and a maximum individual meter pulse demand of 2000kW. With these values, the maximum BESS demand rating that should be used is 2000kW. Considering a case where the BESS size is made to be 1000kW, then the Threshold Demand for this conjunctive case would be 49000kW (=50000-1000), which indicates that the BESS will be accessed' each time the meter pulse summations rise above the 49000kW Threshold.

ConjYN = N

Setting the Conjunctive option to no indicates that the user will be simulating a substation that is not conjunctively billed. For this case, only one meter data file will be read in. This data should reflect the meter pulses for the substation to be modeled.

A.4.1.2.4 Raised Battery Voltage Option (RaiseKW2YN and BatVolt)

In a conjunctive system, it may be economically worthwhile to utilize a BESS which has a higher demand and capacity rating than the substation where it is to be housed. However, the BESS size is typically limited to the maximum demand and capacity provided by the substation. A means to enable increasing the BESS size beyond the substation rating can be accomplished by raising the BESS voltage, thus inducing the BESS to provide energy to trains that would normally be getting this energy from adjacent substations. The development of an equation which simulates the effect of increased BESS voltage on demand was covered in section 2.1.6. Within the BESS simulation program, this phenomena is modeled using the variable RaiseKW2YN.

RaiseKW2YN=Y

When the user has set ConjYN=Y, setting the variable RaiseKW2YN=Y causes the program to read in the BESS voltage (BatVolt). The program calculates the percent increase above system voltage that the BESS will be operated at, and uses the equation developed in section 2.1.6 to calculate a pulse multiplier which all the individual meter pulses will be multiplied by. These higher individual pulses reflect the extra energy that will be obtained from this BESS due to it's increased voltage, and will also enable simulation of a larger BESS size.

RaiseKW2YN=N

Setting RaiseKW2YN=N means the program will not attempt to read in a raised battery voltage (BatVolt), and will simply use the individual pulse meter demand values as input to determine the BESS size.

A.4.1.2.5 Rate Structure Option (BillType)

The BESS simulation utilizes the variable BillType to offer two specific and one general rate structure options. The two specific system rate structures are: PEPCO DC, which applies for the Washington, DC Metro Red Line, and Duquesne Light, which applies to the Pittsburgh, PA PAT system. These two, as well as the general option, will be discussed below.

BillType=W

This option causes the program to utilize the Washington, DC Washington Metropolitan Area Transit Authority (WMATA) rate structure. The numerous WMATA substations are supplied power from several utilities, each providing power at a different rate schedule. The WMATA Red Line, which will be evaluated with this model in a subsequent section, is supplied power from the Potomac Electric Power Company (PEPCO). The WMATA Red Line falls within the PEPCO DC rate structure jurisdiction. The PEPCO DC rate structure charges \$.0356 per kWh for energy, \$11.26 for each kW of the maximum monthly demand, and a base charge of \$2800.20 per substation.

The monthly demand is obtained by taking the average of two adjacent 15-minute pulses.

BillType = P

Using this option selects the Pittsburgh Port Authority Transit (PAT) rate structure. PAT substations receive power from either the Duquesne Light or West Penn Power Companies. The PAT substation which will be evaluated within this study receives power from Duquesne Light. Therefore, choosing BillType = P causes the model to implement the PAT Duquesne Light rate structure. This rate structure is comprised of a base charge of $5,493 for the first 300kW of demand, $13.90 per kW for each additional kW of demand, and $.0378 per kWh for energy. The maximum demand used for billing purposes is simply the maximum 15-minute pulse seen for the month.

Billtype = S

Selecting this option turns on the Standard rate structure calculation. For this option the user must enter values for the base charge (BasChg), free number of demand kW's (BasKW), cost per kW of demand (KWChg) and cost per kWh of energy(KWhChg). The demand calculated for bill purposes is simply the maximum pulse demand.

A.4.1.2.6 BESS Component Cost Option (CstTyp)

Three pre-defined and two user-input costs were developed for this program. For the three pre-defined costs, specific BESS application studies were used to obtain unit costs for each of the major BESS component systems (Batteries, Power Conditioning System, and Balance of Plant). These costs were all normalized to 1993 dollars. A brief description of these costs is contained in chapter 2.2, and Table 2-2 defines the actual per dollar values. A description of each of the five Component Cost Options is given below.

CstTyp = E

Selecting this option causes the program to use cost values obtained from an EPRI report on Transportation Energy Storage[4]. These values are shown below:

250. <== BatDolPerKWh, Battery Cost ($/kWh)
212. <== PCSDolPerKW, Power Conditioning Cost ($/kW)
55. <== BOPDolPerKW, Balance of Plant Cost ($/kW)
165. <== BOPDolPerKWh, Balance of Plant Cost ($/kWh)

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[4] Walter J. Stolte, "Characterization of Energy Storage for Transportation", p.2-16.

500000. <== Balance of Plant Base Cost ($)

CstTyp=M

Selecting this option makes the program utilize costs obtained from the Bechtel report evaluating the feasibility of a BESS at the Metro-North System[5]. These costs are shown below:

346. <== BatDolPerKWh, Battery Cost ($/kWh)
149. <== PCSDolPerKW, Power Conditioning Cost ($/kW)
246. <== BOPDolPerKW, Balance of Plant Cost ($/kW)

CstTyp=A

Selecting this option makes the program use average costs of several studies, as shown below:

248. <== BatDolPerKWh, Battery Cost ($/kWh)
264. <== PCSDolPerKW, Power Conditioning Cost ($/kW)
160. <== BOPDolPerKW, Balance of Plant Cost ($/kW)

CstTyp=U

This option allows the user to enter fixed costs that the program will use to determine the BESS cost. This option is useful if the user has obtained specific costs for the BESS components. The values that the user can enter are:

Battery Cost ($/kWh) <== BatDolPerKWh
Power Conditioning Cost ($/kW) <== PCSDolPerKW
Balance Of Plant Demand Cost ($/kW) <== BOPDolerKW
Balance Of Plant Energy Cost ($/kWh) <== BOPDolPerKWh
Balance Of Plant Base Cost ($) <== BOPBaseCost

CstTyp=V

This option allows the user to input limits on cost for each of the BESS component systems, and develops linear costs from this data for the battery and balance-of-plant costs, while developing logarithmic costs for the power conditioning system. From information received from battery manufacturers and BESS reports, the variation of battery costs due to BESS size is not very extreme, ranging from about $170 to $250 per kWh. A similar relationship also exists for the balance-of-plant costs. Therefore, within the CstTyp=V option these costs are modeled with a linear cost estimation routine,

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[5] Walter J. Stolte, "Assessment of a Battery Storage System for the Metro-North Commuter Railroad 126th Street Traction Rectifier Substation", p.3-28.

whereby the user enters the minimum and maximum costs for the respective size, and the program will then use a linear interpolation routine to determine the cost of the system for the specific BESS demand and capacity that the program is currently evaluating.

For the PCS costs, however, a number of reports and information received from manufacturers indicates that the unit cost of the transformer/rectifier equipment is extremely dependent on the BESS demand size[6,7]. As the BESS demand rating rises, the cost falls off logarithmically. Therefore, PCS costs are modeled with a logarithmic routine.

Figure A-3 gives an example of how these costs are modeled within the program. The input required from the user for this option is shown below:

Battery Cost @ 1st capacity ($/kWh) < = = BatLinCostPerKWh(1)
Battery capacity for 1st Cost (kWh) < = = BatLinKWh(1)
Battery Cost @ 2nd capacity ($/kWh) < = = BatLinCostPerKWh(2)
Battery capacity for 2nd Cost (kWh) < = = BatLinKWh(2)
PCS Cost @ 1st demand ($/kW) < = = PCSLogCostPerKW(1)
PCS demand for 1st Cost (kW) < = = PCSLogKW(1)
PCS Cost @ 2nd demand ($/kW) < = = PCSLogCostPerKW(2)
PCS demand for 2nd Cost (kW) < = = PCSLogKW(2)
BOP Cost @ 1st capacity ($/kWh) < = = BOPLinCostPerKWh(1)
BOP capacity for 1st Cost (kWh) < = = BOPLinKWh(1)
BOP Cost @ 2nd capacity ($/kWh) < = = BOPLinCostPerKWh(2)
BOP capacity for 2nd Cost (kWh) < = = BOPLinKWh(2)
BOP Cost @ 1st demand ($/kW) < = = BOPLinCostPerKW(1)
BOP demand for 1st Cost (kW) < = = BOPLinKW(1)
BOP Cost @ 2nd demand ($/kW) < = = BOPLinCostPerKW(2)
BOP demand for 2nd Cost (kW) < = = BOPLinKW(2)

It is important to note that for the linear interpolation routine values, the user-input values are considered to bound the potential costs. For example, if the user specified a battery cost of $150 per kWh for a 1MWh capacity plant, and $250 per kWh for a 500kWh plant, if the program were evaluating a 5MWh plant size the $150 per kWh value would be used to determine battery costs, whereas if a 750kWh plant were being evaluated then a $200 per kWh value would be used.

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[6] Walter J. Stolte, "Characterization of Energy Storage for Transportation", p.2-14.

[7] Information in letter to the author from Jennifer Young of Control Power Limited, October 4, 1993.

Sample BESS Variable Component Costs

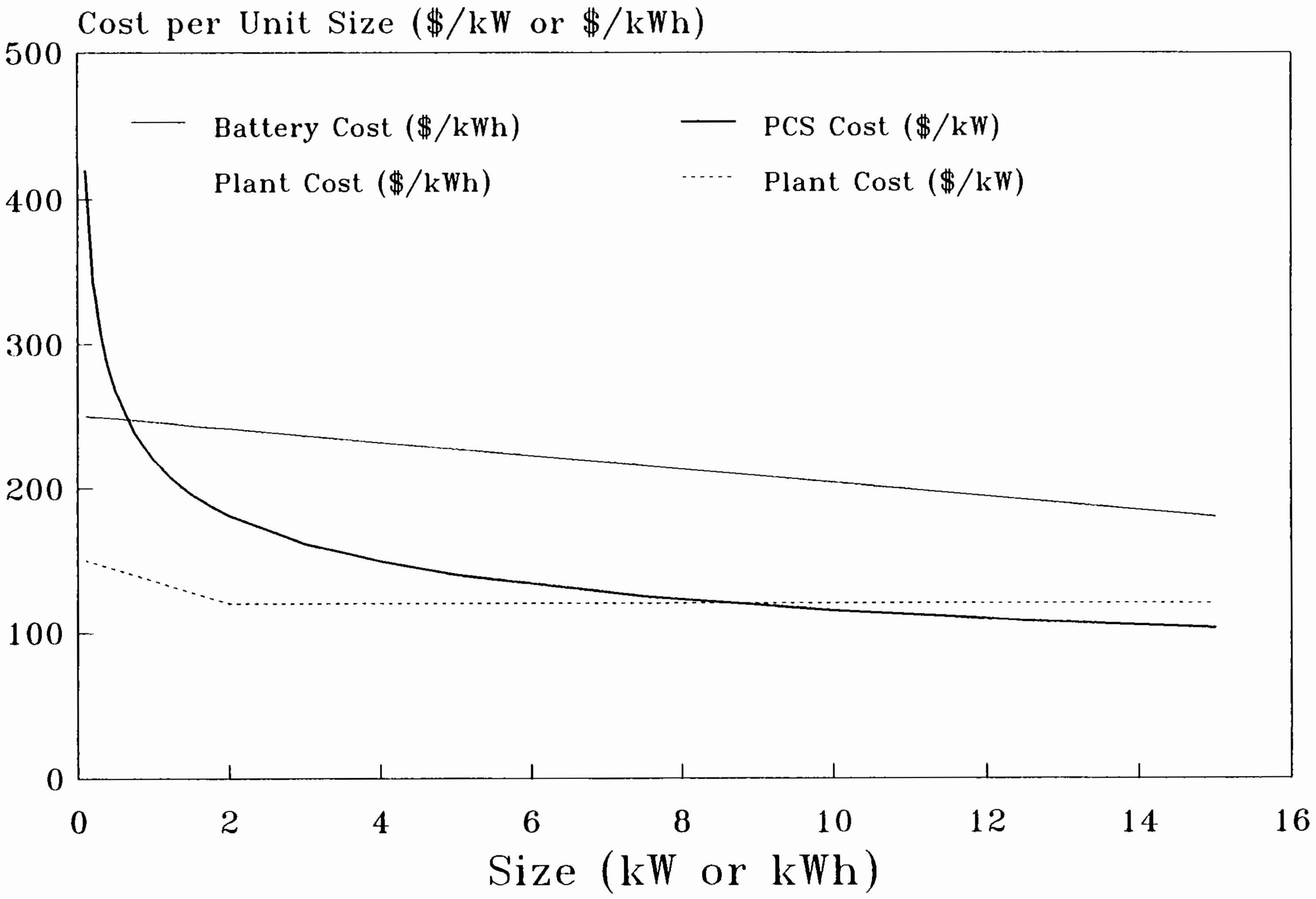

Figure A-3

A.4.1.2.7 Yearly or Monthly Peak Shaving Option (KWMonthYN)

Extreme temperatures cause transit authorities to turn on either heating or air-conditioning units both in their cars and at their stations. The use of these devices result in higher demands for the various months of the year. These seasonal temperature effects and commensurate impacts on demand are fairly constant for the various months of the year. The Monthly Peak Shaving option enables the program to consider these monthly variations and make more efficient use of the BESS.

To better understand this phenomena, consider the case where a user selects a 500kW demand BESS with the Partial Discharge Option. If the maximum meter demand value found from evaluating the meter data is 3000kW, then whenever the meter demand goes over 2500kW the BESS will be used. But due to seasonal effects, the meter in question only has a demand value that goes above 2500kW for two months out of the year. In this case, since the BESS Threshold demand was set to the constant 2500kW, it will only successfully shave energy two months out of the year.

But if the BESS Threshold is set to a value commensurate with each month's peak, then it could be utilized far more efficiently. For instance, for this same BESS the monthly peak in April is 1900kW. If the BESS were reset with a Threshold Demand of 1400kW (=1900kW - 500kW BESS rating), then it would be just as effective in April as it is in January or July. This is what the KWMonthYN option addresses.

KWMonthYN=Y

When this option is selected and the Partial Discharge Method is chosen, the program sets the Threshold Demand (the point above which the BESS is turned 'ON') based on each individual months' meter demand peak.

When the Full Discharge Method is chosen and the program must determine which pulse intervals are 'ON' (ie for Mode=2 or 3), then the program considers the seasonal variations when the monthly peak option is chosen.

KWMonthYN=N

When this option is chosen, then the program sets the constant Threshold Demand to be equal to the maximum meter demand pulse for the year minus the BESS rated demand. No seasonal effects are considered.

A.4.2 BESS Output

The user has the option to produce three different output files: a Summary Output, Detailed Output and Meter Output Files. These files will be discussed below.

If a Summary Output File is desired, then a portion of the output data is optionally printed to a user-defined file name. A sample of the Summary output file is shown in Figure A-4. Within this file all of the input data, as well as several of the key parameters calculated within the program, are displayed for each battery evaluated. The maximum Actual and Available Depths of Discharge for the battery, as well as the Utility Annual Savings, BESS costs, and the resultant economic parameters (Net Present Value, Internal Rate of Return, and PayBack Period) are all printed out for each specific battery being evaluated. For BESS runs searching for the optimum economics, the specific BESS demand and capacity which resulted in the highest positive NPV is printed at the end of the Summary File. The Summary File is also printed to the screen. The Summary File is all the user need specify if the overall economic results of the simulation is all that is desired.

A sample of a Detailed Output file is given in Figure A-5. The Detailed Output file begins by presenting the input reflecting the current run. Before printing out the results for the BESS cases looked at within the run, the program prints out the monthly bill for the meter being evaluated for the case where no BESS is used.

The program then begins printing the results for the BESS cases evaluated within the run. The program first prints the capacity and energy ratings for the BESS being evaluated, and then prints the new bill and commensurate cost savings considering implementation of the BESS. If the run is either in the first energy iteration of a multiple run, or if it is a single BESS evaluation, it prints out the battery discharge statistics. These numbers show which pulses the battery is to be used for, how many occasions throughout the year that particular pulse was over the threshold chosen, the total amount of demand that it is over, and finally the maximum amount the demand was over for any one pulse. These numbers can be useful if the user is considering changing the number of 'battery on' pulse intervals. By inspection of these numbers, the user can determine which intervals are either infrequently utilized or have peaks just over the threshold, and can re-run the program to determine what effect turning these pulses off have on the economics.

The costs associated with each major subsystem (Batteries, Power Conditioning System, and Balance of Plant Costs) are then presented to the user, followed by the data which reflects battery life characteristics. As previously mentioned, the code assumes that the batteries will be exchanged at least every 8 years.

The final items printed to the Detailed Output file are the economic parameters associated with the case. These include the cash flow for the life of the project, the Net Present Value, Internal Rate of Return, and Payback Period. Net Present Values are displayed at the end of the file for a range of discount rates spanning from two to twenty percent.

Figure A-4

SAMPLE SUMMARY OUTPUT FILE

```
                         BATTERY ENERGY STORAGE
                           SUMMARY OUTPUT FILE
                      Simulation of the WMATA system


  Full Discharge - 75% DOD, 2356KW, 9800KWh, Single Run


  Project Charges reflect user-defined costs


  General Program Options:
     Battery used at Full or Partial Demand for Chosen Intervals =     Full
     Amount Pulses must be above Full Battery Demand to be used  =       .0 KW
     Is Chosen Demand to be Shaved from each monthly peak        =      YES


  Utility Costs used:
     Demand Charge            = $  11.26/KW    Energy Charge     = $  .0356/KWh
     Demand Charged After     =        0. KW   Base Charge       = $2800.20

  Project Costs used:
     Battery Number 1 cost    = $ 250.00/KWh @ Battery Size      =     100. KWh
     Battery Number 2 cost    = $ 180.00/KWh @ Battery Size      =   15000. KWh
     PCS Number 1 cost        = $ 420.00/KW  @ PCS Size          =     100. KW
     PCS Number 2 cost        = $ 220.00/KW  @ PCS Size          =    1000. KW
     BOP Number 1 cost        = $  50.00/KWh @ BOP Size          =     100. KWh
     BOP Number 2 cost        = $  30.00/KWh @ BOP Size          =   15000. KWh
     BOP Number 1 cost        = $ 150.00/KW  @ BOP Size          =     100. KW
     BOP Number 2 cost        = $ 120.00/KW  @ BOP Size          =    2000. KW

  Financial Data used:
     Project Life             =        35 Yrs  Discount rate     =   5.0000 %
     Inflation rates:  Energy =   5.0000 %     Battery           =   3.0000 %

  Battery Information:
     Energy Amount Recoverable=   10.000 %     Recovery Rate     =    2.000
 %/Hr
     Round-Trip Efficiency    =   80.000 %     Nominal Voltage   =    750.0 V
     Maximum Allowable DOD    =   75.000


  Other Information:
     Number of Days considered=      365       NumberPulses/Day  =       96
     Starting KW % of maximum =     .000 %     Ending KW % of max=     .000 %
     Starting KWh% of maximum =     .000 %     Ending KWh% of max=     .000 %
     Demand increments        =        1       Energy increments =        1
     Charge Grp 1: First Pulse=        1       Last Pulse Grp 1  =       20
     Charge Grp 2: First Pulse=       90       Last Pulse Grp 2  =       96

  File Information:
     Input Conjunctive File   =  KWALLDC.DAT
     Input Individual File    =  KWAP01.DAT
     Output Summary File      =  S75DOD98.KWH
     Output Detailed File     =  D75DOD98.KWH
     Output New Meter File    =  M75DOD98.KWH
```

Figure A-4 (Cont'd)

SAMPLE SUMMARY OUTPUT FILE

```
Demand    Energy    Maximum    Utility    System          Net Intrnal     Pay
Shaved  Capacity   Act   Avl    Annual      Cost      Present Rate of    Back
                   DOD   DOD   Savings                  Value  Return    Time
  (KW)     (KWh)   (%)   (%)       ($)       ($)                         (Yrs)

 2356.     9800.    75    94   255799.  3055989.      207111.    5.36   19.65
```

Figure A-5

SAMPLE DETAILED OUTPUT FILE

```
                              BATTERY ENERGY STORAGE
                               DETAILED OUTPUT FILE
                          Simulation of the WMATA system


Full Discharge - 75% DOD, 2356KW, 9800KWh, Single Run


 Project Charges reflect user-defined costs


 General Program Options:
    Battery used at Full or Partial Demand for Chosen Intervals =     Full
    Amount Pulses must be above Full Battery Demand to be used  =       .0 KW
    Is Chosen Demand to be Shaved from each monthly peak        =      YES


 Utility Costs used:
    Demand Charge            = $  11.26/KW    Energy Charge      = $  .0356/KWh
    Demand Charged After     =        0. KW    Base Charge        = $2800.20

 Project Costs used:
    Battery Number 1 cost    = $ 250.00/KWh @ Battery Size       =     100. KWh
    Battery Number 2 cost    = $ 180.00/KWh @ Battery Size       =   15000. KWh
    PCS Number 1 cost        = $ 420.00/KW  @ PCS Size           =     100. KW
    PCS Number 2 cost        = $ 220.00/KW  @ PCS Size           =    1000. KW
    BOP Number 1 cost        = $  50.00/KWh @ BOP Size           =     100. KWh
    BOP Number 2 cost        = $  30.00/KWh @ BOP Size           =   15000. KWh
    BOP Number 1 cost        = $ 150.00/KW  @ BOP Size           =     100. KW
    BOP Number 2 cost        = $ 120.00/KW  @ BOP Size           =    2000. KW

 Financial Data used:
    Project Life             =        35 Yrs    Discount rate      =   5.0000 %
    Inflation rates:  Energy =   5.0000 %      Battery            =   3.0000 %

 Battery Information:
    Energy Amount Recoverable=   10.000 %      Recovery Rate      =    2.000
%/Hr
    Round-Trip Efficiency    =   80.000 %      Nominal Voltage    =    750.0 V
    Maximum Allowable DOD    =   75.000


 Other Information:
    Number of Days considered=      365         NumberPulses/Day   =      96
    Starting KW % of maximum =     .000 %      Ending KW % of max=     .000 %
    Starting KWh% of maximum =     .000 %      Ending KWh% of max=     .000 %
    Demand increments        =        1         Energy increments =        1
    Charge Grp 1: First Pulse=        1         Last Pulse Grp 1   =      20
    Charge Grp 2: First Pulse=       90         Last Pulse Grp 2   =      96

 File Information:
    Input Conjunctive File   =  KWALLDC.DAT
    Input Individual File    =  KWAP01.DAT
    Output Summary File      =  S75DOD98.KWH
    Output Detailed File     =  D75DOD98.KWH
    Output New Meter File    =  M75DOD98.KWH
```

Figure A-5 (Cont'd)

SAMPLE DETAILED OUTPUT FILE

```
Electric bill generated based on WMATA rate structure

This program determines the electric bill based on input utility pulse data.


Bill below based on following battery characteristics:
     Battery Peak Demand Capability =       0. (KW)
     Battery Energy Capacity        =       0. (KWh)

          Energy    Energy    Demand    Demand    Demand    Demand    Base
           Used      Cost      Used      Day      Pulse      Cost     Cost
Month     (KWh)      ($)       (KW)                           ($)      ($)

    1 11896300.  423508.   37428.         9        35  421439.    2800.
    2 11227050.  399683.   43368.        59        30  488324.    2800.
    3 12007180.  427456.   42070.        74        33  473708.    2800.
    4 10748290.  382639.   37802.       100        30  425651.    2800.
    5 10959440.  390156.   38866.       150        32  437631.    2800.
    6 10589230.  376976.   40422.       172        68  455152.    2800.
    7 11583990.  412390.   40952.       191        35  461120.    2800.
    8 10942340.  389547.   38610.       235        32  434749.    2800.
    9 10055400.  357972.   37462.       260        71  421822.    2800.
   10  9983317.  355406.   37462.       274        71  421822.    2800.
   11  9126851.  324916.   33776.       330        70  380318.    2800.
   12 10261070.  365294.   37890.       351        31  426641.    2800.

Total annual electric bill   = $  9887923.
```

Figure A-5 (Cont'd)

SAMPLE DETAILED OUTPUT FILE

```
Bill below based on following battery characteristics:
     Battery Peak Demand Capability =    2356. (KW)
     Battery Energy Capacity        =    9800. (KWh)

           Energy    Energy    Demand    Demand    Demand    Demand     Base
            Used      Cost      Used      Day       Pulse     Cost      Cost
Month      (KWh)      ($)       (KW)                          ($)       ($)

    1 11926680.  424590.   35312.         9        35  397613.    2800.
    2 11261240.  400900.   41154.        59        30  463394.    2800.
    3 12052100.  429055.   40038.        74        33  450828.    2800.
    4 10779770.  383760.   35826.       100        30  403401.    2800.
    5 10999740.  391591.   36970.       122        64  416282.    2800.
    6 10632320.  378511.   38544.       172        68  434005.    2800.
    7 11617480.  413582.   38848.       191        35  437429.    2800.
    8 10989400.  391222.   36830.       235        32  414706.    2800.
    9 10085140.  359031.   35344.       260        71  397973.    2800.
   10 10023790.  356847.   35344.       274        71  397973.    2800.
   11  9166231.  326318.   31956.       330        70  359825.    2800.
   12 10295890.  366534.   35804.       351        31  403153.    2800.

Total annual electric bill    = $  9632124.
Annual electric bill savings = $   255799.


Statistics based on input meter KW data:

Pul # :        1      2      3      4      5      6      7      8      9     10
# Over:        0      0      0      0      0      0      0      0      0      0
Tot KW:        0      0      0      0      0      0      0      0      0      0
Max KW:        0      0      0      0      0      0      0      0      0      0

Pul # :       11     12     13     14     15     16     17     18     19     20
# Over:        0      0      0      0      0      0      0      0      0      0
Tot KW:        0      0      0      0      0      0      0      0      0      0
Max KW:        0      0      0      0      0      0      0      0      0      0

Pul # :       21     22     23     24     25     26     27     28     29     30
# Over:        0      0      0      0      0      0      0      0      0      3
Tot KW:        0      0      0      0      0      0      0      0      0   4324
Max KW:        0      0      0      0      0      0      0      0      0   2072

Pul # :       31     32     33     34     35     36     37     38     39     40
# Over:        7      6      8      4      7      7      1      0      0      0
Tot KW:     8596   6060   9644   3272   4584   7892   1360      0      0      0
Max KW:     2116   1816   2356   1524   1492   2064   1360      0      0      0

Pul # :       41     42     43     44     45     46     47     48     49     50
# Over:        0      0      0      0      0      0      0      0      0      0
Tot KW:        0      0      0      0      0      0      0      0      0      0
Max KW:        0      0      0      0      0      0      0      0      0      0

Pul # :       51     52     53     54     55     56     57     58     59     60
# Over:        0      0      0      0      0      0      0      0      0      0
Tot KW:        0      0      0      0      0      0      0      0      0      0
Max KW:        0      0      0      0      0      0      0      0      0      0
```

Figure A-5 (Cont'd)

SAMPLE DETAILED OUTPUT FILE

```
Pul # :      61      62      63      64      65      66      67      68      69      70
# Over:       0       0       0       0       2       3       2       6       4       7
Tot KW:       0       0       0       0    3268    1924    2460    7076    2528    5796
Max KW:       0       0       0       0    1816    1052    1528    1880    1012    1888

Pul # :      71      72      73      74      75      76      77      78      79      80
# Over:       8       7       2       3       0       0       0       0       0       0
Tot KW:    9700    5788    1768    1884       0       0       0       0       0       0
Max KW:    2176    1964     912     892       0       0       0       0       0       0

Pul # :      81      82      83      84      85      86      87      88      89      90
# Over:       0       0       0       0       0       0       0       0       0       0
Tot KW:       0       0       0       0       0       0       0       0       0       0
Max KW:       0       0       0       0       0       0       0       0       0       0

Pul # :      91      92      93      94      95      96
# Over:       0       0       0       0       0       0
Tot KW:       0       0       0       0       0       0
Max KW:       0       0       0       0       0       0

Calculated BESS Component Costs:
   Battery Cost (recurrent)                = $  2003410.
   Power Conditioning System Cost          = $   407457.
   Balance of Plant Costs                  = $   645123.


Calculated Battery Life Data:
   Annual Average Depth of Discharge (%)   =        73.07
   Annual Number of Days Used (Cycles/Yr)  =          251
   Potential Battery Life (Yrs)            =         7.62
   Battery Life Used for Economics (Yrs)   =         7.62


Cash Flow for 35 Years (in $K's) :

   Initial investment =     -3056.
Year==>       1       2       3       4       5       6       7       8       9      10
$K's==>     268     282     296     310     326     342   -2104     377     396     416

Year==>      11      12      13      14      15      16      17      18      19      20
$K's==>     437     459     482     506   -2589     558     586     615     646     678

Year==>      21      22      23      24      25      26      27      28      29      30
$K's==>     712   -3090     785     824     866     909     955    1002    1052   -3757

Year==>      31      32      33      34      35       0       0       0       0       0
$K's==>    1160    1218    1279    1343    1410       0       0       0       0       0

Battery Economics:
   Net Present Value @   5.00% Discount Rate ($K's) =    207.
   Internal Rate of Return (%)                      =    5.36
   Payback Period                                   =   19.65

Net Present Values shown below for a range of discount rates:
Disc Rate(%)==>     2     4     6     8    10    12    14    16    18    20
NPV (K's)    ==> 3053.  905. -326.-1054.-1500.-1784.-1972.-2101.-2193.-2262.
```

All of this information capacity value that is evaluated. For a BESS run searching for an optimum economics case, the demand and capacity value which resulted in the highest positive NPV is also presented at the end of each Detailed Output File. If during an optimization run no positive NPV's were seen, the program prints out a message to the user stating this condition.

The final output file is the Meter Output file. This file prints out the revised meter pulses based on implementation of the BESS evaluated. This file can be useful if the user desires clarification on how the program has actually modeled the implementation of the BESS. By comparing the input meter file to the Meter Output file, the user can easily see how much and where pulses have been shaved. It is important to note, however, that each of the Meter Output files require around 250K bytes of storage space on the disk. For an optimization run using a 6x6 demand and capacity matrix and needing 3 iterations to identify the optimum case, choosing to utilize the Meter Output file would result in a file requiring approximately 27M bytes of data storage space. Therefore, users should typically only use this option for single-run cases.

A.4.3 BESS Sample Runs

A.4.3.1 Sample Input Files

Since the BESS code expects to read simple, unformatted ASCII data, creation of the necessary BESS code input files can be accomplished using any word processor, text editor or spreadsheet program. It is important, though, that if a word processor or spreadsheet program is used, that the user save the file in ASCII format, with no printer control characters, such that each of the data inputs falls on the appropriate line and column as described in section A.2.1.

The program needs a large amount of data in order to simulate BESS operation. Before any input files can be built, the user must obtain the necessary data, which will be entered into one of the two input files that the BESS program uses: (1) general BESS input data file; and (2) meter demand input file (there will be either one or two of these, depending on whether a conjunctive evaluation is being performed). The largest amount of data needed will be meter(s) demand pulses, which must be obtained from the utility for the substation(s) in question. Once received, this data must be put in the proper format, as previously defined in Table A-2. If enough data does not exist for one year's worth of pulses (365 days), then the user may consider replicating a portion of the data and substituting that for the missing data. Obviously, the more actual data that is used, the more Confidence can be put in the BESS program output. For a non-conjunctive case, only meter pulse data for the substation being evaluated need be obtained. For a conjunctive system meter data must be obtained for both the substation where the BESS will be located, and for each of the other substations that are included within the conjunctive billing. This data will be used to produce two input files that the BESS program will use: (1) an individual meter demand file reflecting data for the substation where the BESS will be housed; and (2) a cumulative data file that reflects meter demand for ALL the conjunctive meters, including the individual file, for each pulse and day of the year.

If the utility cannot provide meter data which reflects the summation for all the conjunctive meters, then the user must obtain all the individual meters' data and sum it. A spreadsheet program can easily perform this function. A spreadsheet will accept the individual meter's pulse demands, add the separate pulses together for a particular day and time, and print this data in the appropriate format to an ASCII file which is accessed by the BESS program.

Figure A-6 shows sample input for individual and conjunctive meter demand data in the format needed by the code for three days worth of data. Complete meter data files would contain 365 days worth of data, in chronological order beginning with January 1st and extending to December 31.

The other data file that the BESS program requires is the BESS General Input data file. Several samples of these are presented in Figures A-7 to A-9 to give examples of how the files look when various BESS options are used. To the far right of each value shown in these figures is what the value represents. In an actual user's file, this information should not exist, but is included in these examples to facilitate understanding of the values.

A.4.3.2 Running the BESS Program

Before running the code, the user must copy the file BESS.EXE to their computer. Execution of the code is then completed by typing the following command at the DOS prompt:

```
C:\> BESS
```

The program will ask the user whether an input file containing all the desired information will be used. If the user does not enter a filename, the program will prompt the user for data line-by-line. The disadvantage of this approach is that if the user makes a mistake, and hits a carriage return, then the program must be started over. Using an input file is also desirable due to the ease with which changes to the input are completed. If the user wishes to evaluate the impact of several different discount rates using input files, they need only create one input file, save it with the first discount rate, change the discount rate, save it again with a different name (being careful

FIGURE A-6

Sample Individual and Conjunctive Meter Pulse Data

WMATA Individual Substation 3 days' Pulse Data (Farragut North)

```
           185 1  788. 1096.  840.  940.  856.  660.  824.  756.  500.  328.   88
0.  436.  212.   20.   36.  208.  152.    0.    4.   16.   88.    4.    0.    0.
    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.   28.
240.  648.  264.  832.  804.  724.  788.  660.  816.  716.  724.  788.  724.   73
6.  736.  720.  764.  696.  948.  708.  756.  784.  784.  788.  812.  772.  808.
  664.  848.  896.  840.  832.  756.  676.  796.  612.  612.  624.  664.  544.
788.  664.  612.  568.  592.  616.  556.  648.  580.  764.  584.  704.  388.   86
0.  524.  592.  588.  636.  504.
           285 4  408.  316.  252.   52.   24.   24.  108.   48.   28.   64.
4.    0.    8.  168.   68.   44.   16.   28.  168.   48.   76.  280.  180.  960.
 1180. 1248. 1308. 1316. 1280. 1368. 1260. 1176. 1380. 1140. 2008. 1412. 1548. 1
372. 1324.  984. 1120. 1108. 1088. 1024. 1380. 1288. 1128. 1184. 1064. 1024.  118
4.  888.  852. 1396. 1052. 1120. 1088. 1088. 1052. 1248.  976. 1236. 1180. 1444.
 1344. 1220. 1476. 1332. 1380. 1456. 1316. 1492. 1232. 1200. 1048. 1116.  732.
744. 1052.  816.  652.  868.  776.  876.  716.  960.  624.  720.  560.  548.  124
0.  816.  640.  736.  720.  488.
           385 4  328.  292.   16.   52.   36.   96.  212.  192.   84.  116.   21
2.  196.   92.  360.   52.   64.   16.  168.   56.   76.   28.   56.  348.  696.
 1292. 1272. 1404. 1156. 1172. 1428. 1300. 1472. 1564. 1392. 1372. 1396. 1224. 1
340.  992. 1428. 1332. 1224. 1272. 1208.  976. 1056.  972. 1060. 1056. 1016.  101
2. 1024. 1112.  992. 1288. 1060.  876. 1148. 1160. 1128. 1284. 1552. 1152. 1356.
 1392. 1412. 1084. 1996. 1584. 1076. 1744. 1276. 1276. 1412. 1524. 1060. 1384. 1
148. 1320. 1084.  880. 1376. 1012. 1076.  892. 1064. 1156. 1144. 1004.  740.  148
8.  804.  800. 1020.  996.  744.
```

WMATA Conjunctive System 3 days' Pulse Data (Red Line)

```
           185 116100.16220.18852.17100.18844.16592.18136.18600.14152.11456.1056
8. 8536. 5056. 3312. 2392. 3064. 2244. 1480. 1412. 1532. 1980. 1444. 1316. 1328.
 1440. 1340. 1504. 1604. 1708. 1812. 2324. 2904. 2736. 2160. 2592. 2972. 3880. 6
536.10476. 8340.15452.17852.15812.15272.15188.15548.15972.16372.16920.15440.1613
2.15428.15076.15360.15840.18008.16876.15532.15516.15264.15692.15960.15688.16436.
15956.16716.17048.18328.17476.16292.16184.15828.15660.14568.13700.13668.13236.13
252.13420.12468.12212.11832.13224.13692.14256.13752.13528.13044.14904.12468.1297
2.14100.12892.12856.12104.11132.
           285 4 9280. 9240. 5784. 3528. 2464. 2604. 2228. 1656. 1604. 1812. 196
8. 2124. 2188. 1788. 2064. 1656. 1500. 1648. 1964. 1804. 2784. 5472. 9000.10132.
19320.22672.25308.27220.29088.30140.29804.31852.30604.30964.32116.31668.31192.26
508.23152.21080.20144.20592.20464.18216.21616.21708.20640.20456.19200.19648.1979
2.18384.19068.21216.21288.19812.20008.18916.19260.20668.21152.24512.27844.29056.
29164.30488.30360.29828.28008.31704.32988.31640.30588.27788.27004.26224.21756.18
408.18420.17684.16988.16168.16760.16504.17552.16536.16720.15824.14380.13996.1641
2.16836.15288.14512.13760.12316.
           385 4 9940. 9104. 5428. 3828. 2756. 3344. 3200. 3132. 2612. 3156. 352
4. 3396. 2928. 2672. 2388. 2068. 1636. 2216. 2012. 2472. 2300. 4768.10256. 9612.
19904.22420.24536.28208.29740.30996.30020.30240.31780.31020.29996.30304.28324.25
408.22580.23660.23480.22748.21748.20296.19304.19308.19736.19528.20044.20156.2048
8.19980.20516.21296.21208.20768.19996.19876.21348.21560.22920.26140.29136.29216.
30120.30680.32232.32292.33036.30544.29528.29472.28084.31172.31216.25512.21784.21
288.22116.19992.19268.20344.20372.19032.19628.20456.20488.19856.18892.17732.1846
8.18324.15852.15872.16444.14140.
```

Figure A-7

Sample General Input File with Mode=1

```
1                                  <== Mode
Full - 75%DOD, 2356KW, 10000KWh    <== Title
Y S75DD100.KWH                     <== OutputYN(1),OutputFile(1)
N D75DD100.KWH                     <== OutputYN(2),OutputFile(2)
N M75DD100.KWH                     <== OutputYN(3),OutputFile(3)
365                                <== NumDays
 96                                <== PulsPerDay
F                                  <== DischrgMethod
Y                                  <== ConjYN
KWALLDC.DAT                        <== InputFile(1)
KWAP01.DAT                         <== InputFile(2)
750.                               <== TransitNominalVoltage
75.                                <== DepthOfDischarge
2.                                 <== KWhIdleRcvryRate
10.                                <== PcntLostKWhRecoverable
80.                                <== RoundTripEff
  2                                <== NumRechrg
  1                                <== BegRechrgPuls(1)
 20                                <== EndRechrgPuls(1)
 90                                <== BegRechrgPuls(2)
 96                                <== EndRechrgPuls(2)
N                                  <== RaiseKW2YN
W                                  <== BillType
 35                                <== ProjectYears
5.                                 <== DiscountRate
5.                                 <== EnergyInflationRate
3.                                 <== ElectEquInflatRate
2356.                              <== Shaved
10000.                             <== ShaveKWh
18                                 <== NumOvr
30 31 ... 36 37 65 66 ... 73 74    <== PulOvr(i)
V                                  <== CstTyp
250.                               <== BatLinCostPerKWh(1)
100.                               <== BatLinKWh(1)
180.                               <== BatLinCostPerKWh(2)
15000.                             <== BatLinKWh(2)
420.                               <== PCSLogCostPerKW(1)
100.                               <== PCSLogKW(1)
220.                               <== PCSLogCostPerKW(2)
1000.                              <== PCSLogKW(2)
50.                                <== BOPLinCostPerKWh(1)
100.                               <== BOPLinKWh(1)
30.                                <== BOPLinCostPerKWh(2)
15000.                             <== BOPLinKWh(2)
150.                               <== BOPLinCostPerKW(1)
100.                               <== BOPLinKW(1)
120.                               <== BOPLinCostPerKW(2)
2000.                              <== BOPLinKW(2)
Y                                  <== KWMonthYN
19.23                              <== Amp(1)
8.                                 <== Time(1)
76.92                              <== Amp(2)
1.                                 <== Time(2)
170.                               <== Depltd(1)
200.                               <== CycLif(1)
24.                                <== Depltd(2)
6000.                              <== CycLif(2)
```

Figure A-8

Sample General Input File with Mode=2

```
2                                  <== Mode
Full Discharge - 75% DOD w/ Mode=2 <== Title
Y S75PCTDD.MD2                     <== OutputYN(1),OutputFile(1)
N D75PCTDD.MD2                     <== OutputYN(2),OutputFile(2)
N M75PCTDD.MD2                     <== OutputYN(3),OutputFile(3)
365                                <== NumDays
 96                                <== PulsPerDay
F                                  <== DischrgMethod
0.                                 <== DischrgAddKW
Y                                  <== ConjYN
KWALLDC.DAT                        <== InputFile(1)
KWAP01.DAT                         <== InputFile(2)
750.                               <== TransitNominalVoltage
75.                                <== DepthOfDischarge
2.                                 <== KWhIdleRcvryRate
10.                                <== PcntLostKWhRecoverable
80.                                <== RoundTripEff
  2                                <== NumRechrg
  1                                <== BegRechrgPuls(1)
 20                                <== EndRechrgPuls(1)
 90                                <== BegRechrgPuls(2)
 96                                <== EndRechrgPuls(2)
N                                  <== RaiseKW2YN
W                                  <== BillType
 35                                <== ProjectYears
5.                                 <== DiscountRate
5.                                 <== EnergyInflationRate
3.                                 <== ElectEquInflatRate
0.                                 <== StartKWPcntOfMax
100.                               <== EndKWPctnOfMax
0.                                 <== StartKWhPcnt
100.                               <== EndKWhPcnt
 6                                 <== KWIter
 6                                 <== KWhIter
V                                  <== CstTyp
250.                               <== BatLinCostPerKWh(1)
100.                               <== BatLinKWh(1)
180.                               <== BatLinCostPerKWh(2)
15000.                             <== BatLinKWh(2)
420.                               <== PCSLogCostPerKW(1)
100.                               <== PCSLogKW(1)
220.                               <== PCSLogCostPerKW(2)
1000.                              <== PCSLogKW(2)
50.                                <== BOPLinCostPerKWh(1)
100.                               <== BOPLinKWh(1)
30.                                <== BOPLinCostPerKWh(2)
15000.                             <== BOPLinKWh(2)
150.                               <== BOPLinCostPerKW(1)
100.                               <== BOPLinKW(1)
120.                               <== BOPLinCostPerKW(2)
2000.                              <== BOPLinKW(2)
Y                                  <== KWMonthYN
19.23                              <== Amp(1)
8.                                 <== Time(1)
76.92                              <== Amp(2)
1.                                 <== Time(2)
170.                               <== Depltd(1)
200.                               <== CycLif(1)
24.                                <== Depltd(2)
6000.                              <== CycLif(2)
```

Figure A-9

Sample General Input File with Mode=3

```
3                                  <== Mode
Full Discharge - 75% DOD w/ Mode=3 <== Title
Y SWF07210.05M                     <== OutputYN(1),OutputFile(1)
N DWF07210.05M                     <== OutputYN(2),OutputFile(2)
N MWF07210.05M                     <== OutputYN(3),OutputFile(3)
365                                <== NumDays
 96                                <== PulsPerDay
F                                  <== DischrgMethod
0.                                 <== DischrgAddKW
Y                                  <== ConjYN
KWALLDC.DAT                        <== InputFile(1)
KWAP01.DAT                         <== InputFile(2)
750.                               <== TransitNominalVoltage
75.                                <== DepthOfDischarge
2.                                 <== KWhIdleRcvryRate
10.                                <== PcntLostKWhRecoverable
80.                                <== RoundTripEff
  2                                <== NumRechrg
  1                                <== BegRechrgPuls(1)
 20                                <== EndRechrgPuls(1)
 90                                <== BegRechrgPuls(2)
 96                                <== EndRechrgPuls(2)
N                                  <== RaiseKW2YN
W                                  <== BillType
 35                                <== ProjectYears
5.                                 <== DiscountRate
5.                                 <== EnergyInflationRate
3.                                 <== ElectEquInflatRate
0.                                 <== StartKWPcntOfMax
100.                               <== EndKWPctnOfMax
0.                                 <== StartKWhPcnt
100.                               <== EndKWhPcnt
 6                                 <== KWIter
 6                                 <== KWhIter
V                                  <== CstTyp
250.                               <== BatLinCostPerKWh(1)
100.                               <== BatLinKWh(1)
180.                               <== BatLinCostPerKWh(2)
15000.                             <== BatLinKWh(2)
420.                               <== PCSLogCostPerKW(1)
100.                               <== PCSLogKW(1)
220.                               <== PCSLogCostPerKW(2)
1000.                              <== PCSLogKW(2)
50.                                <== BOPLinCostPerKWh(1)
100.                               <== BOPLinKWh(1)
30.                                <== BOPLinCostPerKWh(2)
15000.                             <== BOPLinKWh(2)
150.                               <== BOPLinCostPerKW(1)
100.                               <== BOPLinKW(1)
120.                               <== BOPLinCostPerKW(2)
2000.                              <== BOPLinKW(2)
Y                                  <== KWMonthYN
19.23                              <== Amp(1)
8.                                 <== Time(1)
76.92                              <== Amp(2)
1.                                 <== Time(2)
170.                               <== Depltd(1)
200.                               <== CycLif(1)
24.                                <== Depltd(2)
6000.                              <== CycLif(2)
```

to also change the output file names), and continue this process for as many different discount rates as they may wish to evaluate. Then run the program, and enter a different discount rate General Input filename for each of the runs.

A.4.3.3 Sample BESS Outputs

The summary output files for each of the sample input files given in section A.4.3.1 are shown in Figures A-10 to A-12.

Figure A-10

SAMPLE SUMMARY OUTPUT WITH MODE=1

```
                               BATTERY ENERGY STORAGE
                                 SUMMARY OUTPUT FILE
                           Simulation of the WMATA system


Full Discharge - 75% DOD, 2356KW, 10000KWh, Single Run



 Project Charges reflect user-defined costs


 General Program Options:
    Battery used at Full or Partial Demand for Chosen Intervals =     Full
    Amount Pulses must be above Full Battery Demand to be used  =       .0 KW
    Is Chosen Demand to be Shaved from each monthly peak        =      YES


 Utility Costs used:
    Demand Charge             = $  11.26/KW    Energy Charge      = $  .0356/KWh
    Demand Charged After      =        0. KW   Base Charge        = $2800.20

 Project Costs used:
    Battery Number 1 cost     = $ 250.00/KWh @ Battery Size       =     100. KWh
    Battery Number 2 cost     = $ 180.00/KWh @ Battery Size       =   15000. KWh
    PCS Number 1 cost         = $ 420.00/KW  @ PCS Size           =     100. KW
    PCS Number 2 cost         = $ 220.00/KW  @ PCS Size           =    1000. KW
    BOP Number 1 cost         = $  50.00/KWh @ BOP Size           =     100. KWh
    BOP Number 2 cost         = $  30.00/KWh @ BOP Size           =   15000. KWh
    BOP Number 1 cost         = $ 150.00/KW  @ BOP Size           =     100. KW
    BOP Number 2 cost         = $ 120.00/KW  @ BOP Size           =    2000. KW

 Financial Data used:
    Project Life              =        35 Yrs  Discount rate      =   5.0000 %
    Inflation rates:  Energy  =   5.0000 %     Battery            =   3.0000 %

 Battery Information:
    Energy Amount Recoverable=   10.000 %      Recovery Rate      =    2.000
%/Hr
    Round-Trip Efficiency     =   80.000 %     Nominal Voltage    =    750.0 V
    Maximum Allowable DOD     =   75.000


 Other Information:
    Number of Days considered=      365        NumberPulses/Day   =      96
    Starting KW % of maximum =     .000 %      Ending KW % of max=     .000 %
    Starting KWh% of maximum =     .000 %      Ending KWh% of max=     .000 %
    Demand increments         =        0       Energy increments  =       0
    Charge Grp 1: First Pulse=        1        Last Pulse Grp 1   =      20
    Charge Grp 2: First Pulse=       90        Last Pulse Grp 2   =      96

 File Information:
    Input Conjunctive File    =  KWALLDC.DAT
    Input Individual File     =  KWAP01.DAT
    Output Summary File       =  S75DD100.KWH
    Output Detailed File      =  D75DD100.KWH
    Output New Meter File     =  M75DD100.KWH
```

Figure A-10 (Cont'd)

SAMPLE SUMMARY OUTPUT WITH MODE=1

```
Demand    Energy    Maximum    Utility    System        Net  Intrnal    Pay
Shaved  Capacity   Act   Avl    Annual      Cost    Present  Rate of   Back

                   DOD   DOD   Savings                Value   Return   Time
  (KW)     (KWh)  (%)    (%)       ($)       ($)                        (Yrs)

 2356.    10000.    75    91   255653.  3092190.    123522.     5.21  19.84
```

Figure A-11

SAMPLE SUMMARY OUTPUT WITH MODE=2

```
                           BATTERY ENERGY STORAGE
                             SUMMARY OUTPUT FILE
                        Simulation of the WMATA system


 Full Discharge - 75% DOD w/ Mode=2



 Project Charges reflect user-defined costs


 General Program Options:
    Battery used at Full or Partial Demand for Chosen Intervals =     Full
    Amount Pulses must be above Full Battery Demand to be used  =       .0 KW
    Is Chosen Demand to be Shaved from each monthly peak        =      YES


 Utility Costs used:
    Demand Charge             = $  11.26/KW    Energy Charge       = $  .0356/KWh
    Demand Charged After      =        0. KW   Base Charge         = $2800.20

 Project Costs used:
    Battery Number 1 cost     = $ 250.00/KWh @ Battery Size        =     100. KWh
    Battery Number 2 cost     = $ 180.00/KWh @ Battery Size        =   15000. KWh
    PCS Number 1 cost         = $ 420.00/KW  @ PCS Size            =     100. KW
    PCS Number 2 cost         = $ 220.00/KW  @ PCS Size            =    1000. KW
    BOP Number 1 cost         = $  50.00/KWh @ BOP Size            =     100. KWh
    BOP Number 2 cost         = $  30.00/KWh @ BOP Size            =   15000. KWh
    BOP Number 1 cost         = $ 150.00/KW  @ BOP Size            =     100. KW
    BOP Number 2 cost         = $ 120.00/KW  @ BOP Size            =    2000. KW

 Financial Data used:
    Project Life              =        35 Yrs  Discount rate       =   5.0000 %
    Inflation rates:   Energy =   5.0000 %     Battery             =   3.0000 %

 Battery Information:
    Energy Amount Recoverable=   10.000 %      Recovery Rate       =    2.000
%/Hr
    Round-Trip Efficiency     =   80.000 %     Nominal Voltage     =    750.0 V
    Maximum Allowable DOD     =   75.000


 Other Information:
    Number of Days considered=      365        NumberPulses/Day    =      96
    Starting KW % of maximum =     .000 %      Ending KW % of max=  100.000 %
    Starting KWh% of maximum =     .000 %      Ending KWh% of max=  100.000 %
    Demand increments         =        6       Energy increments =         6
    Charge Grp 1: First Pulse=        1        Last Pulse Grp 1    =      20
    Charge Grp 2: First Pulse=       90        Last Pulse Grp 2    =      96

 File Information:
    Input Conjunctive File    =  KWALLDC.DAT
    Input Individual File     =  KWAP01.DAT
    Output Summary File       =  S75PCTDD.MD2
```

Figure A-11 (Cont'd)

SAMPLE SUMMARY OUTPUT WITH MODE=2

```
Demand    Energy    Maximum    Utility    System         Net  Intrnal    Pay
Shaved  Capacity   Act   Avl    Annual      Cost     Present  Rate of   Back
                   DOD   DOD   Savings                 Value   Return   Time
  (KW)     (KWh)   (%)   (%)       ($)       ($)                        (Yrs)

    0.        0.     0     0        0.        0.          0.      .00    .00
    0.        0.     0     0        0.        0.          0.      .00    .00
    0.        0.     0     0        0.        0.          0.      .00    .00
    0.        0.     0     0        0.        0.          0.      .00    .00
    0.        0.     0     0        0.        0.          0.      .00    .00
    0.        0.     0     0        0.        0.          0.      .00    .00


  471.      173.    23   100     1598.   247846.          0.      .00    .00
  471.      485.    38   100     6764.   340303.          0.      .00    .00
  471.      797.    48   100    14931.   431586.          0.      .00    .00
  471.     1108.    57   100    22092.   521695.          0.      .00    .00
  471.     1420.    63   100    29873.   610631.          0.      .00    .00
  471.     1732.    68    98    40649.   698393.    -435227.      .11  29.55


  942.      502.    30   100     4206.   489070.          0.      .00    .00
  942.     1406.    48   100    19734.   750374.          0.      .00    .00
  942.     2310.    64   100    42968.  1001807.          0.      .00    .00
  942.     3214.    71   100    57259.  1243370.          0.      .00    .00
  942.     4118.    75   100    76077.  1475062.          0.      .00    .00
  942.     5022.    75    90   114448.  1696883.    -970508.     1.81  27.83


 1414.      847.    35   100     6350.   715169.          0.      .00    .00
 1414.     2371.    58   100    24621.  1143806.          0.      .00    .00
 1414.     3896.    70   100    66189.  1544366.          0.      .00    .00
 1414.     5420.    75   100    84254.  1916850.          0.      .00    .00
 1414.     6945.    75    93   138245.  2261257.   -1777244.      .38  34.58
 1414.     8469.    75    86   177019.  2577587.   -1495074.     1.69  33.23


 1885.     1112.    40   100     7758.   903471.          0.      .00    .00
 1885.     3114.    65   100    27956.  1454101.          0.      .00    .00
 1885.     5116.    74   100    83195.  1956326.          0.      .00    .00
 1885.     7117.    75   100   137668.  2410146.          0.      .00    .00
 1885.     9119.    75    92   231543.  2815560.    -137059.     4.75  19.95
 1885.    11121.    75    85   233974.  3172569.   -1074793.     2.68  22.06


 2356.     1232.    42   100     8441.  1051360.          0.      .00    .00
 2356.     3450.    67   100    31190.  1655281.          0.      .00    .00
 2356.     5667.    75   100    96683.  2199790.          0.      .00    .00
 2356.     7885.    75   100   176409.  2684888.   -1354287.     2.19  27.44
 2356.    10103.    75    94   255568.  3110574.      57067.     5.10  19.93
 2356.    12320.    75    84   255291.  3476850.   -1098193.     2.85  21.96
```

Figure A-12

SAMPLE SUMMARY OUTPUT WITH MODE=3

```
                              BATTERY ENERGY STORAGE
                                SUMMARY OUTPUT FILE
                           Simulation of the WMATA system


 Full Discharge - 75% Depth of Discharge



  Project Charges reflect user-defined costs


  General Program Options:
     Battery used at Full or Partial Demand for Chosen Intervals =     Full
     Amount Pulses must be above Full Battery Demand to be used  =       .0 KW
     Is Chosen Demand to be Shaved from each monthly peak        =      YES


  Utility Costs used:
     Demand Charge             = $  11.26/KW    Energy Charge       = $  .0356/KWh
     Demand Charged After      =        0. KW   Base Charge         = $2800.20

  Project Costs used:
     Battery Number 1 cost     = $ 250.00/KWh @ Battery Size        =     100. KWh
     Battery Number 2 cost     = $ 180.00/KWh @ Battery Size        =   15000. KWh
     PCS Number 1 cost         = $ 420.00/KW  @ PCS Size            =     100. KW
     PCS Number 2 cost         = $ 220.00/KW  @ PCS Size            =    1000. KW
     BOP Number 1 cost         = $  50.00/KWh @ BOP Size            =     100. KWh
     BOP Number 2 cost         = $  30.00/KWh @ BOP Size            =   15000. KWh
     BOP Number 1 cost         = $ 150.00/KW  @ BOP Size            =     100. KW
     BOP Number 2 cost         = $ 120.00/KW  @ BOP Size            =    2000. KW

  Financial Data used:
     Project Life              =        35 Yrs  Discount rate       =   5.0000 %
     Inflation rates:   Energy =   5.0000 %     Battery             =   3.0000 %

  Battery Information:
     Energy Amount Recoverable=   10.000 %      Recovery Rate       =    2.000
%/Hr
     Round-Trip Efficiency    =   80.000 %      Nominal Voltage     =    750.0 V
     Maximum Allowable DOD    =   75.000


  Other Information:
     Number of Days considered=      365        NumberPulses/Day  =       96
     Starting KW % of maximum =     .000 %      Ending KW % of max=  100.000 %
     Starting KWh% of maximum =     .000 %      Ending KWh% of max=  100.000 %
     Demand increments        =        6        Energy increments =        6
     Charge Grp 1: First Pulse=        1        Last Pulse Grp 1  =       20
     Charge Grp 2: First Pulse=       90        Last Pulse Grp 2  =       96

  File Information:
     Input Conjunctive File    =  KWALLDC.DAT
     Input Individual File     =  KWAP01.DAT
     Output Summary File       =  SWF07210.05M
```

Figure A-12 (Cont'd)

SAMPLE SUMMARY OUTPUT WITH MODE=3

```
Iteration # 1 to find optimum Net Present Value w/ following KW & KWh ranges:
   Starting KW % of maximum =      .000 %     Ending KW % of max=  100.000 %
   Starting KWh% of maximum =    10.000 %     Ending KWh% of max=  100.000 %

Demand    Energy    Maximum     Utility     System        Net  Intrnal    Pay
Shaved  Capacity   Act   Avl    Annual       Cost     Present  Rate of   Back
                   DOD   DOD   Savings                  Value   Return   Time
  (KW)     (KWh)   (%)   (%)       ($)        ($)                       (Yrs)

    0.        0.     0     0        0.         0.          0.      .00    .00
    0.        0.     0     0        0.         0.          0.      .00    .00
    0.        0.     0     0        0.         0.          0.      .00    .00
    0.        0.     0     0        0.         0.          0.      .00    .00
    0.        0.     0     0        0.         0.          0.      .00    .00
    0.        0.     0     0        0.         0.          0.      .00    .00


  471.      173.    23   100     1598.    247846.          0.      .00    .00
  471.      485.    38   100     6764.    340303.          0.      .00    .00
  471.      797.    48   100    14931.    431586.          0.      .00    .00
  471.     1108.    57   100    22092.    521695.          0.      .00    .00
  471.     1420.    63   100    29873.    610631.          0.      .00    .00
  471.     1732.    68    98    40649.    698393.    -435227.      .11  29.55


  942.      502.    30   100     4206.    489070.          0.      .00    .00
  942.     1406.    48   100    19734.    750374.          0.      .00    .00
  942.     2310.    64   100    42968.   1001807.          0.      .00    .00
  942.     3214.    71   100    57259.   1243370.          0.      .00    .00
  942.     4118.    75   100    76077.   1475062.          0.      .00    .00
  942.     5022.    75    90   114448.   1696883.    -970508.     1.81  27.83


 1414.      847.    35   100     6350.    715169.          0.      .00    .00
 1414.     2371.    58   100    24621.   1143806.          0.      .00    .00
 1414.     3896.    70   100    66189.   1544366.          0.      .00    .00
 1414.     5420.    75   100    84254.   1916850.          0.      .00    .00
 1414.     6945.    75    93   138245.   2261257.   -1777244.      .38  34.58
 1414.     8469.    75    86   177019.   2577587.   -1495074.     1.69  33.23


 1885.     1112.    40   100     7758.    903471.          0.      .00    .00
 1885.     3114.    65   100    27956.   1454101.          0.      .00    .00
 1885.     5116.    74   100    83195.   1956326.          0.      .00    .00
 1885.     7117.    75   100   137668.   2410146.          0.      .00    .00
 1885.     9119.    75    92   231543.   2815560.    -137059.     4.75  19.95
 1885.    11121.    75    85   233974.   3172569.   -1074793.     2.68  22.06


 2356.     1232.    42   100     8441.   1051360.          0.      .00    .00
 2356.     3450.    67   100    31190.   1655281.          0.      .00    .00
 2356.     5667.    75   100    96683.   2199790.          0.      .00    .00
 2356.     7885.    75   100   176409.   2684888.   -1354287.     2.19  27.44
 2356.    10103.    75    94   255568.   3110574.      57067.     5.10  19.93
 2356.    12320.    75    84   255291.   3476850.   -1098193.     2.85  21.96
```

Figure A-12 (Cont'd)

SAMPLE SUMMARY OUTPUT WITH MODE=3

```
Iteration # 2 to find optimum Net Present Value w/ following KW & KWh ranges:
   Starting KW % of maximum =    60.000 %     Ending KW % of max=  100.000 %
   Starting KWh% of maximum =    64.000 %     Ending KWh% of max=  100.000 %

Demand     Energy      Maximum     Utility     System         Net  Intrnal     Pay
Shaved   Capacity    Act    Avl     Annual       Cost     Present  Rate of    Back
                     DOD    DOD    Savings                  Value   Return    Time
  (KW)      (KWh)    (%)    (%)        ($)        ($)                        (Yrs)

 1414.      5420.     75    100     84254.   1916850.          0.      .00     .00
 1414.      6030.     75    100    102430.   2057982.          0.      .00     .00
 1414.      6640.     75     95    124827.   2194621.          0.      .00     .00
 1414.      7250.     75     91    151151.   2326769.   -1552332.     1.20   33.68
 1414.      7860.     75     88    177837.   2454424.   -1061005.     2.67   26.96
 1414.      8469.     75     86    177019.   2577587.   -1495074.     1.69   33.23


 1602.      6143.     75    100     89952.   2129798.          0.      .00     .00
 1602.      6834.     75    100    128504.   2283374.          0.      .00     .00
 1602.      7525.     75     96    152344.   2431180.   -1758580.      .81   34.11
 1602.      8217.     75     91    192989.   2573216.    -829163.     3.30   26.32
 1602.      8908.     75     88    201504.   2709482.    -981973.     3.03   26.73
 1602.      9599.     75     86    200986.   2839978.   -1358582.     2.00   27.87


 1791.      6847.     75    100    120906.   2330315.          0.      .00     .00
 1791.      7617.     75    100    156679.   2494567.   -1717630.     1.03   33.85
 1791.      8388.     75     96    200510.   2651651.    -729237.     3.55   26.05
 1791.      9158.     75     91    224780.   2801568.    -378104.     4.30   20.33
 1791.      9928.     75     88    224042.   2944317.    -803214.     3.39   21.28
 1791.     10698.     75     85    223917.   3079898.   -1161457.     2.37   22.26


 1979.      7356.     75    100    148256.   2481941.   -1844076.      .49   34.47
 1979.      8183.     75    100    193891.   2653027.    -860838.     3.27   26.32
 1979.      9011.     75     96    235273.   2815840.      44393.     5.08   19.66
 1979.      9838.     75     90    242275.   2970381.    -172807.     4.68   20.24
 1979.     10666.     75     87    241954.   3116649.    -553464.     3.85   21.25
 1979.     11493.     75     84    241916.   3254644.   -1027479.     2.85   21.94


 2168.      7653.     75    100    162015.   2590650.   -1645479.     1.36   33.47
 2168.      8514.     75    100    214795.   2765386.    -405392.     4.24   25.33
 2168.      9375.     75     96    247554.   2931167.     187578.     5.32   19.46
 2168.     10236.     75     91    252248.   3087993.     -94860.     4.82   20.15
 2168.     11097.     75     88    252070.   3235863.    -495263.     4.01   21.14
 2168.     11958.     75     83    252049.   3374778.    -973122.     3.06   21.80


 2356.      7885.     75    100    176409.   2684888.   -1354288.     2.19   27.44
 2356.      8772.     75    100    229448.   2862292.    -115025.     4.79   19.89
 2356.      9659.     75     96    254168.   3030190.     239484.     5.42   19.60
 2356.     10546.     75     92    255410.   3188583.    -104510.     4.79   20.57
 2356.     11433.     75     86    255306.   3337469.    -617877.     3.80   21.30
 2356.     12320.     75     84    255291.   3476850.   -1098193.     2.85   21.96
```

Figure A-12 (Cont'd)

SAMPLE SUMMARY OUTPUT WITH MODE=3

```
Iteration # 3 to find optimum Net Present Value w/ following KW & KWh ranges:
   Starting KW % of maximum =    84.000 %     Ending KW % of max=  100.000 %
   Starting KWh% of maximum =    71.200 %     Ending KWh% of max=   85.600 %

Demand    Energy    Maximum    Utility    System         Net   Intrnal      Pay
Shaved  Capacity  Act   Avl     Annual      Cost     Present   Rate of     Back
                  DOD   DOD    Savings                 Value    Return     Time
  (KW)     (KWh)  (%)   (%)        ($)       ($)                          (Yrs)

 1979.     8183.   75   100    193890.  2653024.    -860865.      3.27    26.32
 1979.     8514.   75    96    213544.  2719142.    -402987.      4.24    25.35
 1979.     8845.   75    94    231956.  2783937.      15707.      5.03    19.67
 1979.     9176.   75    94    237856.  2847407.      24970.      5.05    19.70
 1979.     9507.   75    91    242623.  2909555.     -24652.      4.96    19.77
 1979.     9838.   75    90    242274.  2970378.    -172833.      4.68    20.24


 2054.     8339.   75   100    204665.  2702419.    -610453.      3.82    25.76
 2054.     8676.   75    97    223245.  2769147.    -192441.      4.65    24.94
 2054.     9013.   75    94    239074.  2834500.     157597.      5.28    19.49
 2054.     9351.   75    94    244458.  2898479.     123355.      5.21    19.55
 2054.     9688.   75    91    247992.  2961083.      79348.      5.15    19.83
 2054.    10025.   75    90    247727.  3022313.     -95129.      4.82    20.15


 2130.     8461.   75   100    212143.  2745427.    -451896.      4.15    25.42
 2130.     8803.   75    96    231175.  2812615.     -19794.      4.96    19.73
 2130.     9145.   75    96    243391.  2878389.     202467.      5.35    19.43
 2130.     9487.   75    94    248747.  2942748.     165782.      5.28    19.49
 2130.     9830.   75    93    251281.  3005693.      86015.      5.16    19.82
 2130.    10172.   75    91    251066.  3067222.     -87378.      4.84    20.14


 2205.     8568.   75   100    217746.  2785284.    -348279.      4.36    25.21
 2205.     8914.   75    97    238456.  2852867.     164720.      5.29    19.48
 2205.     9261.   75    95    246226.  2918998.     206596.      5.36    19.43
 2205.     9608.   75    93    251652.  2983679.     221336.      5.39    19.62
 2205.     9954.   75    92    253125.  3046908.      78885.      5.14    19.87
 2205.    10301.   75    91    252945.  3108687.      -7441.      4.98    20.43


 2281.     8675.   75   100    223861.  2824914.    -226212.      4.59    24.97
 2281.     9026.   75    97    243306.  2892879.     241302.      5.42    19.37
 2281.     9377.   75    94    248883.  2959356.     205100.      5.35    19.43
 2281.     9728.   75    93    254392.  3024346.     222028.      5.39    19.62
 2281.    10079.   75    92    254318.  3087848.      46495.      5.08    19.95
 2281.    10430.   75    92    254173.  3149863.     -60195.      4.88    20.51


 2356.     8772.   75   100    229448.  2862292.    -115024.      4.79    19.89
 2356.     9127.   75    97    245837.  2930592.     244467.      5.42    19.37
 2356.     9482.   75    94    251399.  2997371.     206577.      5.35    19.44
 2356.     9836.   75    94    255759.  3062629.     182676.      5.31    19.68
 2356.    10191.   75    92    255526.  3126366.       1042.      5.00    20.01
 2356.    10546.   75    92    255410.  3188583.    -104510.      4.79    20.57
```

Figure A-12 (Cont'd)

SAMPLE SUMMARY OUTPUT WITH MODE=3

```
Iteration # 4 to find optimum Net Present Value w/ following KW & KWh ranges:
   Starting KW % of maximum =   93.600 %     Ending KW % of max=  100.000 %
   Starting KWh% of maximum =   71.200 %     Ending KWh% of max=   76.960 %

Demand    Energy    Maximum    Utility    System       Net  Intrnal    Pay
Shaved  Capacity   Act   Avl    Annual      Cost   Present  Rate of   Back
                   DOD   DOD   Savings               Value   Return   Time
  (KW)     (KWh)   (%)   (%)       ($)       ($)                     (Yrs)

 2205.     8568.    75   100   217746.  2785284.   -348279.     4.36  25.21
 2205.     8706.    75   100   224525.  2812491.   -205779.     4.63  24.95
 2205.     8845.    75    98   233784.  2839466.     24274.     5.04  19.66
 2205.     8984.    75    96   241346.  2866209.    219480.     5.39  19.40
 2205.     9122.    75    96   244095.  2892720.    223478.     5.39  19.40
 2205.     9261.    75    95   246226.  2918998.    206596.     5.36  19.43


 2235.     8611.    75   100   220161.  2801163.   -300601.     4.45  25.12
 2235.     8750.    75   100   226979.  2828434.   -156974.     4.72  19.95
 2235.     8889.    75    98   237020.  2855470.    123815.     5.22  19.55
 2235.     9029.    75    96   242899.  2882272.    236390.     5.42  19.38
 2235.     9168.    75    96   245139.  2908839.    222357.     5.39  19.40
 2235.     9307.    75    94   247319.  2935171.    206982.     5.36  19.43


 2266.     8654.    75   100   222630.  2817006.   -250948.     4.54  25.02
 2266.     8794.    75   100   229876.  2844340.    -92577.     4.83  19.85
 2266.     8934.    75   100   240315.  2871436.    202006.     5.36  19.43
 2266.     9074.    75    96   244022.  2898296.    238340.     5.42  19.38
 2266.     9214.    75    96   246171.  2924919.    220910.     5.38  19.41
 2266.     9354.    75    94   248336.  2951305.    204803.     5.35  19.43


 2296.     8697.    75   100   225048.  2832813.   -202995.     4.64  24.93
 2296.     8837.    75   100   233074.  2860209.    -17559.     4.97  19.73
 2296.     8978.    75   100   242264.  2887365.    233177.     5.41  19.38
 2296.     9119.    75    96   245045.  2914282.    236883.     5.41  19.38
 2296.     9259.    75    96   247211.  2940960.    219837.     5.38  19.41
 2296.     9400.    75    94   249429.  2967398.    205383.     5.35  19.43


 2326.     8736.    75   100   227346.  2847946.   -156932.     4.72  19.95
 2326.     8878.    75   100   236122.  2875398.     54541.     5.10  19.62
 2326.     9019.    75   100   243594.  2902609.    245026.     5.43  19.37
 2326.     9160.    75    96   246041.  2929578.    236843.     5.41  19.38
 2326.     9302.    75    96   248221.  2956306.    220094.     5.38  19.41
 2326.     9443.    75    94   250416.  2982792.    204650.     5.35  19.44


 2356.     8772.    75   100   229448.  2862292.   -115024.     4.79  19.89
 2356.     8914.    75   100   238810.  2889795.    140414.     5.24  19.52
 2356.     9056.    75   100   244765.  2917054.    254048.     5.44  19.36
 2356.     9198.    75    96   246962.  2944069.    236937.     5.41  19.39
 2356.     9340.    75    96   249161.  2970842.    220681.     5.38  19.41
 2356.     9482.    75    94   251399.  2997371.    206577.     5.35  19.44
```

Figure A-12 (Cont'd)

SAMPLE SUMMARY OUTPUT WITH MODE=3

```
Iteration # 5 to find optimum Net Present Value w/ following KW & KWh ranges:
   Starting KW % of maximum =   97.440 %     Ending KW % of max=  100.000 %
   Starting KWh% of maximum =   72.352 %     Ending KWh% of max=   74.656 %

Demand    Energy     Maximum     Utility     System           Net  Intrnal    Pay
Shaved  Capacity   Act    Avl     Annual       Cost       Present  Rate of   Back
                   DOD    DOD    Savings                    Value   Return   Time
 (KW)      (KWh)   (%)    (%)        ($)        ($)                         (Yrs)

 2296.     8837.    75    100    233074.   2860211.       -17564.     4.97  19.73
 2296.     8894.    75    100    236786.   2871102.        97989.     5.18  19.59
 2296.     8950.    75    100    241424.   2881955.       222590.     5.39  19.40
 2296.     9006.    75     98    242827.   2892770.       234089.     5.41  19.38
 2296.     9062.    75     97    244173.   2903546.       243717.     5.43  19.37
 2296.     9119.    75     96    245045.   2914284.       236878.     5.41  19.38


 2308.     8855.    75    100    234394.   2866548.        13895.     5.02  19.68
 2308.     8911.    75    100    238112.   2877449.       129659.     5.23  19.54
 2308.     8968.    75    100    241875.   2888311.       223599.     5.39  19.40
 2308.     9024.    75    100    243541.   2899135.       244268.     5.43  19.37
 2308.     9080.    75     97    244587.   2909921.       243362.     5.42  19.37
 2308.     9137.    75     96    245495.   2920668.       237748.     5.41  19.38


 2320.     8870.    75    100    235542.   2872516.        40619.     5.07  19.64
 2320.     8927.    75    100    239265.   2883425.       156559.     5.27  19.50
 2320.     8983.    75    100    242153.   2894296.       219842.     5.39  19.41
 2320.     9040.    75    100    244078.   2905128.       249545.     5.44  19.36
 2320.     9096.    75     97    244954.   2915921.       242657.     5.42  19.37
 2320.     9153.    75     96    245828.   2926676.       235824.     5.41  19.39


 2332.     8885.    75    100    236616.   2878280.        89041.     5.16  19.60
 2332.     8941.    75    100    240393.   2889197.       183285.     5.32  19.46
 2332.     8998.    75    100    242488.   2900076.       218784.     5.38  19.41
 2332.     9055.    75    100    244468.   2910915.       250382.     5.44  19.36
 2332.     9111.    75     97    245347.   2921716.       243571.     5.42  19.37
 2332.     9168.    75     96    246219.   2932479.       236639.     5.41  19.39


 2344.     8899.    75    100    237737.   2884040.       115563.     5.21  19.56
 2344.     8956.    75    100    241154.   2894964.       197177.     5.35  19.44
 2344.     9013.    75    100    242990.   2905851.       223581.     5.39  19.40
 2344.     9069.    75    100    244814.   2916698.       249691.     5.43  19.36
 2344.     9126.    75     97    245686.   2927507.       242605.     5.42  19.38
 2344.     9183.    75     96    246568.   2938276.       235995.     5.41  19.39


 2356.     8914.    75    100    238810.   2889795.       140414.     5.24  19.52
 2356.     8971.    75    100    241541.   2900727.       197989.     5.35  19.44
 2356.     9027.    75    100    243572.   2911622.       231188.     5.40  19.39
 2356.     9084.    75    100    245203.   2922476.       250514.     5.43  19.36
 2356.     9141.    75     97    246080.   2933292.       243575.     5.42  19.38
 2356.     9198.    75     96    246962.   2944069.       236937.     5.41  19.39

Optimum Battery:  Demand            =        2356.00 (KW)
                  Capacity          =        9055.88 (KWh)
                  Net Present Value= $     254047.90
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