01 Jan 1990

Economic Models For Battery Energy Storage: Improvements For Existing Methods

Ronald C. Reckrodt

Max Darwin Anderson
Missouri University of Science and Technology, mda@mst.edu

Raymond Michael Kluczny
Missouri University of Science and Technology, rkluczny@mst.edu

Recommended Citation

R. C. Reckrodt et al., "Economic Models For Battery Energy Storage: Improvements For Existing Methods," *IEEE Transactions on Energy Conversion*, vol. 5, no. 4, pp. 659 - 665, Institute of Electrical and Electronics Engineers, Jan 1990.
The definitive version is available at https://doi.org/10.1109/60.63136

IEEE Transactions on Energy Conversion, Vol. 5, No. 4, December 1990

ECONOMIC MODELS FOR BATTERY ENERGY STORAGE: IMPROVEMENTS FOR EXISTING METHODS

Ronald C. Reckrodt
Missouri Public Service Company

Max D. Anderson, Senior Member

Raymond M. Kluczny
University of Missouri-Rolla
Rolla, Missouri

Abstract - While the technology required to produce viable Battery Energy Storage System exists, the economic feasibility (cost vs. benefits) of building these systems requires justification. First, a generalized decision diagram was developed to ensure that all of the economic factors were considered and properly related for the customer-side-of-the meter. Next, two economic models that had consistently given differing results were compared. One was the McKinney model developed at UM-Rolla in 1987; the second was the SYSPLAN model developed by Battelle.

Differences were resolved on a point by point basis with reference to the current economic environment. The economic model was upgraded to include the best of both models based on the resolution of these differences. The upgrades were implemented as modifications to the original SYSPLAN (1986 version) to preserve user friendliness.

Four specific cases were evaluated and compared. The results were as predicted, since comparison was made with two known models.

Key Words: Battery Energy Storage, Peak Shaving, Load Leveling, Power Distribution Systems.

INTRODUCTION

The electric utility industry is concerned with the cyclic disparity between on-peak and off-peak energy demands that currently exist. On-peak energy demands require the expense of adequate generation; however, this generating capacity will sit idle during off-peak periods when it is not needed. While demand side management systems are effective for peak shaving, battery energy

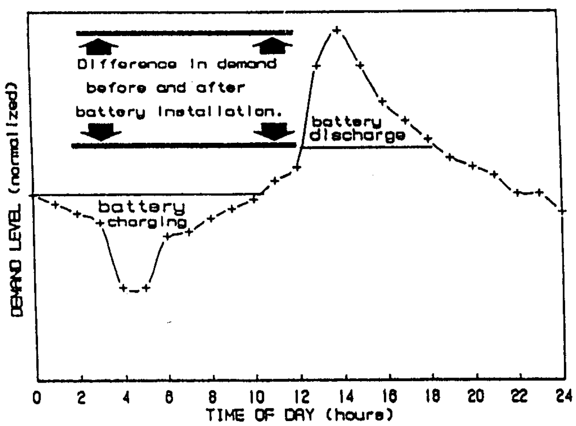


Figure 1. Example of Typical Daily Cyclic Load Profile

90 SM 431-7 EC A paper recommended and approved by the IEEE Energy Development and Power Generation Committee of the IEEE Power Engineering Society for presentation at the IEEE/PES 1990 Summer Meeting, Minneapolis, Minnesota, July 15-19, 1990. Manuscript submitted January 31, 1990; made available for printing May 18, 1990.

storage should prove to be a feasible augmentation to demand side management (customer-side-of-meter). In addition to better use of energy resources, some of the major advantages to be gained from battery energy storage are:

1. Load leveling
2. Quick response emergency power (spinning reserve).
3. Frequency and voltage control.
4. Deferred generation and transmission capacity construction.

Given the example cyclic daily load profile shown in Figure 1, it can be seen that load leveling will decrease the peak demand. Total economic impact depends on two factors;

1. System parameters which include battery size (power and energy), converter size, efficiency and other factors affecting the cost of the system.

2. The rate structure environment in which the system resides, specifically, demand and energy charges. Also included are interruptible load riders and any other specific contractual agreements between supplier and user that impact potential savings.

LITERATURE REVIEW

Work has been done toward development and analysis of various battery energy storage (BES) system configurations. This work has progressed in the areas of economics [1, 2, 3, 4, 5] and technology [6, 7, 8]. Much (if not all) of the technical data and know how is currently available on a commercial basis. EPRI has been very active in the areas of research and development [3, 4, 5]. All equipment and components have been developed and are commercially available at this time. Economic models are available both on a commercial basis [5] and as public domain software [1, 2].

OBJECTIVES

1. Energy Considerations. One of the potential benefits of BES technology is the possibility of deferring generation and transmission equipment procedure. Large scale acceptance of BES at the customer level would allow utility and generating unit managers to improve their load factor. Any improvement in the load factor would represent a more efficient use of energy resources, both natural and human.

2. Economic Factors. Because economics play such a dominating rule in business, it is imperative that reliable unambiguous economic models be made available to investors and decision makers.

Two models currently available are SYSPLAN, developed by Battelle [2], and the McKinney model [1] developed by Brent McKinney at the University of Missouri-Rolla. Both of these models produce results relating to specific economic points of interest on a spreadsheet format. These two models may produce significantly different end results. These differences occur in several categories including the areas of payback period and internal rate of return. Investors in the business sector are sensitive to variations in specific economic measures, and they will make decisions on projects based on the Minimum Attractive Rate of Return (MARR) or payback periods.

The objective of this effort is to define an unambiguous (standardized) model that gives accurate results for battery energy storage systems. As a minimum the model should;

1. Be capable of giving accurate results for both prototype and mature market systems.
2. Be adaptable to any rate environment from demand charge to time-of-day rates with little or no internal modification.
3. Have the ability to adjust, for maturing technology.

TASK STATEMENT

The problem was to develop generic economic model for large scale Battery Energy Storage. Overall work took place in four basic task modules.

1. Design a decision diagram that represented all possible economic considerations that could be encountered in a BES system. This task is presented in the "Influence Diagram" section below.
2. Use available public domain software models along with the results of task number one to develop a more complete and flexible software model.
3. Develop the modeling program capable of providing more decision making information to the user.
4. Compare specific cases. A straightforward comparison is presented in the "Results and Conclusions" section.

MODELING TECHNIQUES

The first task was to determine a method of development for a generic (standardized) model. By using a "Top down" design, a generalized explanation that progresses naturally into specifics is provided. For example, the term "economic measures" can be made more specific by breaking it up into factors such as cash flow, rate of return (ROR), present worth, payback, etc. Next, the model should be presented on two formats, as a decision diagram and as algorithms. The decision diagram representation is the predecessor to the algorithms in that a general model description can be more easily carried out from the decision diagram format. The tradeoff afforded is that the inherent generality manifest in a decision diagram format is inversely proportional to the amount of specifics one wishes to represent. An in-depth analysis can be accomplished using the algorithms. The decision diagram model seemed appropriate because it very closely resembled a decision making model in both structure and content. The means by which the model would be represented was chosen to be the "Influence Diagram" as described by Bodily [8]. This model building and decision making methodology was chosen because of it's flexibility and depth. The flexibility stems from the method's ability to accurately represent the many types of relationships that can exist in any abstract concept. The depth is available because of the manner in which the model building methodology allows for any category or concept to be broken up into more specific sub-categories or concepts without substantial loss of clarity. The depth of the model is at the designer's discretion. Finally, the influence diagram as described will be a representation of all decisions, intermediate variables, and outcome attributes that pertain to the problem.

An attribute is a measurable aspect of an objective. For example, if an objective is to maximize profit, some possible attributes are: rate of return, cash flow, and payback period. Attributes are depicted in the influence diagram as ovals. The circle is used to signify an intermediate variable. A rectangle represents a decision variable. These properties are shown in more detail for the BES Economic model developed in the next section.

ECONOMIC MODEL OF A BES SYSTEM

Avoided costs for electric utility customers are greatly dependent on the rate structure and will be the result of demand reduction. It is shown in Figure 1 that, given an appropriate customer load profile, a substantial demand reduction can be obtained. Depending on the rate structure environment, this application could represent a substantial savings. Assuming the peak shaving system has energy storage capability, such as a battery, it would need to be charged during an off-peak time period. The disparity in energy prices plays a part here because charging the energy storage device during off-peak periods should provide a lower cost for each unit of energy.

Customer Demand (kW) Requirements, defined by the load profile, are used to determine the Technical Specifications; e.g., peak shaving capacity in kW for battery and converter, battery energy capacity in kWhr, and other equipment sizes and capacities required for a system specification. The Economic Environment affects the width of the peak (kWhr) that the BES system should be designed to serve. These relationships are depicted in Figure 2.

While Economic Environment and customer Demand Requirements both influence the Technical Specifications decisions, these are not division variables. The individual customer has little, if any, influence on economic factors such as taxes, utility rates, and interest rates. Conversely, the customer does have a measured amount of influence on his own demand requirements.

A Capital Investment value requires these Technical Specifications in order to determine prices of major components. As McKinney [1] discussed, major component prices (battery, power conditioning system, and balance of plant) are determined by formula related to the size of the battery system.

Once Technical Specifications have been decided, Technical Performance can be determined. These data will be available through the manufacturer and consist of items such as component efficiency, cycle life of the battery, etc. Technical Performance has a direct influence on operation and maintenance (O & M) costs. This becomes more evident when one considers the difference in one aspect of the system, the batteries. The O & M costs for sealed cell batteries are much lower than the same costs for conventional lead acid batteries. (Reference preliminary data from SCE Chino facility [5].) The latter requires periodic specific gravity checks and electrolyte replenishment while the sealed cell batteries are purported to be maintenance free. The significance of Figure 2 is that it represents all variables having an effect on the final model.

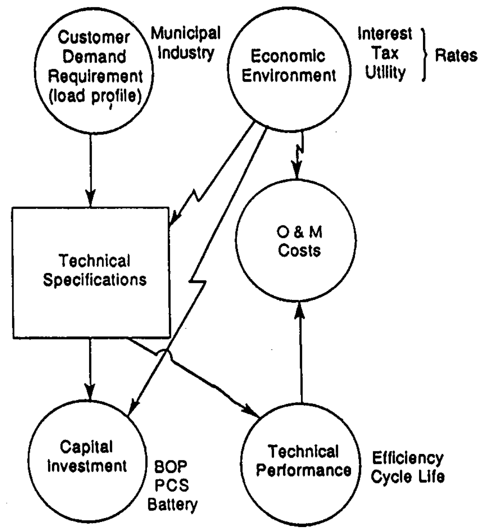


Figure 2. Influence Diagram Without Attributes

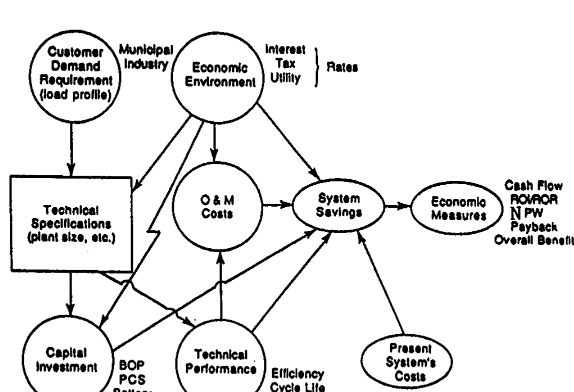


Figure 3. Final Influence Diagram in General Form

The final model contains attributes added to answer economic questions: How much did it cost then? How much will a new system save now? Figure 3 represents the final version of our decision diagram model. The outcome attributes, System Savings and Present System Costs are shown. Present System Costs is required as a reference value by which to measure System Savings. All items of economic importance are accounted for in Figure 3. The influence diagram shown here represents a general form of the economic model for a BES system. The flexibility and depth available in the model is shown in the attribute System Saving, Figure 4. This attribute can be broken down into various sub-categories such as return on investment (ROI), net present worth (NPW), cash flow, payback period, and overall benefit. This illustrates the model's design flexibility and depth, which become tools for the designer. Any, or all, or the attributes can be displayed as shown in Figure 4. This modeling technique provides traceability of the BES design specifications to all of the requirements and economic factors.

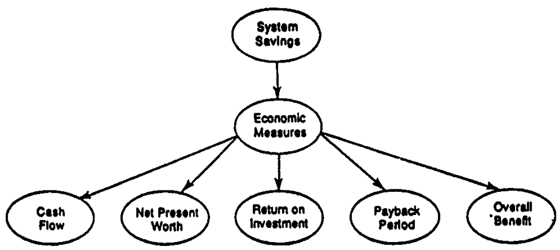


Figure 4. Demonstration of Influence Diagram Flexibility

COMPUTER SOFTWARE DEVELOPMENT: MODIFICATION FOR SYSPLAN

Two choices were available for software implementation of the economic model. 1.) Modify McKinney's program written in IFPS. This was done to a limited extent when a spreadsheet version (in QUATTRO) was made to enable algorithmic comparisons with SYSPLAN. 2.) Modify SYSPLAN to incorporate the improved economic model. The latter was chosen for the following reasons. First, SYSPLAN is more aesthetic and presents a user friendly environment. Second, because SYSPLAN has additional features built in such as battery sizing and graphing routines. In addition to these routines SYSPLAN also has a built in sensitivity analysis. Provisions have also been made for a much broader range of rate schedule types such as time of day (TOD), monthly, and seasonal rate schedules. The User's Guide for SYSPLAN [2] is adequate for the modified version. Samples of the modified Input Data Forms are shown in Figures 5 and 6. A detailed description of the changes is given in reference [1].

****

UTILITY: UM-ROLLA TEST 4

OFF-PEAK CHARGES

MONTH	ENERGY CENTS/KWH	DEMAND $/KW-MONTH
1	1.27	0.00
2	1.27	0.00
3	1.26	0.00
4	1.27	0.00
5	1.26	0.00
6	1.27	0.00
7	1.26	0.00
8	1.27	0.00
9	1.26	0.00
10	1.27	0.00
11	1.26	0.00
12	1.27	0.00

ON-PEAK CHARGES

MONTH	ENERGY CENTS/KW	DEMAND $/KW-MONTH
1	1.40	13.59
2	1.40	13.59
3	1.40	13.59
4	1.40	13.59
5	1.40	13.59
6	1.40	13.59
7	1.40	13.59
8	1.40	13.59
9	1.40	13.59
10	1.40	13.59
11	1.40	13.59
12	1.40	13.59

****

Figure 5. Demand and Energy Charges Input Data

****

BATTERY SYSTEM DESCRIPTION

SYSTEM REQUIREMENTS
BASED ON BATTERY DUTY CYCLE:

MINIMUM DISCHARGE DURATION (HRS)	2.00
MAXIMUM PEAK SHAVED (MW)	1.00
REQUIRED BATTERY CAPACITY (MWH)	2.00
REQUIRED BATTERY POWER	1.00

PROPOSED BATTERY SYSTEM:

BATTERY EFFICIENCY	71.33 %
BATTERY CAPACITY (MWH)	2.00
BATTERY POWER (MW)	1.00
BATTERY LIFE (CYCLES)	2000
CHARGE/DISCHARGE POWER RATIO	0.50
ONE WAY CONVERTER EFFICIENCY	97.10 %
ROUND TRIP EFFICIENCY	67.13%

****

BATTERY SYSTEM COST, ESCALATION RATES AND TAX DATA

INSTALLED BATTERY COST	249.00 $/KWH
INSTALLED CONVERTER COST	282.00 $/KW
INSTALLED BALANCE OF PLANT COST	123.75 $/KWH
ANNUAL O & M COST ($/KWH)	0.80
LOST ENERGY (KWH/CYCLE)	657.44
SALVAGE VALUE (PERCENT OF BATTERY COST)	11.00 %
CAPITAL COST ESCALLATION RATE	5.00 %
O & M COST ESCALATION RATE	4.50 %
DEMAND CHARGE ESCALATION RATE	4.50 %
ENERGY CHARGE ESCALATION RATE	4.50 %
FRACTION OF FIRST YEAR ON LINE	1.00
INVESTMENT TAX CREDIT RATE	0.00 %
SALES TAX RATE	5.00
FEDERAL TAX RATE	34.00 %
EFFECTIVE INCOME TAX RATE	37.30 %
DISCOUNT RATE FOR PRESENT WORTH ANALYSIS = 8.0	12.5 %

****

Figure 6. System Description and Economic Environment Input Section

DESCRIPTION OF PROGRAM OUTPUT

Most of the economic output values for the author's modified version of SYSPLAN are contained in the spreadsheet labelled 'SYSPLAN ECONOMIC ANALYSIS SUMMARY'. This contains twenty years of annual values and is divided into four major subjects; 1) Savings 2) Expenses 3) Taxable income and 4) Net income. The modified version of this output section is shown for the base case inputs as Figure 7. Note that all values are in thousands of dollars (e.g., 163.1 across from "DEMAND CHARGE REDUCTION" and under "1990" actually represents $163,100). Also note that program output items that follow are enclosed in quotation marks.

1. Savings. Below this heading the items represented are "DEMAND CHARGE REDUCTION" and "BATTERY SALVAGE VALUE".

a. "Demand Charge Reduction". This qualifies the system savings due to peak shaving. The numbers represented in this row are determined by multiplying the kW's of demand reduced by the

SYSPLAN ECONOMIC ANALYSIS SUMMARY (THOUSANDS OF DOLLARS) YEAR:	1990	1991	1992	1993	1994
SAVINGS:					
DEMAND CHARGE REDUCTION	163.1	170.4	178.1	186.1	194.5
BATTERY SALVAGE VALUE	0.0	0.0	0.0	0.0	0.0
TOTAL SAVINGS ------->	163.1	170.4	178.1	186.1	194.5
EXPENSES:					
ENGINEERING COSTS	237.9	0.0	0.0	0.0	0.0
ENERGY CHARGE INCREASE	1.3	1.4	1.4	1.5	1.5
ANNUAL O & M COST	1.7	1.7	1.8	1.9	2.0
COST OF LOST ENERGY	0.9	0.9	0.9	1.0	1.0
TAX DEPRECIATION	180.8	289.3	173.6	104.1	104.1
TOTAL EXPENSES	422.5	293.3	177.7	108.5	108.7
TAXABLE INCOME	-259.4	-122.9	0.3	77.6	85.8
LESS: INCOME TAXES	-96.8	-45.8	0.1	28.9	32.0
PLUS: INVESTMENT TAX CREDITS	0.0	0.0	0.0	0.0	0.0
NET INCOME	-162.7	-77.0	0.2	48.6	53.8
PLUS: TAX DEPRECIATION	180.8	289.3	173.6	104.1	104.1
LESS: BATTERY COSTS	498.0	0.0	0.0	0.0	0.0
LESS: CONVERTER COSTS	282.2	0.0	0.0	0.0	0.0
LESS: BALANCE-OF-PLANT COSTS	247.5	0.0	0.0	0.0	0.0
NET BEFORE-TAX CASH FLOW	-868	166	174	182	190
NET AFTER-TAX CASH FLOW	-1010	212	174	153	158
CUM. AFTER-TAX CASH FLOW	-1010	-797	-624	-471	-313
NET PRESENT WORTH @ 8.0 %	-935	-753	-615	-503	-395
NET PRESENT WORTH @ 12.5 %	-897	-730	-608	-512	-425
AFTER-TAX RETURN ON INVESTMENT		ERR	-46.7	-27.0	-14.0
PAYBACK PERIOD	8.00				
20 YEAR PRESENT WORTH @ 8.0 %	561				

Figure 7. First Five Years of "SYSPLAN ECONOMIC ANALYSIS SUMMARY"

battery, times the demand charge, times the escalation rate. In a mathematical format the first year's equation is:

$$\beta(\$) = \left[\sum_{i=1}^{12} \chi_i(kW)\gamma_i(\$/kW)\right](1+\varepsilon)$$

where: β = Demand Charge Reduction in thousands of dollars.
χ = Peak kW demand reduced in month i (reset monthly)
γ = Price of capacity power per kW for month i
ε = Demand charge in $ escalation rate. (annual)

Subsequent years are determined by using the previous year value and multiplying it by the demand charge escalation rate plus one. A constant escalation rate throughout the twenty year life of the model is assumed in the examples.

b. "Battery Salvage Value". This savings occurs only when the battery is replaced. The value is a result of reclamation of the lead still remaining in the battery. Most systems considered profitable will show payback and positive return on investment within the first five to ten years. With this in mind, note that a battery life of fifteen or twenty years will not impact these values unless a heavy usage of the battery (more than 250 cycles per year) will cause the battery to be replaced earlier.

2. Expenses. Of particular importance here is the afore mentioned addition of "ENGINEERING COSTS". The remaining values were all given in the original SYSPLAN model. These costs, along with the three other components, make up the remainder of the EXPENSES section. The sum of all four expenses gives the "TOTAL EXPENSES".

a. "Engineering Costs". Bechtel; [4] has determined that $161,000 engineering costs (1985 dollars) for a plant cost of $860,000 or less is appropriate. At an annual average inflation rate of 5% these numbers translate to $237,870 and $1,045,300 for the same values respectively (1989 dollars). Given these data and plant size the method of determining the engineering costs for a system whose total plant cost is above $1.05 million is given below; [6]

$$\text{Engineering cost} = [188{,}000 \times \zeta \times e^{(-\zeta/857)}] \times (E)$$

where: ζ = Plant cost in millions of dollars.
E = Capital escalation rate (adjusted to 1989 dollars).

b. "Energy Charge Increase". This will represent a savings only if the disparity in off-peak and on-peak energy charges is sufficient in magnitude to offset the systems inefficiencies. As such the number shown in this row will be negative . If it is an expense (as will be the case under most rate structures), this number will be positive (see Figure 7). An equation showing the method of determination is shown below for the first year:

Energy charge increase($) =

$$((P_{off\text{-}peak})/\Gamma - P_{on\text{-}peak}) \times (1+\varepsilon) \times P \times \#year$$

where:

$P_{on\text{-}peak}$ = On-peak energy charge ($/KWH).
$P_{off\text{-}peak}$ = Off-peak energy charge ($/KWH).
Γ = Round trip efficiency of the system.
ε = Energy escalation rate.
P = Battery size in (KWH).
$\#year$ = The number of cycles per year.

As with the other quantities dealing with escalation rates, subsequent years are determined by multiplying the previous year's value by the escalation rate plus one.

c. "Annual O & M Cost". This is a tax deductible item. In the interest of generality, operation and maintenance cost would also account for any "unexpected" expenses. An example of this type of expense is toxic liquid clean up and disposal, in the case of an acid spill from the batteries.

d. "Cost of Lost Energy". This is a cost due to inefficiency of the battery and converter cost. This cost is also an expense and will be nearly constant for the life of the system as long as battery and converter efficiencies remain the same.

e. "Tax Depreciation". Tax laws are assumed to remain constant for the twenty year life of the model. Depreciation is listed under "EXPENSES" because it is the method for which the owner is allowed to recover initial project construction and equipment costs.

3. Taxable Income. This item is determined by subtracting "TOTAL EXPENSES" from "TOTAL SAVINGS". Income taxes are subtracted from this number and investment tax credits are added to it giving "NET INCOME".

a. "Income Tax". This tax is a combination of both federal and state income tax values. The method of determining this value is not as straightforward as expected because the state taxes are an allowable deduction when considering federal taxes. Federal taxes are not, however, generally deductible in the computation of state taxable income. Therefore, the state income tax is applied to a larger taxable income than the federal income tax rate. As a result the combined incremental tax rate will not be the sum of the two tax rates. The method of derivation is borrowed from Newnan [11].

For an increment of income; $\Delta Income$
State income taxes = $\Delta T_{state} \times \Delta Income$
Federal taxable income = $\Delta Income \times (1 - \Delta T_{state})$
or; Federal taxable income = $\Delta T_{fed} \times \Delta income \times (1 - \Delta T_{state})$

Therefore the final incremental tax rate (also referred to as effective income taxrate) will be;

$$\Phi = \Delta T_{state} + \Delta T_{fed} \times (1 - \Delta T_{state})$$

where: ΔT_{state} = Incremental state tax rate.
ΔT_{fed} = Incremental federal tax rate.

SYSPLAN uses this convention while the McKinney Model implements another method involving "contingency rates and "K" factors". This tax system ("K" factors) is generally not used because of recent tax law changes. Contingency rates may be added in if deemed necessary. Contingency is largely subjective in an emerging market and becomes irrelevant in the mature market environment. If an investor wants this included, 5% is the current standard. This could be added to the unit price of the basic system components.

b. "Investment Tax Credits". These are currently not available for BES systems according to the St. Louis office of the IRS. Prior to The Tax Reform Act of 1986, investment tax credits did exist for this type of system. Although "zeroed out" this item will be left in the spreadsheet, because some forms of alternative energy sources do still qualify. Because we cannot predict if or how any future tax relief will effect the system, a generic investment tax credit is impossible to develop. For this reason the current method used by SYSPLAN will remain intact. Briefly, this method gives tax relief on the initial investment of PCS, battery, and half of the BOP.

4. Net Income. Net Income is obtained by taking "TAXABLE INCOME" and subtracting income taxes, then adding investment tax credits (if any). This value will then be modified by tax depreciation and equipment (also construction) costs to provide cash flow analysis data.

a. "Tax Depreciation". This item has been discussed in a previous section and is reflected in the output description. Note that tax depreciation is zero beyond the sixth year. The only other time depreciation plays a role is when a new component is placed into service. In most cases this "new" component will be the replacement batteries.

b. Battery, Converter, and BOP. In all years except the first (and battery replacement) years, this value will be zero.

c. Cash Flows. "Net Before-Tax Cashflow" represents the annual net revenue flow due to the installed system. This value is determined by subtracting the following values from "TOTAL SAVINGS"; 1) Energy Charge Increase 2) Annual O & M costs 3) Auxiliary Power costs 4) Battery cost 5) Power Conditioning System cost and 6) Balance of Plant cost.

d. "Net After-Tax Cashflow" is determined by the equation:

$$\text{Net After-Tax Cashflow} = I_{Net} + T_{depreciation} - \Omega_{battery} - \Omega_{PCS} - \Omega_{BOP}$$

where:

I_{Net} = Net Income

$T_{depreciation}$ = Tax Depreciation

$\Omega_{battery}$ = Battery costs

Ω_{PCS} = Power Conditioning System costs

Ω_{BOP} = Balance of Plant costs

e. "Cumulative After-Tax Cashflow". This cashflow value will account for total "Net After-Tax Cashflow" up to the year in question. For example, the first year's "Cumulative After-Tax Cashflow" is the same as the first year "Net After-Tax Cashflow" value. The second year value consists of the second year "Net After-Tax Cashflow" plus the first year's cumulative value. All subsequent years are handled in the same manner.

f. "Net Present Worth". NPW is determined by discounting the future value back to the present value. The discount value (interest rate) used is the one supplied by the input section "BATTERY SYSTEM COST, ESCALATION RATES, AND TAX DATA" shown in Figure 6. This method allows the user to enter an expected high and low interest rate, to "bracket" NPW.

RESULTS

Results in the form of a tabular comparison for the base case are shown in Table I. All three models are represented with their respective values for, 1) Twenty year Net Present worth (NPW), 2) Twenty year Return On Investment (ROI), and 3) payback period. Results for three additional cases are shown in Table II-IV. As evidenced by these results, SYSPLAN is the most optimistic while the McKinney Model is the least. The modified version is between the other two for virtually all values. Inputs used are shown as the first two pages of Appendix A of reference [13].

Table I.
COMPARISON OF MODEL OUTPUTS (BASE CASE)
(1 MW, 2 HR Battery)

20 YEAR			PAYBACK PERIOD
MODEL	NPW	ROI	
SYSPLAN	665	20.7%	6
MCKINNEY	415	11.8%	14
RECKRODT	561	15.4%	8

NPW values in table are in thousands of dollars.

Table II.
COMPARISON OF MODEL OUTPUTS (CASE TWO)
(500 KW, 1 HR Battery)

20 YEAR			PAYBACK PERIOD
MODEL	NPW	ROI	
SYSPLAN	591	53.1%	3
MCKINNEY	15.9	10.8%	14
RECKRODT	345	18.5%	7

NPW values in table are in thousands of dollars.

Table III.
COMPARISON OF MODEL OUTPUTS (CASE THREE)
(1 MW, 3 HR Battery)

20 YEAR			PAYBACK PERIOD
MODEL	NPW	ROI	
SYSPLAN	290	12.0%	9
MCKINNEY	-168	6.3%	20+
RECKRODT	-100	6.9%	20+

NPW values in table are in thousands of dollars.

Table IV.
COMPARISON OF MODEL OUTPUTS (CASE FOUR)
(1 MW, 1/2 HR Battery)

20 YEAR			PAYBACK PERIOD
MODEL	NPW	ROI	
SYSPLAN	944	> 100%	3
MCKINNEY	9	12.3%	12
RECKRODT	644	23.1%	6

NPW values in table are in thousands of dollars.

CONCLUSION

Improvements over both the McKinney and SYSPLAN models were implemented. These include the additions of converter cost, engineering cost, auxiliary power requirements, O & M costs and conversion from ACSR to MACRS to be consistent with changes in the tax laws that began in 1986. All of the improvements were implemented in the form of modifications to SYSPLAN rather than McKinney's IFPS program, to have a program that is more user friendly on the PC, and one that allows for macro execution under Borland's QUATTRO with compatibility for LOTUS 123.

The modified version is the result of an investigation into current standards and practices in engineering economics as well as power distribution engineering; hence, more accurate results are returned to the user. Comparisons have shown that this program generally returns values between the more conservative McKinney model and the more optimistic SYSPLAN model; however the

results do not follow a linear relationship between the two extremes. (See Tables I - IV).

Finally, this program provides the following benefits: 1) more general than previous versions and models, 2) the economic factors and their relationships are traceable through the "influence diagram", 3) erroneous (or outdated) assumptions have been addressed, 4) the user friendliness of the SYSPLAN model has been preserved, and some improvements have been made.

ACKNOWLEDGEMENTS

The authors greatly appreciate the project support provided by the International Lead Zinc Research Organization, Inc. (ILZRO) and for early graduate student support provided by the Union Electric Company.

Our thanks is given to Battelle Pacific Northwest Labs for providing SYSPLAN and C. J. Hostick and K. Humphreys for their help.

GLOSSARY

ACRS (Accelerated Cost Recovery System): a depreciation system requiring that a cost recovery allowance be computed on the unadjusted cost of the property being recovered.

MACRS (Modified Accelerated Cost Recovery System): a depreciation system prescribed by the Tax Reform Act of 1986 which retains most of the concepts of ACRS, but does increase the period of cost recovery and does change the accelerated method of depreciation to 200 percent declining balance.

MARR (Minimum Attractive Rate of Return): the lowest acceptable rate of return at which a project would be considered for investment, usually considered to be the opportunity cost for not being able to invest in the next best available alternative.

NPW (Net Present Worth): a capital investment evaluation method based on future cash flows that are discounted back to their present value before being used to support a capital expenditure decision.

Payback Period: a capital investment evaluation method based on the time required to recoup the original investment through the cash flow from the project.

Return on Investment (Rate of Return): an index of the profitability of an investment which is defined as the interest rate that reduces the net present worth of a series of receipts and disbursements to zero.

REFERENCES

1. Brent McKinney, An Assessment of Large Scale Battery Energy Storage For Industrial Loads, M.S. Thesis, University of Missouri-Rolla, 1987, also North American Power Symposium, Purdue University, Sept. 1988.

2. Hostick, Hutchison, and Winter, SYSPLAN: Model Documentation and Users Guide, US Department of Energy Contract DE-AC06-76RLO 1820, January 1986.

3. Battelle-Columbus Division, Load-Leveling Lead-Acid Battery System for Customer-Side Applications, Market Potential and Commercialization Strategy, Project 1084-21, Report AP/EM-5895, Electric Power Research Institute, July 1988.

4. Bechtel Group, Inc., Design and Cost of Standardized Lead-Acid Battery Systems for Utility Energy Management, Project 1275-12, Report EM-4200, Electric Power Research Institute, August 1985.

5. Bechtel Group, Inc., Design and Costs for a Generic 10-MW Utility Lead-Acid Battery Energy Storage Plant, Project 2123-6, Report AP-5845, Electric Power Research Institute, June 1988.

6. Bechtel Group, Inc., Updated Cost Estimate and Benefit Analysis of Customer-Owned Battery Energy Storage, Project 1275-12, Report EM-3872, Electric Power Research Institute, January 1985.

7. John Douglas, "The Future of Transmission: Switching to Silicon", EPRI JOURNAL, June 1989, pp. 4-12.

8. S. E. Bodily, Modern Decision Making, McGraw Hill, Inc., 1985.

9. Depreciation, Publication 534, Department of Treasury Internal Revenue Service, (Rev. Nov. 88).

10. G. J. Thuesen and W. J. Frabrycky, Engineering Economy, Seventh Edition, Prentice Hall International Series in Industrial and Systems Engineering, 1988, pp. 386-392.

11. Donald G. Newnan, Engineering Economic Analysis, Third Edition, Engineering Press Inc., 1988, pp. 303-304.

12. Lisa Biow, Quattro: The Professional Spreadsheet Made Easy, Osborne McGraw Hill, 1988.

13. Ronald C. Reckrodt, A Comparative Study of Economic Models for Battery Energy Storage Systems, M.S. Thesis, University of Missouri-Rolla, November 1989.

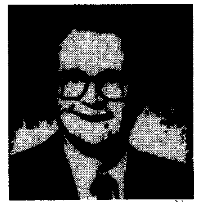
Ronald Courdt Reckrodt was born on May 3, 1959 in Blue Island, IL. He received his primary education from schools in Illinois and Missouri. His secondary education was accomplished at Milan C-2 High School in Milan, Missouri.

After high school he spent four years in the US Navy as an electrical/electronics bench technician. Upon completion of this tour he attended college in a pre-engineering program at Northeast Missouri State University beginning June 1982. In June 1984 he enrolled at the University of Missouri-Rolla where he received a Bachelor of Science degree in Electrical Engineering in May 1988. During this time at Rolla a one year break was taken to attend flight school for the US Army at Ft. Rucker, AL.

He enrolled in the Graduate School at the University of Missouri-Rolla in August of 1988 and received the MSEE degree in December 1989. He was the recipient of the Union Electric Power Fellowship and participated in the graduate research program as a Graduate Research Assistant.

Raymond M. Kluczny is an Associate Professor of Engineering Management at the University of Missouri-Rolla. He holds a Ph.D. in Quantitative Systems from Arizona State University. His work has appeared in IEEE Computer, ASHRAE Journal, SPHE Technical Journal, Lighting Design and Application, and Journal of Systems Management.

Dr. Kluczny's research interests include the design anduse of systems to support decision making.



Max D. Anderson (M'67, SM'84) received the BSEE and MSEE from Oklahoma State University, attended Northwestern University, and received the Ph.D. from Arizona State University. Since 1975 he has been with the University of Missouri-Rolla where he is now Professor of Electrical Engineering and Director of the Power Engineering Education Program. He has published many papers in the area of power system monitoring, control, and operations. Dr. Anderson has over fourteen years of industrial and consulting experience on power system projects; such as battery storage systems, operator training simulator requirements, load management requirements, human factors review of energy control centers.

Utility experience includes requirements definition for the Union Electric Load Dispatch System, software requirements, design and testing for the Ontario Hydro DACS Control Center project and engineering studies for Bonneville Power Administration's Dittmer Control Center.

He is a senior member of IEEE and past Chairman of the Working Group on Operator Training (WG 78-4). He is a registered professional engineer and a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.