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Abstract

A two-fold study of wind energy in an industrial application is presented in this paper. The first phase of the study concerned the possibility of using wind energy to supply power for electric forklift trucks. The second phase related the feasibility of propane power versus electric power in forklift truck operations.

INTRODUCTION

This study was initiated by a senior design group at Marquette University, with the majority of data collected at Wisconsin Centrifugal, Incorporated, of Waukesha, Wisconsin. Its main objective was to determine the feasibility of installing a wind generator as a source of electrical power for two limited-use forklift trucks. As so frequently happens in design, a second study evolved from this main objective. This study concerned the feasibility of replacing propane forklift trucks with electric forklift trucks.

FEASIBILITY STUDY

The first step in the design process is the feasibility study. Included in this study was a review of present wind generators and a monitoring of forklift trucks at Wisconsin Centrifugal, Incorporated. The study showed that a vertical multi-blade windmill (which was capable of generating energy in the wind velocity range of 6-16 miles per hour) was the most desirable generator design. It was determined that, although the cost of wind generators was extremely high at the present time, price projections indicate a significant reduction in cost due mainly to research and mass assembly line production.

The entire forklift truck fleet at Wisconsin Centrifugal was monitored to determine the average hours of use per truck per week. The results of this study are shown in Table 1. Electric and propane cost projections were based on both utility forecasts and post price rate increases.

Table 1

FORK TRUCK USAGE AT WISCONSIN CENTRIFUGAL, INC.

Truck No.	Department	*Usage (Hours/Week)
16	Maintenance	15.6
43	Stainless	28.7
47	Maintenance	15.8
48	Cut-off	26.2
49	Bronze	38.9
50	Stainless	5.3
51	Die Shop	38.6
52	Fabrication	37.9
53	Machine Shop	83.2
54	Cut-off	42.0
55	Shipping	24.2
56	Fabrication	63.2
57	Smelting	42.7
58	Smelting	57.3
59	Machine Shop	50.5
60	Die Shop	10.9
61	Receiving	40.2
63	Smelting	8.7
64	Stainless	21.9
65	Stainless	6.6
66	Stainless	12.3

Table 1 (cont'd.)

Truck No.	Department	Usage (Hours/Week)
67	Stainless	68.8
68	Stainless	10.3
69	Maintenance	16.1
70	Die Shop	37.0
71	Heat Treat	72.8
72	Bronze	64.3
73	Shipping	Broken Hour Meter
74	Stainless	52.6
75	Maintenance	Broken Hour Meter
76	Maintenance	4.1

*The preceding averages are the results of a weekly survey of fork truck usage for one month. These averages were corrected for any loss time caused by equipment maintenance or repair.

WINDMILL THEORY

Windmill performance may be investigated theoretically using the Betz Momentum Theory which concerns the deceleration of the air traversing the windmill disc. The power originally contained in a cylinder of air of radius R can be written

$$P_T = (\text{Volumetric Flow Rate}) \times (\text{Kinetic Energy per Unit Volume})$$

$$= (AV)(\tfrac{1}{2}\tfrac{\rho}{g}V^2) = (\tfrac{1}{2}\pi R^2)(\tfrac{\rho}{g}V^3) \qquad (1)$$

The Betz Momentum Theory expresses the power obtainable from the wind as a function of interference factor a, which represents the slowing down of the air in the windmill disc. The power obtainable thus becomes

$$P_o = (2\pi R^2)(\tfrac{\rho}{g}V^3)a(1-a)^2 \qquad (2)$$

Differentiating Eq. (2) with respect to a, it can be seen that maximum power obtainable occurs when a=1/3. Substituting this value into Eq. (2), the maximum efficiency of a vertical windmill is

$$\frac{P_o\big|_{a=1/3}}{P_T} = 9{,}583 = \underline{59.3\%} \qquad (3)$$

Further assuming the windmill mechanism to be 80% efficient, the generator 70% efficient, and the battery 85% efficient, the maximum power output in kilowatts can be expressed as

$$P(kw) = (4.3587 \times 10^{-6})(R)^2(V)^3 \qquad (4)$$

Fig. 1 shows the power output for various size blades as a function of velocity.

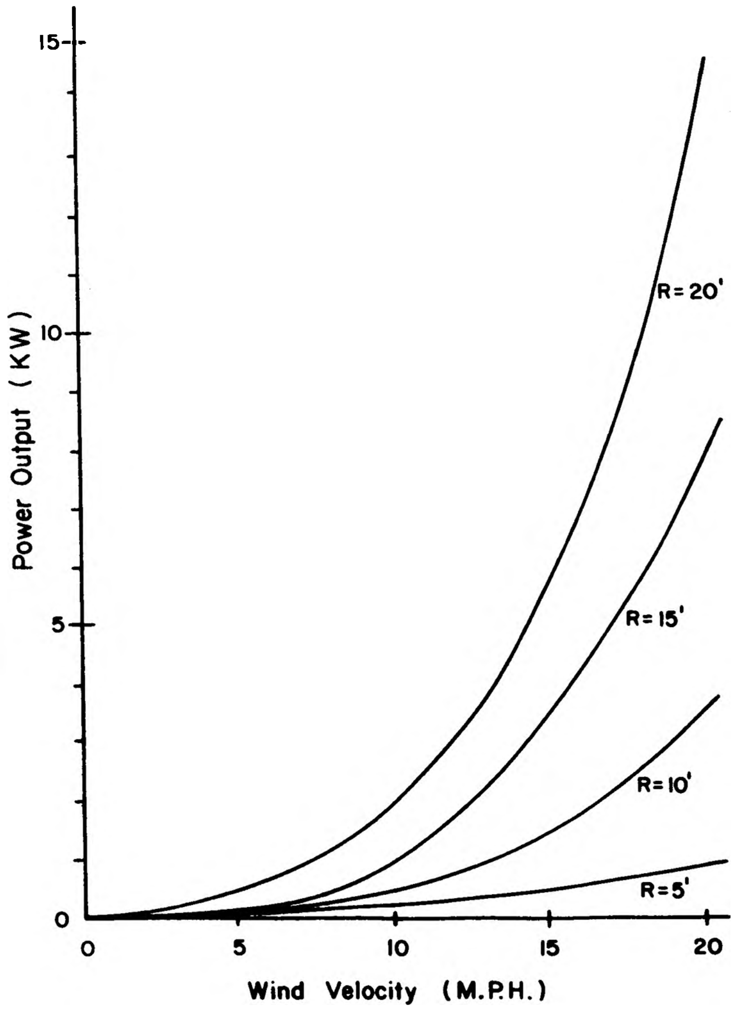

Fig. 1 Power Output as a Function of Wind Velocity and Blade Radius

SITE MEASUREMENTS

Wind measurements taken at Wisconsin Centrifugal corresponded closely with the United States Weather Bureau measurements compiled at General Mitchell Field in Milwaukee. This allowed the use of Weather Bureau data which had been compiled over a ten-year period. Fig. 2 shows that the wind has a velocity of 16 mph or less 72% of the time. This implies that a light multiblade windmill that swings out of the wind at velocities of 16 mph or greater would not use 28% of high energy winds. Thus a windmill with a governor to prevent excessive shaft speeds but still allow for power generation at wind velocities of 16 mph or greater is desirable. At the other end of the spectrum, a windmill capable of producing energy in the velocity range of 6 to 16 mph will afford a monthly power output approximately 14% greater than a windmill operating in the range of 8 to 16 mph.

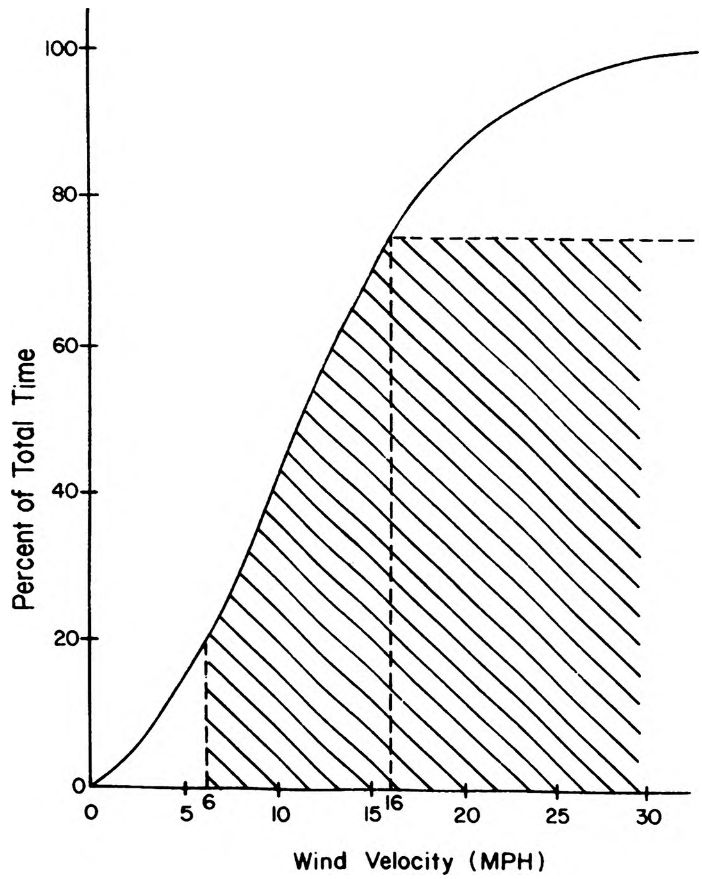

Fig. 2 Percent of Time Wind is less than a Given Velocity

POWER CALCULATIONS

The shaded area of Fig. 2 represents usable energy winds if a governor is used as previously mentioned. Fales[1] states that the available energy of all varying winds adds up to double the amount computed using the average hourly wind velocity for that month. Using the above mentioned information and Eq. (4), the expected power obtainable from a windmill with a blade diameter of 30 feet ranges from 1250 to 2500 kw-hr/month. Referring to Table 1, the limited use trucks, nos. 68 and 69, were our target trucks. Assuming a power consumption of 2.7 kwh/hr it can be shown that a power source capable of supplying 286 kw-hr/month would be sufficient. The power calculations indicate the system to be capable of supplying enough energy for 78 hours of operation per week, or almost triple the average usage of trucks 68 and 69.

ECONOMIC ANALYSIS

It has been shown that a savings of energy can be realized through the use of a wind generator. The final phase of this study was to show that (1) electric forklift trucks are more economical to operate than propane trucks, and (2) that a wind generator does have a place in the economic forecast.

The decision whether or not to buy electric or propane powered lift trucks was in the format of a traditional capital budgeting decision. This type of problem is analyzed by restating all costs in the present value equivalent, therefore neutralizing any timing differences in equipment life.

While the propane alternative is a straightforward one-time decision, the electrical alternative involves a sequential decision making process. This process is depicted graphically in Fig. 3. Electric

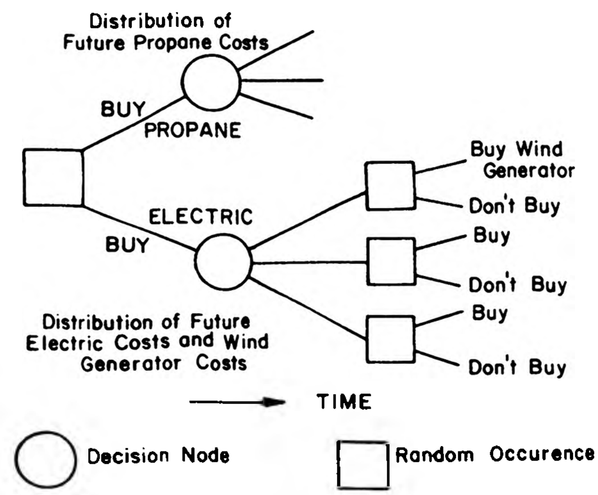

Fig. 3 Sequential Decision-making Process

power can be obtained by either purchasing from an electric utility or through a wind electrical generating station. Currently it is not economical to generate electricity via a wind generator because of the relatively high cost of the generating station and the relatively low cost of purchased electrical power. Wind generation does enter the current decision, however, because of its potential as a source of power in the future. The relevant cost stream to use in analyzing the electric alternative is the lower segment of either the cost of purchased power or the cost of wind generated power. Fig. 4 shows a situation where the cost of purchased power increases over time due to inflationary or other factors and the cost of wind generated power decreases due to possible economies in the production of wind generating equipment. Up to time period N the cost of purchased power is the relevant cost curve. Beyond period N the relevant

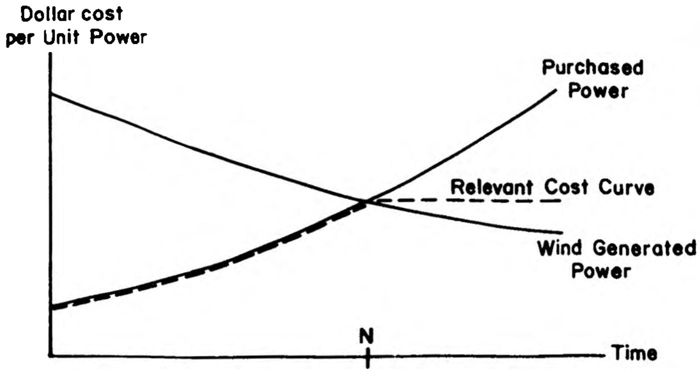

Fig. 4 Cost vs. Time Curves

cost curve is a flat line segment reflecting the constant amortization of investment in generating equipment over the power generating life of the equipment.

Since the economic life of the propane and electric trucks differs, the planning horizon is extended to 24 years, the point in time where the two pieces of equipment have a common termination point. Structuring the analysis as a series of replacement decisions is a standard approach to removing the bias in the net present value analysis where different lived assets are being compared. Table 2 lists the economic data used in the study.

Table 2

	Propane Truck	Electric Truck
Capacity	5000#	5000#
Price of Truck	$13,655	$15,495
Estimated Life of Truck	6 years	8 years
Battery Cost	--	$3,260
Battery Life	--	6.5 years
Charger Cost	--	$938
Charger Life	--	10 years
Energy Cost		
Propane	$.52/gal	--
Electric Cost	--	.0289$/kwh
Power Consumption	1.2 gas/hr	2.7 kwh/hr
Annual Hours of Operation	3144 hrs/yr	3144 hrs/yr
Truck Maintenance	$1.20/hr	.90 $/hr
Battery	--	.06 $/hr
Cost Growth in Propane costs	25% years 1-10 15% years 11-20 5% years 21-24	-- -- --
Cost Growth in Electric Costs	-- --	17% years 1-15 5% years 16-24

Table 2 (cont'd.)

Decrease in wind generation costs - $1000/yr years 1-8

The first step in this sequential decision making process is to determine if and when the wind generator enters the electric truck cost structure. In sequential decision making the decision furthest in the future is made first, and this information is carried backward to the current decision. This essentially involves determining if point N on Fig. 4 is within the 24-year horizon. This was determined by the rate at which the price of wind generators falls plus the rate at which the cost of electricity rises.

For this study the current price of a generator was assumed to be $10,000, which would reduce over an 8-year period to $2000. Further, the life of the generator was assumed to be 10 years, and its maintenance cost to be $60.00 per year. The cost of electricity, currently $.0289/kwh, has been growing at the rate of 17% in recent years. The prospect is for continued increase in this cost. It was assumed that the cost of electricity would increase at this 17% annual rate for the next 15 years and at an annual rate of 5% thereafter.

The firm had a marginal tax rate of 48% and used a 15% cost of capital criterion. In cases of environmental investment, the firm was willing to accept a lower return on investment. The wind generator versus purchased power was analyzed at a 10% return criterion, while the overall truck decision was analyzed using the 15% criterion.

The decision of whether or not to buy a wind generator was made by comparing the cost per kilowatt hour of purchased power with the cost per kilowatt hour of wind generated power. The wind generator costs per kwh were determined by amortizing the cost over the life of the generator and over the kwh used. Using the 10% return on environmental investments, the after-tax cost of purchased power in year 10 is $.0617 per kwh, while the amortized cost per kwh is $.0600. Thus in year N=10 the wind generator enters the decision

With the question of the relevant cost curve answered, the economic analysis of propane versus electric lift trucks was then undertaken. The economic analysis revealed the net present cost of the propane truck to be $54,945 as compared to $31,073 for the electric truck. The electric truck alternative clearly dominated the propane truck alternative. Because the dominance was so great, it is apparent that, even under a wide range of assumptions, the electric truck alternative is superior. For instance, if it were assumed that there was no increase in the cost of propane and electric power, the cost of the propane alternative would be $34,017, while the electric alternative would be $30,018. Under this assumption, however, the wind generator would not enter the decision. The contribution of savings due to the wind generator is not large relative to the cost of the entire system. With respect to the assumed wind generator price reduction, if its price stayed at $10,000 it would not enter until year N=23, therefore having no significant affect. Changing the growth in electrical prices showed a similar sensitivity. At a growth rate of 10%/yr, the wind generator would enter into the analysis at year N=14. The conclusion, however, was still that it would play a part in the current decision.

CONCLUSIONS

It has been found that a wind generator as a source of electricity is obviously energy saving. Furthermore, if the cost of such generation systems is reduced to a more reasonable figure, the system enters into the economic picture as a savings in operation. With the economic data given, it is apparent that a decision to phase out propane forklift trucks is warranted as an economic saving. This decision is shown to hold true unless the cost of electricity increases at a rate much greater than the rate increase of propane.

REFERENCES

1. Fales, E. N., Mark's Mechanical Engineering Handbook, McGraw-Hill Book Company, 4th edition, 1941.