Electric Demand Reduction for Industrial Plants

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Abstract

This paper will describe the development of a methodology which can be used to estimate the electric demand reduction due to the use of high-efficiency equipment in an industrial setting. This demand reduction is dealt with on a separate basis from the energy savings attributed to these high-efficiency devices. A summary of the loads surveyed will be presented to give the reader an idea of the scope of this project. A computer program has been written to aid in the calculation process which is described and sample results demonstrated.

Energy efficient equipment and techniques have been used since the original "energy crisis" of the 1970s. Some replacement equipment includes high-efficiency motors, cogged V-belts, high-efficiency lighting, electronic ballasts, and other energy conservation measures. In some instances, industries have been encouraged to use energy conservation by utilities that desire to control demand levels so expansion in capacity can be delayed. Industries have benefited from these measures by reduced utility bills and, in some cases, rebates have been received from the utility to reduce initial capital costs. This paper will address how peak demand can be reduced by the use of energy efficient equipment.

On a per device level, "electric demand is the average load a device imposes on a system during an interval."[1] The interval can be 15, **30,** or 60 minutes or any other predetermined time. From a utility standpoint, demand is the "generation capacity utilized during the billing period .''[2] Billing for the demand is often determined by the peak interval demand that a plant incurs during the billing month. Some utilities bill according to the peak demand over a season or for an entire year. Demand billing is used by the utilities under the rationale that "the utility must have available to the customer some maximum demand capacity even if the customer does not utilize that capacity in any given month"[2]. Utilities generally monitor electric demand at the point of service to the industrial plant. In this respect, the plant could be considered to be black box to the utility since the utility usually is not aware of the devices that contribute to the billing demand - only that the demand is there. Since the demand is measured at a plant's service point, the measured demand is the sum of demands of individual equipment taken during each demand interval. This is referred to as the coincident demand over each interval.

The coincident demand can be stated mathematically for n devices as follows:

$$D_c(t) = \sum_{i=1}^{n} D_i(t)$$

where:

$D_c(t)$ = coincident demand over a specific interval
$D_i(t)$ = demand of device i over the same interval

Figure 1 gives a simple graphical example of the coincident demand. Devices 1 and 2 represent the demand of two individual devices. Coincident represents the coincident demand.

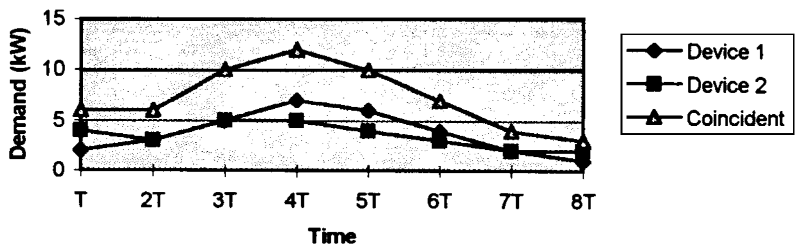


Figure 1

If a company decides to implement high-efficiency equipment, the savings in energy are easily calculated. When calculating energy savings for a device, first calculate the annual energy used by the device and then calculate the energy usage of the high-efficiency replacement for the same operating conditions. The difference between the two energy uses is the energy savings. The demand reduction is not as easily calculated when looking at the coincident or billing demand.

Annual plant-wide energy savings can be found by summing all of the energy savings of the individual devices. The time at which these devices operate is not considered to be a factor in determining energy savings. It is assumed that the devices only have to operate for a specified amount of time for the savings to be realized.

The plant-wide demand reduction depends upon the time at which the devices operate as well as their power level. There is a case in which calculating demand reduction is as simple as calculating energy savings. That case is when all of the devices operate at a constant load level. Lighting is an example of constant load devices. If 100 forty-watt fluorescent lamps are replaced with thirty-four watt lamps, the demand reduction would be six watts per lamp times 100 lamps or 600 watts. However, most loads do not operate at a constant level. Some loads cycle between two power levels and others run at many different levels. The problem compounds itself for the calculation of the coincident demand. The operating power level must be known as well as when the devices operate at those levels. When the power level of each device is known for a specific time, the coincident demand can be calculated at that time.

Determining coincident demand and demand reduction is a virtually impossible task to accomplish unless the problem is treated statistically. Instead of saying that the peak coincident demand occurs at a specific time, we can look at the probability of achieving a certain demand. This eliminates the need for a specific time in the calculations. Figure 2 shows the method of determining the coincident demand of two devices that operate at different power levels.

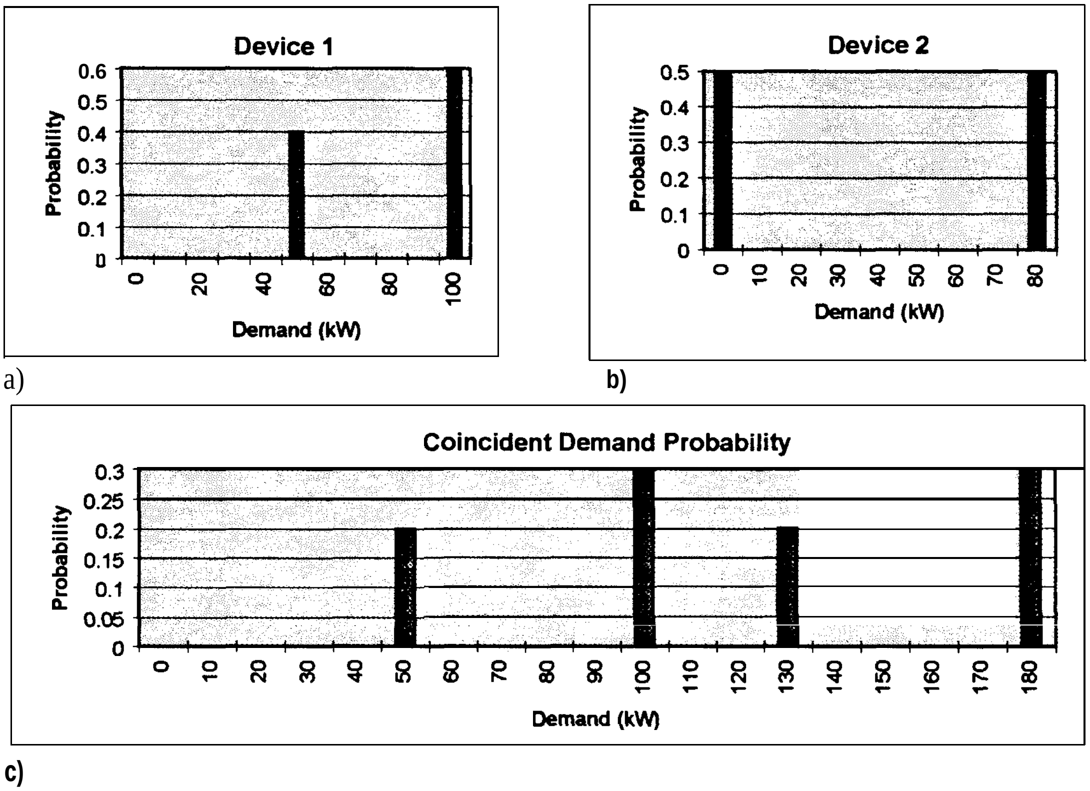


Figure 2: Possible Demand Levels of Two Devices

The probability of operating at a certain power level is the percent of time that the device operates at that level. For example, if Device 1 operates at 50 kW for forty percent of the time, the probability that Device 1 operates at 50 kW is 0.4.

Consider the coincident demand of the two devices in Figure 2. To determine the coincident demand of these devices, four possibilities exist.

First, Device 1 can be operating at 50 kW while Device 2 is off. The assumption is made that these two devices operate independently[1] The probability of the combined event is then:

$$P(D_1 = 50kW \cap D_2 = 0kW) = P(D_1 = 50kW) x P(D_2 = 0kW) = (0.4)X(05) = 02$$

The other possible cases are: Device 1 operates at 100 kW while Device 2 is off, Device 1 operates at 50 kW while Device 2 operates at 80 kW, and Device 1 operates at 100 kW while Device 2 operates at 80 kW. In each case, the resulting power level is the sum of the individual powers and the probability of the combined event is the product of the probabilities of the individual devices. Another way to look at this operation is to note that the resulting coincident demand probability is the discrete convolution of the individual device probabilities. This is the method that has been developed to estimate the demand reduction due to the use of energy efficient equipment.

[1] Equipment operation is dependent upon product flow, but in general not dependent upon other devices operating.

Calculating the coincident demand and the resulting demand reduction with this method involves the discrete convolution of probability characteristics like those shown in Figure 2 for all of the equipment in an industrial plant. A lack of available demand characteristics for individual loads required that enough measurements be made to establish an acceptable database. As a result, a large portion of this project was devoted to the acquisition of demand profiles for individual devices in an industrial setting. Equipment measured includes: air-compressors used for process and HVAC purposes, pumps, cooling towers, grinding mills, mixers, blowers, conveyors, saws, sanders, elevators, and other representative industrial equipment.

The equipment data were taken using a recording power meter and a laptop computer. An example characteristic is shown in Figure 3.

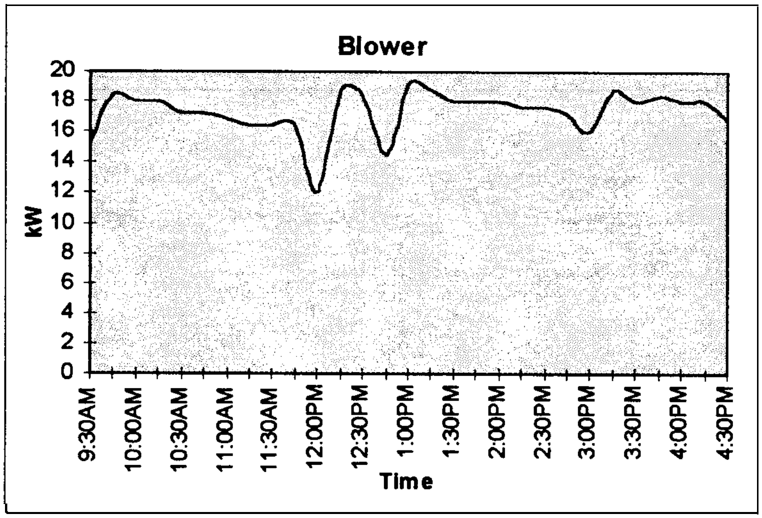


Figure 3

Figure 4 shows a histogram of the data represented in Figure 3. The power levels are divided into 5% intervals.

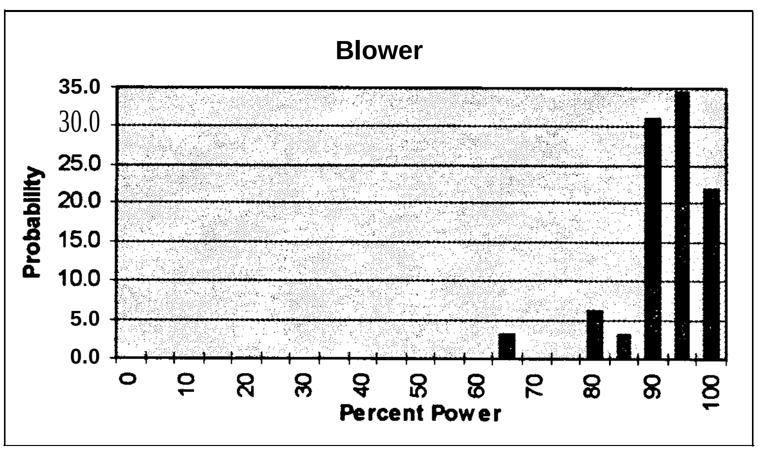


Figure 4

Since the convolution process involves a large number of calculations, a computer program has been written to aid in this process. This program was written using Visual Basic so a user friendly point and click environment could be used. The user data entry interface is shown in Figure 5.

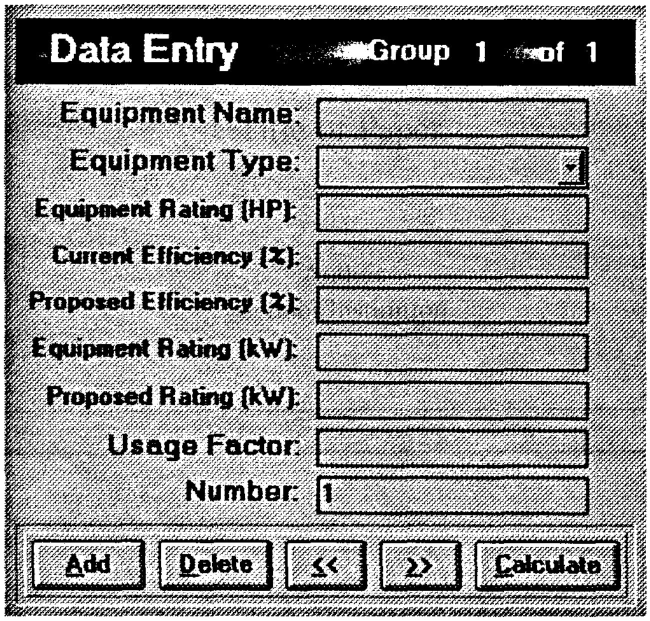


Figure 5

There are nine entry boxes in which each piece or group of equipment is entered. The first box is an optional box that allows the user to index equipment by name. The second box is a combination box that lists all types of equipment that the program covers. The third box is the horsepower of the equipment. Upon entering the equipment type and horsepower, the program automatically enters default values for current efficiency(%), proposed efficiency(%), equipment rating (kW), proposed rating (kW), and usage factor. The horsepower rating is converted into kilowatts and multiplied by the usage factor to give the default for the kW box. The efficiencies are based on average manufacturer nominal efficiencies. The proposed rating (kW) is calculated from the difference in proposed and current efficiency and the equipment rating (kW). If the equipment is rated in kilowatts instead of horsepower, the kilowatt rating is entered. The proposed rating (kW) for the energy efficient replacement must then also be entered. The eighth box is designated for the usage factor and the last entry box is for the number of pieces of equipment that are in the group in question.

The usage factor is defined as the peak measured demand divided by the rated demand. This allows for the determination of the actual demand from the nameplate rating of a piece of equipment. It also gives an idea of how well the equipment and the load are matched. For example, if a motor rated at 100 hp (74.6 kW) had a peak measured demand of 37.3 kW then the usage factor for this piece of equipment would be 37.3/74.6 = 0.5. When this value is multiplied by the rated power of the device, the peak measured demand results. When a type of equipment is chosen, a default value for the usage factor, according to empirical data for that type of equipment, appears in the Usage Factor box. This value can be changed to accommodate equipment that is run closer to or farther away from rated values.

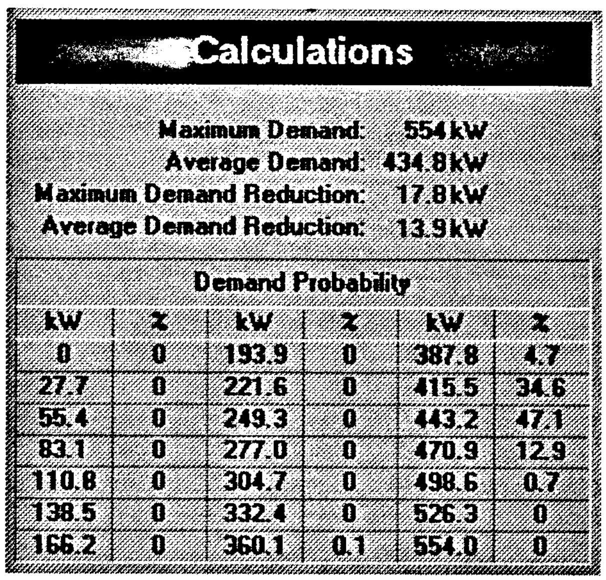
At the bottom of the Data Entry panel, there is a set of command buttons. When the data record for a piece of equipment is completed, the user can use the mouse or keyboard to select the Add command. This will add the record to the database of equipment. The Delete button allows the user to eliminate a record from the database. The << and>> buttons allow the user to scroll through the records. The Calculate button causes the program to perform the discrete convolution of the data sets for all of the entered equipment and produce a graph of the results as well as calculated values.

The program works by calculating the maximum demand for each piece of equipment based on the kilowatt rating and the usage factor. The total maximum demand is the sum of all of the individual demands. The probability characteristics similar to those shown in Figure 4 are then convolved to determine the power levels at which the group can be expected-to operate. All pieces of equipment in the facility should be entered into the program because each device has an impact not only on total demand, but also on the final probability characteristic of the system. Supplying data for only those devices that are being considered for replacement causes slightly different results in demand reduction calculations.

Program output consists of a Calculations Panel and a graph of the system demand probability. After the program runs, this panel shows the calculated values of maximum and average system demand as well as maximum and average demand reduction for the system when energy efficient equipment is used. The Demand Probability Table at the bottom of the panel breaks the maximum calculated system demand into 5% intervals of the maximum demand and gives the probability of the system operating in each interval. This table includes both the 0% and 100% boundaries because equipment can run at these power levels. This gives a total of 21 possible intervals.

The program can be checked by comparing the value of the average demand to the facility's electric bill. The values should be close to the value reported by the utility company in order to get reasonable values for demand reduction. If the calculated demand is not close to the actual demand, the equipment records can be fine tuned by adjusting the usage factor.

As an example, the demand of a small industry has been analyzed using this technique. This industry has 150 motor loads and a connected lighting load of about 30 kW. The demand reported on the utility bills for this industry runs near 465 kW. The results of the program are shown in Figure 6. The Demand Probability Table at the bottom of the Calculations Panel conveys the same information that is contained in the Demand Probability Graph.


Calculations

Maximum Demand: 554 kW
Average Demand: 434.8 kW
Maximum Demand Reduction: 17.8 kW
Average Demand Reduction: 13.9 kW

Demand Probability

kW	%	kW	%	kW	%
0	0	193.9	0	387.8	4.7
27.7	0	221.6	0	415.5	34.6
55.4	0	249.3	0	443.2	47.1
83.1	0	277.0	0	470.9	12.9
110.8	0	304.7	0	498.6	0.7
138.5	0	332.4	0	526.3	0
166.2	0	360.1	0.1	554.0	0

Figure 6a: Calculation Panel

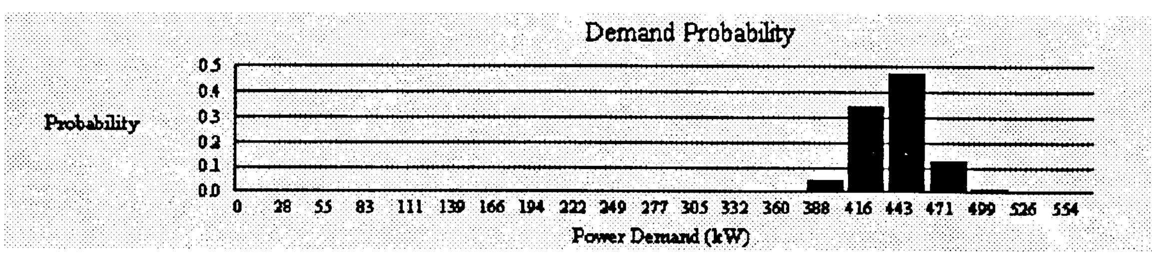


Figure 6b: Demand Probability Graph

The results show that all devices running simultaneously at peak levels could produce a peak demand of 554 kW. On average, the program predicts a demand of 434.8 kW. If all motors were replaced with high-efficiency counterparts, the maximum demand reduction could be 17.8 kW. However, it would be more likely to reduce demand by 13.9 kW.

Conclusions

Electric demand reduction can be achieved through the use of energy efficient equipment and techniques. This paper explored the quantification of the possible reduction in demand on a statistical basis. The program designed for this purpose calculated the average demand within 6% of the actual demand reported on the utility bill. This error is considered to be acceptable since monthly demand can vary in either direction by a larger percentage than this depending on production and startup procedures. Calculated results show that energy efficient equipment could reduce this company's demand by **3°/0.** Small variations in actual monthly demand will have an insignificant effect on this reduction percentage. For example, if all loads peaked coincidentally, the demand could be expected to reach 554 kW. The average demand reduction would change to 2.5'% which says that a 27% change in billing demand caused a 0.5'% change in predicted demand reduction.

[1] Goenen, T.: "Electric Power Distribution System Engineering" McGraw-Hill, St. Louis, 1986, pp. 37-66.

[2] Studebaker, John M.: "Slashing Utility Costs Handbook" The Fairmont Press, Inc., 700 Indian Trail, Lilburn GA 1993 pp. 47, 51,53.

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