SOME ASPECTS OF REDUCING ELECTRICITY DISTRIBUTION LOSSES

by

Z. N. Bemunuge

ABSTRACT
To sell the purchased energy with as little loss as possible helps to conserve energy resources and to enhance revenue and perhaps profits. Losses cannot be measured directly and costs are incurred in reducing them. How are losses to be determined? Are they simply the difference between the purchase and sales figures obtained by reading meters? Cost benefits accrue from the reduction of losses. How are these reductions to be determined? Are they simply the difference between the losses in two consecutive billing periods? If not how is a reduction in the second period to be evaluated? How are reductions in the long term to be evaluated? The paper answers such questions and examines methods that can be used to evaluate loss reductions using billing data obtained in the absence of an automatic meter reading system.

1. SOME PRELIMINARY CONSIDERATIONS
Electricity is a commodity. Buying and selling it and suffering losses therefore is just like with any other commodity like, say, potatoes. They can be incorrectly weighed at the points of purchase and also at the points of sales; some can be stolen; some can fall by the wayside during transport. Each of these factors would cause a loss to the vendor. For every kilo he buys there would be a fraction \( r \) of it he losses, and if he reduces the degree to which these factors affect his losses he will lose a smaller fraction; if the degree is greater the fraction \( r \) will be greater. In either case the more kilos of potatoes that he buys the more the kilos he would loose. If he incurs some cost in reducing the degree and knowing that he is loosing a smaller fraction how would he determine the amount of losses he has reduced as a result of the cost he incurs?

Let \( P_1 \) and \( P_2 \) be the purchases in two consequent periods and \( L_1 \) and \( L_2 \) be the corresponding losses. Consider the fraction \( r \) which is really the rate of losses per unit of purchases. In the first period it is \( r_1 \) \( (= L_1/P_1) \) and in the second period it is \( r_2 \) and smaller \( (= L_2/P_2 < r_1) \). If the factors were to have the same degree of influence in period 2 the prospective losses in period 2 could be taken as \( r_1 P_2 \). Since the actual losses in the second period are \( r_2 P_2 \) which is less than \( r_1 P_2 \) because \( r_2 \) is smaller than \( r_1 \) there would be a reduction of losses \( \Delta L_2 \) equal to \( (L_1/P_1 - L_2/P_2) P_2 \) irrespective of the values of \( L_1 \) and \( L_2 \). From this it could be inferred that generally losses rise with increase of purchases and there will be reductions of losses only if the ratio by which losses increase is less than the ratio in which the purchases increases.

Similarly to achieve a reduction \( \Delta L \) of electricity losses in a distribution network some costs have to be incurred and the utility will benefit financially only if the monetary value of \( \Delta L \) is greater than the costs incurred and therefore it becomes necessary to assess \( \Sigma \Delta L \) over any desired length of time.

Considering the network in a condition \( C_1 \) to carry energy \( P_1 \) and the network in an improved condition \( C_2 \) to carry energy \( P_2 \) in two consequent and equal periods of time the reduction of losses in the second period would be given by \( \Delta L_2 = (r_1 - r_2) P_2 \) as shown above.

Now considering a third period if the network actually remains in condition \( C_2 \) in period 3 and carries energy \( P_3 \) the actual losses would be \( r_2 P_3 \). What would be the prospective losses then? Since there is no other prospective condition to consider except \( C_1 \) the prospective losses could be taken as \( r_1 P_3 \) if the network

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in C1 can be so loaded and its rate of loss remains unaltered. Therefore \( \Delta L_3 = (r_1 - r_2) P_3 \). On the other hand if the network were to remain in C2 while it is actually in a further improved condition C3 then \( \Delta L_3 = (r_2 - r_3) P_3 \). In this case it can also be argued that if the network were to remain in C1 in period 3 and can carry energy \( P_3 \) the prospective losses would be \( r_1 P_3 \) and \( \Delta L_3 = (r_1 - r_3) P_3 \) which is a larger quantum of reduction.

The question therefore arises as to whether to take the initial condition always for assessing the prospective losses or to take the immediately preceding condition. The choice of the prospective condition would depend on how much the network in that condition can be loaded. For instance, when in 12 years the energy purchased increases to 20 times the amount in year 1 the condition of the network in year 1 cannot be taken possibly as the prospective condition. The initial network would have collapsed long before the 12th year.

However for reasons of prestige it is tempting to take the initial condition of the network as the prospective condition during all subsequent periods because a larger amount of saving can be shown. Here one must choose between prestige and realism.

2. SEPARATION OF LOSSES

The losses will be made of sales losses \( L_s \), that is energy used but not billed and energy losses \( L_s \), that is energy dissipated in the network. A reduction \( \Delta S \) in \( L_s \) would increase sales and a reduction \( \Delta E \) in \( L_s \) would reduce purchases, the combined effect of these reductions being to enhance revenue. If the reductions in each of these in period 2 are \( \Delta S_2 \) and \( \Delta E_2 \) then it is shown in the annex that \( \Delta S_2 + \Delta E_2 (1 - r_1) = (r_1 - r_2) P_2 \). So it is not possible to evaluate both \( \Delta S \) and \( \Delta E \) simultaneously. However assuming that one is zero the maximum possible value of the other can be estimated.

3. ESTIMATING THE VALUE OF \( r \)

Losses cannot be measured directly. They can only be assessed by the difference in the amounts of energy purchased and sold. In order that energy supplied or purchased and the energy used or sold may be compared such energy need to be measured over an identical interval of time. In the absence of an automatic meter reading system it is obviously impossible to read all the meters at every point of supply and use at two simultaneous instants spaced one billing period apart. When multiple points of supply are metered the situation becomes even more complicated. The values of sales and purchases obtained in this manner necessarily lead to misleading errors in the estimation of losses and the quantum of their reduction. Therefore there should be methods for estimating losses reasonably accurately.

4. ERRORS IN ESTIMATING \( r \)

As mentioned already the two consecutive meter readings at each point of sale and at each point of purchase can never be taken at two simultaneous instants without an automatic meter reading system.

<table>
<thead>
<tr>
<th></th>
<th>11%</th>
<th>10%</th>
<th>9%</th>
<th>8%</th>
<th>7%</th>
<th>6%</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2.0</td>
<td>12.78</td>
<td>11.80</td>
<td>10.82</td>
<td>9.84</td>
<td>8.86</td>
<td>7.88</td>
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<tr>
<td>+1.0</td>
<td>11.89</td>
<td>10.90</td>
<td>9.91</td>
<td>8.92</td>
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<td>6.94</td>
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<tr>
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<td>8.46</td>
<td>7.47</td>
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<tr>
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<td>9.55</td>
<td>8.55</td>
<td>7.54</td>
<td>6.54</td>
<td>5.53</td>
</tr>
<tr>
<td>-1.0</td>
<td>10.11</td>
<td>9.10</td>
<td>8.09</td>
<td>7.08</td>
<td>6.07</td>
<td>5.06</td>
</tr>
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</table>

For instance, when the meters at the point of purchase are read at the end of each 30 day period the meters at each point of sale may also be read at the end of each 30 day period but these periods are not coincident, they may be staggered over a period of, say, 50 days. Generally the result of such non-coincidence of purchases and sales would be that some purchases would not be accounted for as sales and some sales would not be accounted for as purchases. In effect the measured values of purchases and sales would be \( P + \delta P \) and \( S + \delta S \).

As \( r = (P-S)/P \) the error in \( r \) would be given by \( \delta r = (1-r)(\delta P/P - \delta S/S) \). The table shows the range of values of \( r \) for a given true value when all errors are referred to purchases that is with \( \delta S/S = 0 \) and \( \delta P/P \) in the range \( \pm 2.0 \% \).

5. MINIMISING ERRORS IN ESTIMATING \( r \)

Only a very rough estimate of \( r \) can be made for a given month based on the purchases and sales of that month. Such a value is useless in estimating reductions of losses.
Pro rating

One way of obtaining a better value for r is by prorating the purchases and sales of the month to a fixed number of days, say 30 on the presumption that the pattern of energy consumption is very stable. In any case this is not a reliable method of estimating r.

Arithmetic moving average

Another way is to calculate the moving average up to the current month over any desired period, say 12 months. The presumption here is that errors in $\sum P_n$ and $\Sigma S_n$ are minimised by making n large enough. This presumption becomes questionable considering the fact that any set of $P_i$ and $S_i$ gives the same value of $r$ as long as each set gives the same $\sum P_n$ and $\Sigma S_n$. A curious feature of the moving average value, say over 12 months, is that when a comparison is made between the moving values of the current month and the previous month it becomes in effect a comparison of the monthly values of the current month and the 13th previous month as can be seen from the fact that $r_{12} = (L_{1} + 2L_{2}) / (P_{1} + \Sigma P)$ and $r_{13} = (\Sigma L + L_{13}) / (\Sigma P + P_{13})$ where the $\Sigma S$ are the totals of months 2 to 12. It seems therefore that the moving average value is of no use in showing the trend in the reduction of losses.

Linear regression

Unlike in obtaining the moving average value, linear regression gives a unique value for $r$ from any set of $P_i$ and $S_i$.

$$\Sigma S_1 \quad \star \quad \star$$

$$\star \quad \star \quad \Sigma P_1$$

As shown in the figure on a scatter plot of $\Sigma P_i$ and $\Sigma S_i$, the slope s of any line segment and the rate of loss r are related by $r = \frac{1}{s}$ Therefore a unique value for s and hence for r can be obtained by doing linear regression on any n pairs of $\Sigma P_i$ $\Sigma S_i$. It is found that when n is about 12 a strong correlation coefficient that gives a high common variance in purchases and sales is not obtained as it should be. For instance even a value of 0.9 for the coefficient gives only about 80% as the common variance which leaves about 20% of the variance independent of P and S. But as n becomes large the common variance reaches very high values. For instance, when n = 60 the independent variance falls to a value as low as 0.01%. It may be noted in passing that on the scatterplot the gradient of any line segment joining any two adjacent points gives the monthly value of r and the gradient of the line segment joining one point to the next 12th point gives the moving average value over 12 months. The advantage in obtaining r by linear regression thus becomes clear.

6. METERING AND LOSSES

Accurate metering is clearly a prerequisite. For instance if $U_i$ is the metered value of energy $E_i$ at each of n points the error of the total measurement $(\Sigma U_i - \Sigma E_i) / 2 \Sigma E_i$ contributes to losses when $\Sigma U_i < \Sigma E_i$. The total error of measurement using n meters within a given accuracy class is given by Ugo Gervasoni of Landis and Gyrs S / $\sqrt{n}$ where S is the sample standard deviation of the errors. Therefore the total error using a large number of meters within their accuracy class would be zero and their contribution to losses also would be zero. So it is important for a utility to ensure that all its meters, specially those used in large numbers like Class 2 meters, are within the class accuracy by carrying out acceptance testing before new meters are released to be installed.

7. RESULTS OF A CASE STUDY

The results of an evaluation of the reduction in losses in a distribution utility over a period of 12 years is shown below. The results evaluated for prestige are shown in parenthesis.

<table>
<thead>
<tr>
<th>Reduction in losses</th>
<th>as % of total sales</th>
<th>as % of total purchases</th>
<th>as % of capital investment</th>
<th>GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta S$ (if $\Delta E = 0$)</td>
<td>$&lt; 0.78 (8.9)$</td>
<td>$&lt; 4.0 (64)$</td>
<td>39 (362)</td>
<td></td>
</tr>
<tr>
<td>$\Delta E$ (if $\Delta S = 0$)</td>
<td>&gt; 0.86 (9.8)</td>
<td>$&lt; 5.0 (46)$</td>
<td>32 (448)</td>
<td></td>
</tr>
</tbody>
</table>

8. CONCLUSIONS

The amount of losses per unit of purchases need to be determined first in order to estimate the amount by which losses are reduced and the best way to do this is by linear regression over a sufficiently long
period that gives a high common variance. The reduction of losses cannot be separated into reduction in energy losses, that is a reduction in purchases, and reduction of sales losses, that is a gain in sales using only the data obtained by billing. The evaluated benefits vary over a wide range depending on the prospective condition taken to determine the loss reduction.

9. ANNEXE

Let

\[
\begin{align*}
P &= \text{energy purchased} \\
S &= \text{energy sold} \\
L &= \text{total losses} \\
r &= \text{losses per unit of energy purchased} \\
L_e &= \text{energy losses} \\
L_s &= \text{sales losses} \\
\Delta E &= \text{reduction in energy losses} \\
\Delta S &= \text{reduction in sales losses}
\end{align*}
\]

subscripts refer to the actual condition of the network

bold type refer to the prospective condition of the network

Figure 1 shows the network in its initial condition C1 transmitting energy \( P_1 \) at a rate of loss \( r_1 \).

Figure 2 shows the network in the same condition transmitting energy \( P > P_1 \) at the same rate of loss.

It is assumed here that the network, without any change in its condition, can sustain load growth in the short term without collapsing and that during this period the rate of loss will remain the same.

Therefore \( r_1 = (L_e + \Delta E_e + L_s + \Delta S_s) / P_1 \).

Fig 3 shows the network in a less lossy condition because there is a reduction \( \Delta E_2 \) in purchases and an increase \( \Delta S_2 \) in sales.

Therefore \( r_2 = (L_e + L_s) / P_2 \).

Eliminating \( L_{e2} \) and \( L_{s2} \),

\[
\Delta S_2 + \Delta E_2 (1 - r_2) = (r_1 - r_2) P_2
\]

\[
\begin{align*}
P_1 &= \text{energy purchased} \\
S_1 &= \text{energy sold} \\
L_{e1} &= \text{energy losses} \\
L_{s1} &= \text{sales losses}
\end{align*}
\]

\[
\begin{align*}
P_2 &= \text{energy purchased} \\
S_2 &= \text{energy sold} \\
L_{e2} &= \text{energy losses} \\
L_{s2} &= \text{sales losses}
\end{align*}
\]