An Efficient Method for Planning Low Voltage Secondary Distribution Networks

Synopsis:
The optimal selection of distribution transformer size and low-voltage (LV) network conductors for a given network configuration poses various challenges to distribution utilities. This article proposes an efficient planning methodology to select an optimal combination of transformer size and the LV network conductor that would minimize the Life of Asset (LOA) costs while taking into account the voltage drop and the transformer loading constraints for a period of 30 years including load growth.

In a recent study for Belize Electricity Limited (BEL), using different combinations of typical transformer size, triplex service drop conductor and choice of network configuration, 200 study cases were simulated in PSS®SINCAL. For each case the cost per kVA was calculated by dividing the LOA costs by the initial loading capacity for each transformer. (The initial loading capacity was preferred over the nominal rating, as it takes into consideration the possible loading limitations due to voltage drop.) Finally, all network configurations were generalized based on load density and the coincident peak load per customer, and cost curves were obtained for several possible combinations of transformer size and triplex service drop conductor. The cost versus load density curves were parameterized using trend line analysis for other load densities which were not included in the list of study cases. The optimal combination of transformer size and LV network conductor was found by locating the combination that minimized the LOA costs for several given densities.

This method is described here as applied to the BEL LV distribution network, but it could be deployed for any LV network configuration. This article discusses the study conducted for the BEL LV distribution network using this method, as well as some general results.

BEL LV Network Generalization:
The characteristics of a sample of 60 distribution transformers (including 25, 50, 75, and 100 kVA transformers) and their LV network were statistically analyzed in order to obtain a generalized BEL LV distribution network configuration. Distance between load poles, number of customers per load pole, coincident peak load per customer, and street lighting information were all evaluated. The findings of the statistical analysis were as follows:

- 50% of the samples had distance between poles within the range of 110 to 120 ft, and 80% of the samples had distance less than 150 ft. Hence 115 ft and 150 ft were chosen.
- 50% of the samples had a load per customer less than or equal to 0.5 kVA per customer, and 80% of the samples had 1 kVA per customer. Hence these values were selected.
• A majority of the samples showed that there were two customers per pole. The distance between street lights was chosen to be the same as the distance between the poles, and their power consumption was specified as 150 W.

The transformer ratings chosen for this analysis were: 5, 10, 15, 25, 37.5, 50, 75, and 100 kVA. The LV conductor types were: T 6 Al, T 4 Al, T 2 Al, 1/0 T Al, 2/0 T Al, 3/0 T Al and 4/0 T Al.

Using the generalized network criteria and the sets of transformers and LV conductors, 200 study cases were simulated in PSS®SINCAL in order to answer the following questions:

• How much can a transformer be loaded? (An initial loading limit of 70% of its normal capacity was chosen to give enough margin for future growth of load connected to that transformer. A 3% voltage drop limit was set without using the transformer taps.)

• What would be the total length of the LV network and the peak load losses for different conductor types?

Figure 1 shows one of the 200 study cases with the transformer – LV conductor configuration selected for this analysis. Transformer load was split into four branches (corner location). The first load pole was assumed to be the transformer pole.

![Figure 1 - Example of the Selected LV Network Configuration in PSS®SINCAL](image-url)
Cost Benefit Analysis:

LOA costs were calculated for a period of 30 years and a present value was estimated using a discount rate of 12%. Figure 2 shows an example of the cash flow model set up for a study case which uses a 15 kVA transformer, with a pole distance of 115 ft, with a load of 1 kVA/customer on a T 6 A1 conductor. For each of LV network configuration the LOA costs were estimated using the following criteria:

- Transformer was installed in year 0 (present year) with 20% of the maximum initial load. During the 1st and 2nd year, the transformer reaches 60% and 100% of its initial loading, respectively. After the second year, a load growth of 2% per year was imposed until the load reaches the capacity equal to the transformer nominal rating.
- LV network was installed in 3 years (0, 1 and 2) following the proposed transformer loading.
- Transformer core losses and winding losses were obtained using typical data. Windings losses were adjusted accordingly with the transformer load in each year.
- LV network peak losses were obtained from the PSS®SINCAL simulations.
- Annual energy losses were calculated by applying a loss factor to the power losses.
- Annual losses costs were calculated using the average energy cost.

<table>
<thead>
<tr>
<th>Case ID</th>
<th>Transformer Loading (%)</th>
<th>LV Network Load (kVA)</th>
<th>LV Network Losses (kWh)</th>
<th>LV Network Total Costs (USD)</th>
<th>LV Network Configuration</th>
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<tr>
<td>1</td>
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<td>500</td>
<td>2500</td>
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<td>700</td>
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<td>6%</td>
<td>1700</td>
<td>900</td>
<td>4500</td>
<td>900</td>
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</tbody>
</table>

Figure 2 - Example of Cash Flow Model for a Study Case

Figure 3 - Representation of the Study for Selection of Optimal LV Network Configuration
Conclusion:
All network configurations were generalized based on load density and cost curves were obtained for several possible combinations of transformer size and triplex service drop conductors. The results were depicted in cost curves: cost (US$/kVA) versus load density (kVA/000 ft) for each transformer size and LV conductor type. Several comparisons were made between combinations, in order to filter out the least cost-effective cases.

For the BEL LV distribution network, the load densities were found to be in the range of 10 to 30 kVA/000 ft. After the initial comparisons, the filtered cost curves depicting the results for different load densities are shown in Figure 4, with the combination of transformer rating and LV conductor type shown in the legend.

The optimal combinations were:

- For low voltages networks with initial load density below 14 kVA/000 ft, a distribution transformer of 25 kVA and T 4 Al conductor.
- For low voltages networks with initial load density above 14 kVA/000 ft, a distribution transformer of 50 kVA and 2/0 T Al conductor.

The cost versus load density curves can be parameterized using trend line analysis for load densities greater than 100 kVA/000 ft.

This efficient method for planning low voltage secondary distribution networks has been implemented on the BEL LV distribution network, but it could be deployed for any LV network configuration.

![Cost versus Load Density](image)