COMPARING LOAD ESTIMATION METHODS FOR DISTRIBUTION SYSTEM ANALYSIS

Robert ARRITT
EPRI – USA
barritt@epri.com

Roger DUGAN
EPRI – USA
rdugan@epri.com

ABSTRACT

Load allocations for distribution system analysis is one area in system modelling where simple, generalized assumptions are commonly made by distribution planners for lack of better data. Most of the time, the assumptions are based on measurements taken only at the distribution substation bus or at the feeder head. With widespread application of advanced metering infrastructure (AMI) technologies, loading estimates for distribution system analysis can now be based on actual measurements taken at individual loads. This can result in greatly improved accuracy in distribution power flow analysis. Three techniques for load allocation are analyzed and compared to the case with actual AMI data for all customers. Selected details of the test circuit and analysis process are provided.

INTRODUCTION

Analysis tools used for distribution systems have become very accurate in the representation of line models, regulators, load tapchangers, capacitor switching, etc. [1], [1] However, load estimation is often a weakness. Distribution system analysis tools typically allocate the load demand measured at the substation to individual customer meter points based on the kVA rating of the MV/LV transformer. Some programs also have algorithms for load allocation based on monthly kWh billing. With the advent of Advanced Metering Infrastructure (AMI) metering capable of capturing extensive demand interval data, new opportunities exist to improve customer loading estimates with distribution system analysis based on actual demand interval data. These improvements can have a significant impact on both distribution planning and real-time distribution state estimation.

Efforts are currently underway to use the AMI demand interval data for both defining and verifying distribution system load models. Each load can be defined separately using its own measured loadshape, which should yield the most accurate simulations. Research has been performed on examining the use of AMI for modelling loads in distribution system analysis. [3], [4] This research was inspired by a study by Kersting and Phillips [5] and builds on that work by examining a larger circuit with nearly full AMI coverage. This paper provides some additional details of the simulations.

The results of the load allocations using the actual AMI data are compared to simpler, or more traditional, load allocation methods. This example gives additional insight into the impact of load allocation assumptions on circuit power flow characteristics for distribution state estimation such as voltage profile, equipment evaluations, losses, and state of distribution equipment.

MODELLING THE TEST CIRCUIT

The analysis described in this paper compares power flow results using four different load allocation methods on the same circuit model. [3] The circuit was selected because it had 99% AMI coverage. The results for the load allocation method using AMI demand interval data were assumed to be the most accurate and serve as the reference against which the other load allocation methods are compared. The AMI demand interval data consists of 15-minute kW demand readings over the period from 1 June 2010 to 18 November 2010.

The test circuit is a 13.2 kV residential feeder with only 1% commercial load. There are 1779 individually-metered customers. There are 10 3-phase loads; the remainder are singl-phase. The peak demand on the feeder is 5800 kW with a load factor of 46% (ratio of average load to peak demand). The feeder contains two capacitor banks, rated 450 and 900 kvar, switched under current control.

This circuit was modelled using the EPRI OpenDSS program. One capability of this program that is useful for this analysis is that it can perform sequential power flow simulations efficiently. Each load can be assigned its own loadshape or all loads can be assigned the same loadshape. Both options were exploited in this analysis comparing different load allocation methods. This program was the main research tool used in a similar kind of analysis for distribution efficiency including nearly 80 distribution feeders from the US and Europe reported previously. [6]

All service transformers (MV/LV transformers) on the feeder were modelled. While US utilities use a split-phase 120/240 V transformer, a simplified model was used for this analysis. Only one value – total kW – was available from the AMI data so it was not possible to accurately split the load between 120 V windings. Therefore, the transformers were modelled as simple two-winding transformers with an LV voltage of 240V for single-phase loads. Each LV service drop was modelled using an average length of 31 m since detailed LV circuit data were not available. Due to the low service voltage, LV circuits in the US are relatively short compared to 400 V LV circuits common in other parts of the world. They typically range in length from 15 to 45 m.

Through many case studies of distribution feeders, we have found it relatively easy to match the active power component of the power flow to measured results. Of course, the line and transformer impedances must be sufficiently accurate to account for the losses. It is often more difficult to calibrate the model to the measured reactive power flow, particularly on feeders in the US where it is common to have multiple switched power factor capacitor banks. Fortunately, it was straightforward to match the reactive power characteristic for the test circuit because it serves mostly residential loads. The power factor of each load was estimated to be 0.95 lagging and was assumed to be invariant for the duration of the simulation. By switching on local current the capacitor switching occurs quite naturally in the simulation. Simulation difficulties with reactive power can arise when capacitors are controlled remotely or by less deterministic quantities.

With a full 3-phase circuit model, all MV/LV transformers, and one LV line modelled for each of the metered loads, there are a total of 3107 electrical nodes in the test circuit. For the AMI case, there were 1779 unique loadshapes, each with 16416 intervals. A full simulation requires approximately 4.5 min to execute on a typical Windows-based modern laptop computer. Thus, this type of analysis is not onerous when the data are available.

LOAD ALLOCATION METHODS

The load allocation methods used in this study were:

- **AMI Allocation** – This is the reference method. It uses the actual kW demand interval measurements for each customer. Each customer has a unique loadshape.

  For each of the loads with AMI, the 15-minute average kW measurements were used directly to define the demand value for each interval of the simulation. The unmetered load values (1% of the total load points) were estimated from the substation kW measurements while compensating for system losses.
- **Transformer kVA Allocation –** This technique is commonly used when better data are unavailable. It uses the total feeder load measurements taken at the feeder head and then allocates a portion to each load point based on the kVA rating of the service transformer. In the test circuit, a transformer often has multiple loads, individually metered. The load allocated to a transformer is allocated to the individual loads for the simulation. The loadshape assumed for each load is the same as the total feeder load.
- **Monthly Usage Allocation** – This method uses the monthly kWh billing to allocate loads to each of the customers and then uses the substation load measurements develop a loadshape that is assigned to all loads. Each customer's kW demand allocation was updated for each month in the simulation. This would be similar to a technique that allocates loads based on a customer's billing information from the previous year. The substation load is allocated to each customer in proportion to the specified monthly – or other period – kWh usage. This technique distributes the kW loading more heavily to those customers using more energy regardless of service transformer size. One assumption inherent in this approach is that the heavier users will be the heavier users throughout the billing period, which is obviously not always true.
- **Class Loadshape Allocations –** This is a method used in some distribution state estimation tools as well as distribution planning tools. It uses a combination of the transformer kVA size along with historical information about the type of load being served. The historical load type information consists of various class loadshapes for customers based on season of the year, day of week, and holidays. The class loadshape is used along with the measured substation demand data to develop the loading level for each load. Knowledge of the load class is required.

RESULTS

The four load allocation methods were compared for accuracy in the following three types of predictions:

1. Prediction of equipment loading
2. Prediction of service voltage magnitudes
3. Prediction of losses

Equipment Loading Evaluation

Loading evaluations of power delivery equipment were conducted by comparing the load current ratings of each line and transformer with calculated operating conditions. The evaluation status for each component was flagged as a "exceeds normal rating" when the loading exceeded 110% of user-defined normal limits. The evaluation status was flagged as "exceeds emergency rating" when loading exceeds 150% of user-defined normal limits. This allows the feeder operator to determine the extent of the overload and the location of the overloads on the system.

The test circuit model showed overloads only with respect to the normal rating and all of the overloads occurred on MV/LV transformers. No overloads were reported on lines and cables.

Table 1 shows the number of overloads identified with each allocation method. The reference method, the AMI simulation, reported a total of 51 instances of overloads. Of the other methods, the monthly usage allocation method reported 27 instances of overload, which was the closest to the AMI method. The substation allocation, the common method that allocates loads based on transformer kVA rating, identified only 5 instances of overload. None of the overloaded transformers found with the kVA rating allocation method were found to be overloaded with the AMI simulation, which is assumed to be accurate. Not only are few overloads identified, but they are misidentified. Note that in the kVA allocation model each customer was modeled separately; therefore, the loading on each transformer was proportioned to the total number of customers connected to it.

Table 1. Number of transformers that exceeded their normal rating.

Number of Transformers Identified that Exceeded their Normal Rating			
AMI	kVA rating	Monthly Usage Allocation	Class Loadshapes
51	5	27	4

In addition to identifying transformer overloads, the AMI metering data can also be used to better optimize transformer asset utililization. Table 2 shows the transformer loading at the feeder peak. 71% of the transformers are loaded less than 50%. This information could allow system planners to better match transformer sizes to loads and reduce no-load, or idling, losses.

Table 2. Transformer loading at feeder peak with AMI allocation.

Transformer Loading at feeder peak with AMI Allocation				
<25%	>25% and <50%	>50% and <75%	>75% and <100%	>100%
34%	37%	19%	7%	3%

Voltage Estimation

Distribution state estimation and voltage optimization both require better estimates of the feeder voltage at various times of the day.

Table 3 shows the minimum service voltage for all customers in the circuit at the time of peak loading. The Monthly Usage Allocation comes closest to the voltages predicted by using AMI data. The minimum voltage predicted by the kVA rating allocation is high by approximately 2 out of 120 V, or 1.7%. On average, the minimum voltage levels are nearly the same for all the allocation methods. Rather than providing a basis for a conclusion on voltage drop, this is more a result of the test circuit having relatively little average voltage drop.

Figure 1 displays a time-series simulation of the voltage at the substation bus. The voltages computed for all four cases match closely; however, only the AMI model causes the capacitor bank farthest downstream to change state due to current exceeding the ON setting. This can become a critical modeling issue when performing distribution state estimation.

Table 3. Minimum customer voltage at feeder peak demand.

Minimum Customer Voltage At Peak			
AMI	kVA rating	Monthly Usage Allocation	Class Loadshapes
119.95	121.85	119.86	121.40

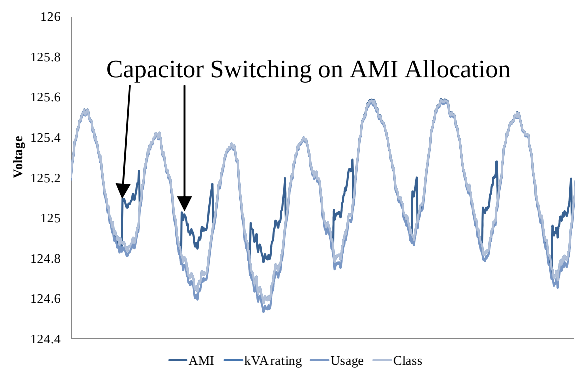

Figure 1. Voltage Computed at the Substation Bus for All Cases.

Loss Estimates

Loss estimates produced by distribution system analysis are sensitive to the assumed load distribution throughout the feeder.

The AMI and Monthly Allocation methods yielded more average losses than the Substation and Class Allocation methods. Both the LV (secondary) and MV (primary) systems showed more losses in these two cases, which is shown in Figure 2. The AMI and Monthly Usage methods each have the same MV line losses; however, the Monthly Usage case shows more LV losses.

All cases showed approximately the same annual no-load losses due primarily to the fact that there was very little voltage drop on this circuit. Thus, the voltages across the service transformers are approximately the same throughout the simulation period.

As for peak losses, the AMI and the Monthly Usage methods again predict higher losses. The AMI method predicts 10% more losses on both the LV and the MV than the traditional Transformer kVA Allocation method. Again, as in the average case, the AMI and Monthly Usage methods have the same MV line losses; however, the Monthly Usage case has more LV losses.

An accurate representation of the LV losses is particularly important for those circuits with long LV lines such as are often encountered in European distribution systems.

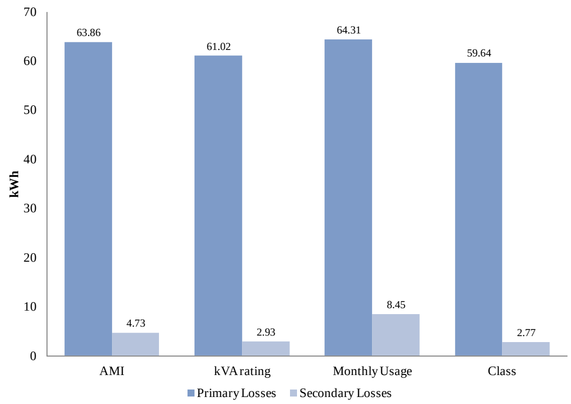

Figure 2. Annual MV and LV Losses.

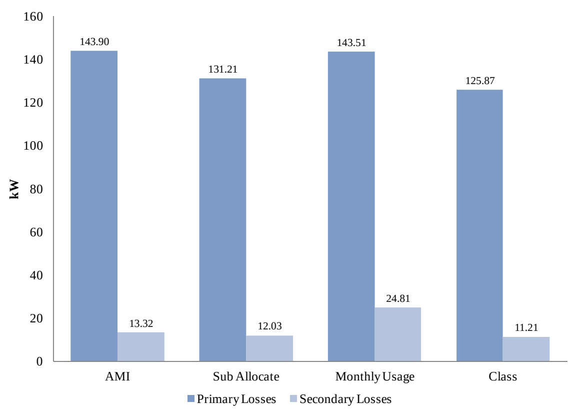

Figure 3. Peak MV and LV Losses.

CONCLUSIONS

The method that is used for estimating the customer load can have a significant impact on distribution system analysis. Some of the general conclusions derived from this example include:

- Loading data from the application of advanced metering infrastructure (AMI) will provide distribution planners with greatly improved predictions of actual system performance, assuming analysis tools are available that can process the data.
- Methods such as allocating based on service transformer kVA rating, not only under-report overloads but can also mis-report overloads. Typically, a kVA allocation only includes a single load at each transformer location and all transformers initially are assigned the same percentage of loading. Few, or no, transformer overloads are reported because all transformers have the same percentage of loading. The test circuit actually resulted in a few transformer overloads due to the way load was allocated for transformers with numerous loads. However, the predicted overloads did not correlate with the transformers found to be overloaded from the AMI data.
- The under loading of transformers can be identified with proper load allocation and transformer sizes may be optimized.
- The AMI and Monthly Usage methods result in nearly the same MV line losses, because the assumed load distribution is approximately the same. This suggests that if AMI data were lacking, the Monthly Usage method would be better than the other methods.
- The Monthly Usage Allocation method tracks the voltage predicted by AMI data more closely than the other allocation methods.
- The use of AMI data can give a better indication of the state of controlled system components such as capacitors.
- General conclusions about the Class Loadshape allocation method cannot be drawn from this example because 99% of the loads were residential.

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