Distribution System State Estimation Using AMI Data

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Abstract– This paper focuses on the use of new data available from the Advanced Metering Infrastructure (AMI) for real time monitoring and control of a distribution system. AMI will provide two new type of data – voltage measurements and power demand at customer sites. This data needs to be processed to get an estimate of operating condition (i.e, the load profile) on a distribution feeder. The paper focuses on the use of a branch current based state estimation (BCSE) method that is adopted for this purpose. BCSE is specially tailored for radial distribution systems and the paper summarizes the enhancements made to adopt the method so that the new data from AMI can be used to improve the accuracy of estimation.

Index Terms—**state estimation, power system monitoring, distribution systems.**

I. INTRODUCTION

Effective management of distribution systems require analysis tools that can estimate the state of the system (the operating condition) and predict the response of the system to changing load and weather conditions. The main tool used for system analysis is the power flow analysis. But this tool is not very suitable for real-time monitoring as it requires accurate load and system data.

Determining the load accurately is a big challenge, as the load at distribution level is highly distributed. For analysis, the ideal load representation will be the load as seen from each distribution transformer on the system. Hence, without extensive monitoring it is difficult to determine the load accurately. The current approach therefore, involves developing "load profiles" for each type of customer (such as residential, commercial, industrial etc), based on some monitoring and energy bill data [1]. This profile approach is based on the observation that the loads of the same type exhibit similar behavior. Since these models give only a rough estimate of the load, the analysis is approximate at best, and therefore, the analysis tools are used mainly for planning purposes.

To improve the load estimation and hence better assess the system operating conditions for system management, recently some utilities have started installing limited SCADA systems at distribution level. These systems usually provide data at the substation level – the power/current on each distribution feeder and the voltage at the substation bus. Some utilities have extended their SCADA to the feeder level to obtain some more measurements (usually current) from the feeder. These measurements provided the opportunity to develop state estimation (SE) algorithms that can use the actual measurements together with the average load data to provide better load estimation and hence system loading conditions. The PI has pioneered the development of such a state estimation method, called BCSE (Branch Current SE), which makes use of the special features of the distribution systems and hence provides a robust and efficient solution [2].

State estimation is a key enabler for any number of "smart grid" applications on the distribution system; these include reactive power management, outage management, loss reduction, demand response, adaptable over-current protection, condition-based maintenance, distributed generation dispatch, integration with transmission system operations, and more. At a February, 2008 DOE meeting hosted by Pacific Northwest National Laboratory (PNNL), state estimation was listed as one of eight non-prioritized requirements for modeling and simulation.

The objective of distribution state estimator (DSE) is to provide robust estimation of operating point (state) for a distribution system on a feeder basis. The goal is to make DSE comparable to what has been available on transmission systems for decades. Classical SE methods work poorly on distribution feeders for several reasons [3-6]:

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- Very few measurements are available, sometimes only the voltage and current at the substation.
- Switch states, capacitor bank states and transformer/regulator taps may not be directly monitored, as they typically are on transmission systems.
- Many of the feeder measurements are current, rather than power (P and Q).
- Three-phase unbalances and low X/R ratios complicate the measurement function

In addition, it's necessary to use historical load data as pseudo-measurements. Due to the radial structure, load and state estimation are practically synonymous for most North American distribution systems.

II. Branch Current Based State estimation

The branch-current-based SE method, like conventional node-voltage-based SE methods, is based on the weighted least square (WLS) approach [4]. Rather than using the node voltages as the system state $\boldsymbol{x}$, the method uses the branch currents and solves the following WLS problem to obtain an estimate of the system operating point defined by the system state x:

$$\min_{x} \;\; J(x) = \sum_{i=1}^{m} w_i (z_i - h_i(x))^2 = [z - h(x)]^T W [z - h(x)]$$

where w_i and $h_i(x)$ represent the weight and the measurements function associated with measurement z_i respectively. For the solution of this problem the conventional iterative method is adapted by solving following normal equations at each iteration, to compute the update $x^{k+1} = x^k + \mathrm{V} x^k$

$$[G(x^k)]\Delta x^k = H^T(x^k) W [z - h(x^k)]$$

where

$$G(x) = H^T(x) W H(x)$$

is the gain matrix and H is the Jacobian of the measurement function $h(x)$.

Hence the only difference between the node voltage based SE and BCSE is the measurement functions associated with the type of measurements to be processed.

The main advantage of the BCSE is that the Jacobian Matrix associated in this case can be decoupled on a phase basis. In addition, the Jacobian is quite well conditioned, and hence the method is much more robust than the conventional SE for radial feeder application.

III. Case Study

To illustrate the capability of BCSE, we used the 34 bus, 23kV, 3-phase radial IEEE test feeder [2,7]. A one-line diagram of the feeder is given in Fig. 1. For test purpose, distributed line section loads are lumped equally at terminal nodes of the line section. The nominal load data is taken as the actual load and the power flow results are used to determine the correct measurements for this load. The minimum voltage for this loading is 0.94 pu., which indicates a heavy loading condition on the feeder. The line data used is given in [7] with line r/x ratios varying between 0.57 and 1.37.

To generate measurement data for testing purposes, measurement error was added to the actual measurements.

$$Z = Z^a \pm e_Z$$

where Z^a is actual data and e_Z is error added based on accuracy of the measurement For simulations, the power and current measurements are assumed to have 2% accuracy.

To illustrate the effect of the additional data from AMI on SE, consider two cases.

Case 1: The real measurement available is at the power measurement at the substation end, mo, and the loads are represented as pseudo-measurements based on the historical data. The accuracy of the loads are assumed to be 30% accurate.

Case 2: We have actual measurements on the feeder as well as load measurements through AMI. Measurements available from the feeder are given in the figure: voltage and power flow at the substation, current measurements on branch 18-19, and voltage measurements on nodes 24, 29 and 33. The load measurements in this case are assumed to have an accuracy of 10%.

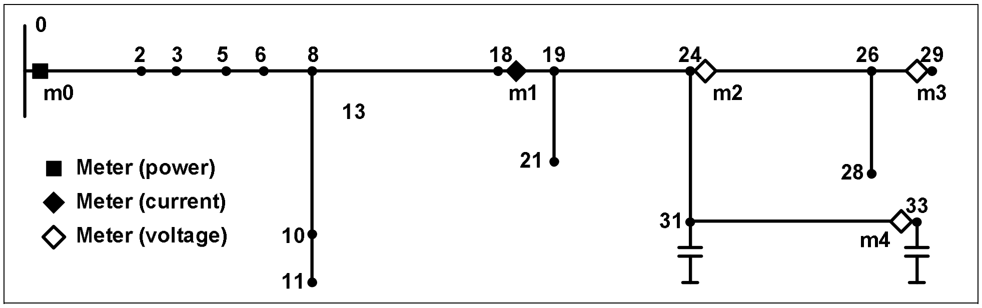

Fig. 1: One-line diagram of reduced feeder

Fig. 2 compares the SE results for these two cases. As the figure shows, the errors in branch current estimates become much smaller when we have the additional data through AMI.

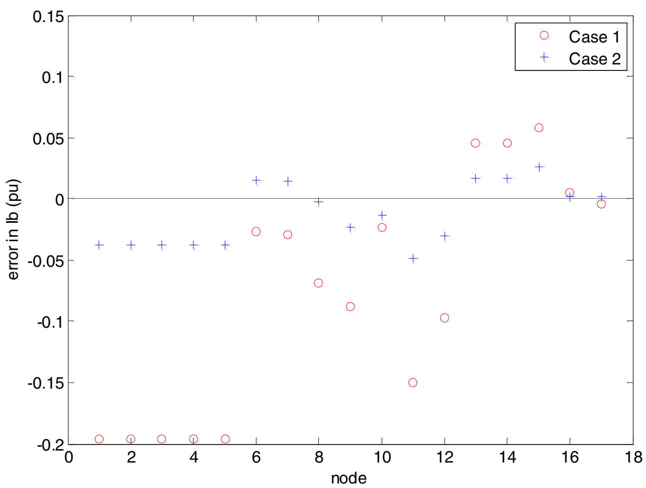

Fig. 2: Error in branch current estimates
(Case 1 is with only measurement at the substation, Case2 is the measurements with AMI)

IV. Conclusions

This paper discusses the application of state estimation for real-time monitoring of distribution systems. It shows that with the availability of new measurements from AMI, such a method can provide quite accurate estimation of operating conditions on a distribution system on a feeder basis.

V. References

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VI. Biographies

Mesut E. Baran (S'87-M'88) is currently an Associate Professor at North Carolina State University in Raleigh, NC. He received his Ph.D. from the University of California, Berkeley in 1988. His research interests include distribution and transmission system analysis and design.

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