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A LINEAR STATE ESTIMATION FORMULATION FOR SMART DISTRIBUTION SYSTEMS

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ABSTRACT

This project presents a linear zed, three-phase, and distribution class state estimation algorithm for applications in smart distribution systems. Unbalanced three-phase cases and single-phase cases are accommodated. The estimator follows a complex variable formulation and is intended to incorporate synchronized phasor measurements into distribution state estimation. Potential applications in smart distribution system control and management are discussed. Index Terms in this project are Distribution management systems, distribution system monitoring and control, distribution system state estimation, power distribution engineering, synchronized phasor measurements, three-phase unbalance.

I. INTRODUCTION

Distribution system monitoring, automation, control and operation are key challenges facing the Smart Grid. Increased efficiency, reliability and flexibility may be achieved through enhancing these features of power distribution. Direct load control, demand response (DR), increased renewable electric generation, and sensory and communication networks are envisioned as part of the Smart Grid. The cited Smart Grid objectives motivate the work reported in this paper, namely state estimation for distribution systems. Three-phase unbalanced radial distribution power flow techniques based on ladder iterative or similar, methods are generally employed for distribution system analysis. However, as utilities tend toward smart distribution systems, the need for enhanced system This work was supported by the Power Systems Engineering Research Center, a Generation III Industry University Cooperative Research Center, under grant NSF EEC-0001880 and EEC-0968993 and the Future Renewable Electric Energy Distribution and Management Center (FREEDM), an Engineering Research Center under grant NSFEEC-08212121.The authors are with the Department of Electrical, Computer, and Energy Engineering, Arizona State University, monitoring and control based on real-time data becomes significant. Smart distribution systems are characterized as having higher penetration of DG, DR enabled loads, and controllable elements. Perhaps integral to the smart distribution system is the distribution management system (DMS) where an information technology (IT) layer allows for enhanced automation and control functions.

Distribution automation (DA) and DM systems may generally include components of voltage or VAR control and outage management. Its transmission engineering analog, energy management system (EMS), is used extensively for near real-time analysis and control. The need for state estimation at the distribution level is particularly acute in the smart distribution applications. For example, monitoring and situational awareness may become necessary for: circuits with active DG injection where potential bi-directional power flows may occur in each phase; exacerbation of voltage unbalance issues due to DG and stochastic loading; and assessment of system conditions after DR enabled loads respond to curtailment commands.

Other key developments in state estimation include incorporation of synchronized phasor measurement devices and smart meter devices. In transmission state estimation, the former enables effective wide-area monitoring for assessment of real-time system state. This is due to its ability to capture measurements in full phasor detail. The latter has recently been adopted by utilities and is expected to drastically enhance monitoring and near real-time data availability for distribution networks. Also automatic meter-reading, remote connect/disconnect and DR initiatives, and variable pricing are enhanced.

II. STATE ESTIMATION FORMULATION FOR ELECTRIC POWER DISTRIBUTION SYSTEMS

State estimation is a mathematical tool in which a set of measurements is combined with an assumed mathematical model of a system so that the resulting set of equations relating measurements to the system are satisfied in the least squares sense. That is, the system states are estimated using an over determined set of equations whose right- and left-hand sides agree with a minimum squared difference. Mathematically, the measurements are arranged in a vector and related to the system states by the vector valued function (of vector valued argument). Attention turns to the development of a three-phase distribution state estimator. The basic design of the estimator is non-iterative, purely real, linear zed and in full phase detail. In the distribution system application, it is assumed that coincident demands (example: smart meter) and selected synchronous measurements will be used. In the formulation below, data shall be represented in complex, rectangular, phasor form. Three-phase unbalanced voltages and current measurements are envisioned along with some branch active and reactive power flow measurements. Measurement vector, the state vector, and the process matrix are complex quantities where the subscripts and refer to real and imaginary components. Note that differentiation with respect to a complex variable is generally non analytic. Therefore is rewritten. Note that residual vector may be separated into real and image.

III. LINEAR THREE-PHASE STATE ESTIMATOR

Attention turns to the development of a three-phase distribution state estimator. The basic design of the estimator is non-iterative, purely real, linearized and in full phase detail. In the distribution system application, it is assumed that coincident demands (e.g., smart meter [22]) and selected synchronous measurements will be used. In the formulation below, data shall be represented in complex, rectangular, phasor form. Three-phase unbalanced voltages and current measurements are envisioned along with some branch active and reactive power flow measurements.

$$r_r + jr_i = (z_r + jz_i) - (h_r + jh_i)(x_r + jx_i).$$

$$\begin{bmatrix} r_r \\ r_i \end{bmatrix} = \begin{bmatrix} z_r - h_r x_r + h_i x_i \\ z_i - h_r x_i - h_i x_r \end{bmatrix}.$$

Then, the minimization of the 2-norm may directly follow (6), where the state variables in this case are real-valued and partitioned into real and imaginary sub-vectors. Direct calculation for the 2-norm of a complex vector is

$$r^H r = (z_r - h_r x_r + h_i x_i)^2 + (z_i - h_i x_r - h_i x_i)^2.$$

IV. DISTRIBUTION SYSTEM MEASUREMENTS

The measurement paucity, characteristic of conventional distribution systems, motivated some researchers to use historical data to supplant measurements to obtain an observable process matrix. However, reliance on historical data with insufficient measurement redundancy may produce inconsistent results when loading patterns deviate from history, or when unexpected outages and topology changes occur. In this case, the estimator may provide spurious results. Exploiting the available real-time data may fulfill the objective of enhanced decision making and control as envisioned for Smart Grid DMS and DA functions.

The state estimation formulation explored here exploits the advantages of the new technologies identified in Section I as they relate to distribution system engineering. That is, the data gathered from smart meters provide the requisite near real-time load measurement and potentially statistical data within short time intervals. Smart meters may record and transmit active and reactive power, energy consumption over time intervals, example 5, 15, 60 min, and voltage magnitude data. Also, synchrophasors are envisioned to provide direct voltage phase angle measurement for distribution buses. The practicality of this implementation is application dependent. Line power Flows and current magnitudes may be ascertained via direct phasor quantity measurement. Note that standards require measurement synchronization to within 1, which corresponds to 0.0216 phase error in a 60-Hz system. Additionally, a maximum phase error of 0.57 produces total vector error (TVE), as defined in, of 1.0% which is the maximum allowable TVE.

In the distribution state estimation formulation, it is assumed that both substation bus voltages and power flows (or current magnitudes) are always available. Other assumptions include sufficient availability of near real-time data (e.g., active and reactive power measurements, some voltage magnitudes and load power factors) to complement the estimator. The measurements may come from smart meters at loads and from distribution class synchrophasors at other buses. Assumed and measured load and DG injection currents are calculated. For example, a constant power load (other models may be used) current injection may be found using where denotes the phase and the voltage angle is assumed near nominal for that phase respectively, when not measured. If measured via synchrophasor, the measured or that of a nearby bus may be used. Currents calculated in are written in linear expressions in terms of the states, namely the bus voltages in rectangular notation. Substation active and reactive power flows may be expressed in terms of real and imaginary part of currents which are also linearly related to the states, particularly since substation bus voltage magnitude is known (as is impedance to the first load node). Other load models may be employed. Field tuning of load models may be required for verification, especially for power flow study accuracy. At the operating point, the solution to the system is linear, irrespective of load model used according to.

The selection of weights for calculated, linearized currents may be approximated mathematically or determined heuristically. Measured and are random variables each with an expected value and variance. Approximate expressions for mean and variance of calculated currents may be obtained when measurements are treated as independent random variables. The expected values of measured variables are, and their variance is chosen based on transducer accuracy. Attention now turns to the approximation of variance of the calculated current. The expectation of real and imaginary parts of (respectively) may be approximated from the nonlinear function Figure. 1. (Left) RBTS one-line diagram showing bus 3 distribution subsystem and load points (LP), recreated from [34]; and (right) flowchart for the state estimation algorithm that runs continuously at the distribution substation. The variance of (and similarly) may be approximated from the Taylor series expansion, also commonly referred to as the delta method Variance of is similarly approximated. Alternatively, a heuristic approach may be taken: the variance of and may be approximated by choosing a value corresponding to the largest variance (normalized) of all random variables, truncate the sum in to only the largest term.

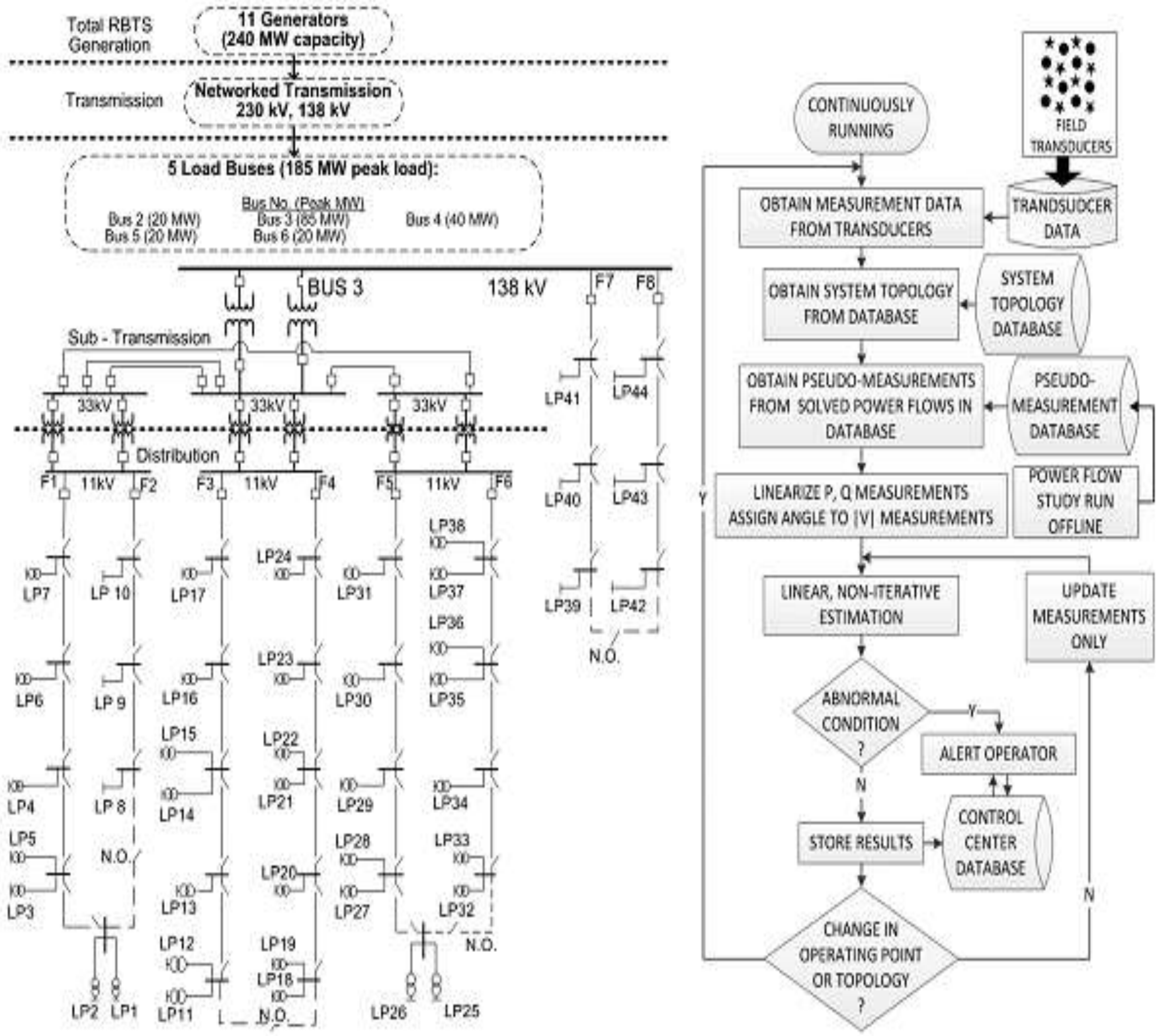

Fig. 1. (Left) RBTS one-line diagram showing bus 3 distribution subsystem and load points (LP), recreated from and (right) flowchart for the state estimation algorithm that runs continuously at the distribution substation

Figure 1 presents the one-line diagram for a sample distribution test system, denominated RBTS after its creator Roy Billiton. Voltages range from 400 V–138 kV. Feeder F1 of this Control theory is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems. The desired output of a system is called the reference. When one or more output variables of a system need to follow a certain reference over time, a controller manipulates the inputs to a system to obtain the desired effect on the output of the system. The usual objective of control theory is to calculate solutions for the proper corrective action from the controller that result in system stability, that is, the system will hold the set point and not oscillate around it.

V. EXPERIMENTAL RESULTS

Fig. 1 presents the one-line diagram for a sample distribution test system, denominated RBTS after its creator Roy Billinton [34]. Voltages range from 400 V–138 kV. Feeder F1 of this system is modified to represent a three-phase unbalanced distribution circuit with DG as shown in Fig. 2. Note that laterals may contain single and two phase conductors and loads/load points (LP). Conductor details are provided in Table I. Power and voltage bases are 100 MVA, 11 kV, and 415 V.

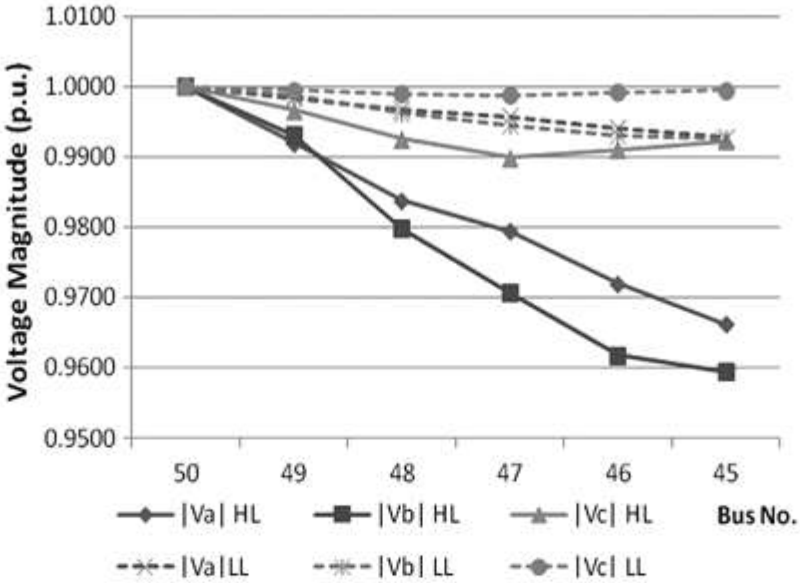

Fig. 2. Main feeder bus voltage magnitudes at heavy load (HL) and light (LL) load, RBTS feeder F1 (all examples)

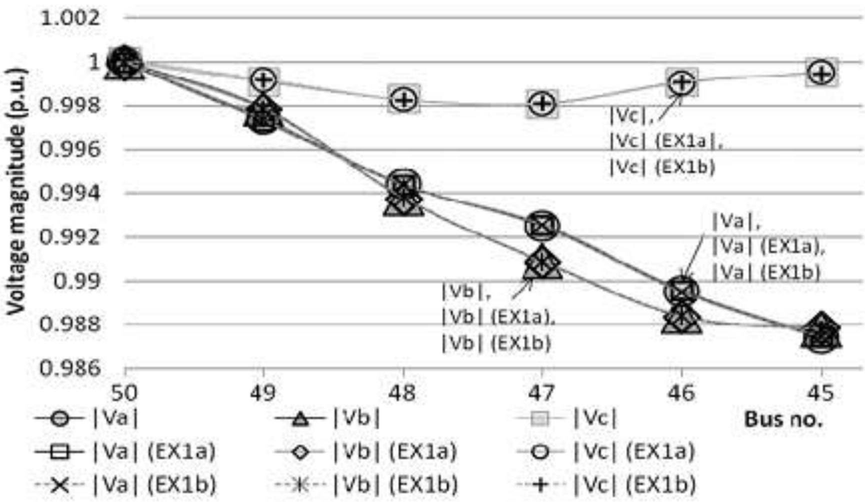

Fig. 3 Main feeder voltage magnitudes in HE5; exact data depicted from a three-phase power flow study, EX1a, EX1b

VI. CONCLUSIONS

The well known weighted least squares method is used to develop linear, non-iterative power system static state estimator for three-phase unbalanced distribution systems. The estimator is envisioned as a tool to aid system monitoring, automation and control efforts in a Smart Grid environment. Decision making based on real-time information communication and better control algorithms are made possible. The formulation presented and examples incorporate smart meter data and synchronized phasor measurements at the primary distribution level. Estimator performance is illustrated on a range of feeder loading conditions. Biasing measurements is shown to increase expected accuracy. In the examples shown, relying on trusted measurements results in nearly an order of magnitude accuracy improvement in voltage magnitude and angle estimates, and also reduced calculated current magnitude errors from 15% down to 4%. Knowledge of bus voltage phase angle from synchronized phasor measurements improves the state estimation process for power systems, and is shown here for distribution circuits. The practicality of large scale deployment of synchrophasors measurements in distribution systems is unknown. Direct measurement of bus voltage angle may be useful in distribution circuits for ascertaining power flows (both directions and magnitudes). DG injections and loading conditions of feeders may create an interesting case of bidirectional power flow. The estimator formulation presented here is shown to be comparable to conventional estimation formulation of positive sequence quantities only, but the proposed formulation has the advantage of providing full three-phase detail. Bad data detection is illustrated on the test system.

REFERENCE

[1] R. E. Larson, W. F. Tinney, L. P. Hajdu, and D. S. Piercy, "State estimation in power systems part II: Implementation and applications," IEEE Trans. Power App. Syst., vol. PAS-89, no. 3, pp. 353–363, 1970.

[2] I. Roytelman and S. M. Shahidehpour, "State estimation for electric power distribution systems in quasi real-time conditions," IEEE Trans. Power Del., vol. 8, no. 4, pp. 2009–2015, Oct. 1993.

[3] M. E. Baran and A. W. Kelley, "State estimation for real-time monitoring of distribution systems," IEEE Trans. Power Syst., vol. 9, no. 3, pp. 1601–1609, Aug. 1994.

[4] M. E. Baran and A. W. Kelley, "A branch-current based state estimation method for distribution systems," IEEE Trans. Power Syst., vol. 10, no. 1, pp. 483–491, Feb. 1995.

[5] C. N. Lu, J. H. Teng, andW. E. Liu, "Distribution system state estimation," IEEE Trans. Power Syst., vol. 10, no. 1, pp. 229–240, Feb. 1995.

[6] R. Billinton and S. Jonnavithalu, "A test system for teaching overall power system reliability assessment," IEEE Trans. Power Syst., vol. 11, no. 4, pp. 1670–1676, Nov. 1996.

[7] O. Alsac, N. Vempati, B. Stott, and A. Monticelli, "Generalized state estimation," IEEE Trans. Power Syst., vol. 13, no. 3, pp. 1069–1075, Aug. 1998.

[8] A. Monticelli, "Electric power system state estimation," Proc. IEEE, vol. 88, no. 2, pp. 262–282, Feb. 2000.

[9] R. Ebrahimian and R. Baldick, "State estimator condition number analysis," IEEE Trans. Power Syst., vol. 16, no. 2, pp. 273–279, May 2001.

[10] Office of Electric Transmission and Distribution, United States Department of Energy, Grid 2030: A National Vision for Electricity's Second 100 Years. Washington, DC, Apr. 2003.

[11] J. Northcote-Green and R. G.Wilson, Control and Automation of Electrical Power Distribution Systems. Boca Raton, FL: CRC, 2006.

[12] W. H. Kersting, Distribution System Modeling and Analysis, 2nd ed. New York: CRC, 2007.

[13] A. J. Wood and B. F. Wollenberg, Power Generation Operation and Control, 2nd ed. New York: Wiley, 2007.

[14] R. Singh, B. C. Pal, and R.A. Jabr, "Choice of estimator for distribution system state estimation," IET Gen., Transm., Distrib., vol. 3, no. 7, pp. 666–678, Jul. 2009.

[15] A.G. Phadke and J. S. Thorp, Synchronized Phasor Measurements and Their Applications. New York: Springer, 2010.

[16] D. Wight et al., Assessment of Demand Response and Advanced Metering Staff Report, U.S. Federal Energy Regulatory Commission, Feb. 2011.

[17] S. Mak, "Smart meters serving as synchro-sensors for smart distribution grid applications," in Proc. IEEE PES General Meeting, Detroit,MI, Jul. 2011.