STATE ESTIMATION USING ARDUINO

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Abstract—In order to understand the concept of power system state estimation it is very much necessary to understand the concept of state estimation, both theoretically and practically. In this paper an attempt has been made to demonstrate the concept of state estimation practically by using simple DC circuit, ARDUINO and MATLAB software.Weighted least square method is used for state estimation, also result of MATLAB program for power system state estimation are discussed in brief
Index Terms—State Estimation, MATLAB, ARDUINO

I. INTRODUCTION

The operation and control of power system requires exact knowledge of power system states i.e voltage magnitude and phase angle at each bus. The conventional power flow can obtain these power system states, but even one of inputs to power flow is unavailable, the conventional power-flow solution cannot be obtained. Moreover, gross errors in one or more of the input quantities can cause the power-flow results to become useless. In case of state estimation, measurements like real and reactive power injection at each bus or real and reactive line power flows can estimate states of power system accurately. Even few measurements are not available, or there are errors in measurements still state estimation by weighted least square error can estimate states of power system accurately.

II. STATE ESTIMATION

State estimation is the process of estimation of some variables which either can not be measured directly or their measurement becomes quite complex (e.g flux in case of induction motor).Even some parameters in models of system can be estimated using state estimation. This estimation process is carried out with the help of certain measurements. The weighted least square error method is used for state estimation.

III. WEIGHTED LEAST SQUARE ERROR METHOD

Consider following circuit
By applying KVL to 3 loops we will get

V1 − R1 ∗ I1 − R4 ∗ (I1 − I2) = 0
(R1 + R4) ∗ I1 − R4 ∗ I2 + 0 ∗ I3 = V1 (1)
−R4 ∗ (I2 − I1) − R2 ∗ I2 − R5 ∗ (I2 − I3) = 0
R4 ∗ I1 − (R2 + R4 + R5) ∗ I2 + R5 ∗ I3 = 0 (2)
−R5 ∗ (I3 − I2) − R3 ∗ I3 − V2 = 0
0 ∗ I1 + R5 ∗ I2 − (R3 + R5) ∗ I3 = V2 (3)

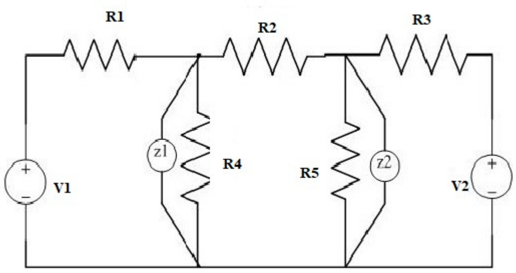

Fig. 1 The above equations can be written in matrix format as

$$\begin{bmatrix} (R_1+R_4) & -R_4 & 0 \\ R_4 & -(R_2+R_4+R_5) & R_5 \\ 0 & R_5 & -(R_3+R_5) \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_1 \\ 0 \\ V_2 \end{bmatrix}$$

$$I_1 = \frac{\Delta I_1}{\Delta}$$

$$= \frac{det \begin{bmatrix} V_1 & -R_4 & 0 \\ 0 & -(R_2+R_4+R_5) & R_5 \\ V_2 & R_5 & -(R_3+R_5) \end{bmatrix}}{(R_1+R_4) \times ((R_2+R_4+R_5)*(R_3+R_5) - R_5^2) + R_4 \times (-(R_3+R_5)*R_4) + 0}$$

$$I_1 = \frac{V_1((R_2+R_4+R_5)*(R_3+R_5) - R_5^2) + R_4(-R_5 V_2)}{(R_1+R_4) \times ((R_2+R_4+R_5)*(R_3+R_5) - R_5^2) + R_4 \times (-(R_3+R_5)*R_4) + 0}$$

$$I_1 = K_1' V_1 - K_2' V_2$$

similarly

$$I_2 = K_3' V_1 - K_4' V_2$$
$$I_3 = K_5' V_1 - K_6' V_2$$
$$Z_1 = R_4(I_1 - I_2)$$
$$Z_2 = R_5(I_2 - I_3)$$
$$Z_1 = K_1 V_1 + K_2 V_2$$
$$Z_2 = K_3 V_1 + K_4 V_2$$

These are the measured values, so there may be some errors, let these errors be e_1 and e_2 and let $X_1 = V_1$ and $X_2 = V_2$ are states to be estimated. Therefore the above equation becomes,

$$Z_1 = K_1 X_1 + K_2 X_2 + e_1$$

$$Z_2 = K_3 X_1 + K_4 X_2 + e_2$$

In matrix form above equation can be written as

$$\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix} = \begin{bmatrix} K_1 & K_2 \\ K_3 & K_4 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix}$$

$$\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \end{bmatrix}$$

$$Z = H * X + e$$

$$\begin{bmatrix} e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \end{bmatrix} - \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$$

$$e = Z - H * X$$

$$\hat{e} = Z - H * \hat{X} \qquad (4)$$

The true values of X_1 and X_2 can not be determined,but we can calculate estimates $\hat{X}_1$ and $\hat{X}_2$ We need to estimate X such that sum of errors will be minimized, but since some errors can be positive and some can be negative, it is better to minimize the direct sum of square of errors. Measurements from meters of known greater accuracy are treated more favorably than less accurate measurements. Each term in the sum of square is multiplied by an appropriate weight factor 'w'to give the objective function

$$f = \sum_{i=1}^{i=2} W_i e_i^2 = W_1 e_1^2 + W_2 e_2^2 \qquad (5)$$

$\hat{X}_1$ and $\hat{X}_2$ are chosen such that f is minimum. so taking partial derivative of f w.r.t. $\hat{X}1$ and $\hat{X}2$ and equating to zero.

$$\frac{\partial f}{\partial \hat{X}_1} = 2W_1 e_1 \frac{\partial e_1}{\partial \hat{X}_1} + 2W_2 e_2 \frac{\partial e_2}{\partial \hat{X}_1} = 0 \qquad (6)$$

$$\frac{\partial f}{\partial \hat{X}_2} = 2W_1 e_1 \frac{\partial e_1}{\partial \hat{X}_2} + 2W_2 e_2 \frac{\partial e_2}{\partial \hat{X}_2} = 0 \qquad (7)$$

$$\begin{bmatrix} \frac{\partial e_1}{\partial \hat{X}_1} & \frac{\partial e_2}{\partial \hat{X}_1} \\ \frac{\partial e_1}{\partial \hat{X}_2} & \frac{\partial e_2}{\partial \hat{X}_2} \end{bmatrix} \begin{bmatrix} W_1 & 0 \\ 0 & W_2 \end{bmatrix} \begin{bmatrix} \hat{e_1} \\ \hat{e_2} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} -h_{11} & -h_{21} \\ -h_{12} & -h_{22} \end{bmatrix} \begin{bmatrix} W_1 & 0 \\ 0 & W_2 \end{bmatrix} \begin{bmatrix} \hat{e_1} \\ \hat{e_2} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$H^T W \hat{e} = 0$$

$$H^T W (z - H\hat{X}) = 0$$

$$H^T W z = H^T W H \hat{X}$$

$$\hat{X} = (H^T W H)^{-1} H^T W z$$

$$\hat{X} = (G)^{-1} H^T W z$$

where G = H^T W H H is network topolog dependent matrix, W is weight matrix (which is inversely proportional to variance of measurement).If variation in measurement is more, weight corresponding to that reading is less.

IV. CASE STUDY

The same circuit as shown in fig 1 is used with all resistances R_1, R_2, R_3, R_4, R_5 = 10kΩ, V1 = 5 V and V2 = 3.3V. Z_1 and Z_2 are voltage measurements through analog pins A0 and A5 of arduino respectively. The MATLAB simulink model has been created to interface arduino and MATLAB as shown in fig 2. A callback has been written, in which the weight matrix is defined and X1 and X2 are estimated.The estimated values are displayed in command window as shown in fig 3. The experimental setup is as shown in fig 4.

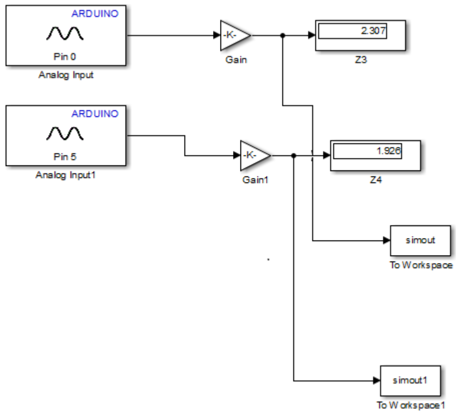

Fig.2:simulink diagram

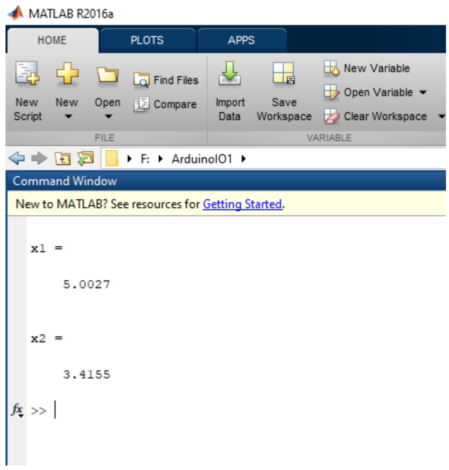

Fig.3:command window

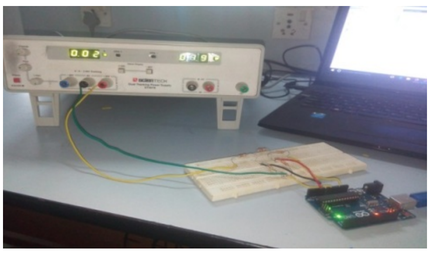

Fig.4:experimental setup

V. CONCLUSION

This paper successfully demonstrates a practical approach to understanding the fundamental concept of power system state estimation using a simple DC circuit, Arduino microcontroller, and MATLAB software. By applying the weighted least squares method, the states of the system (voltages at two nodes) were estimated even in the presence of measurement errors. The experiment validates that accurate state estimation can be achieved using minimal hardware and cost-effective tools, making it an ideal educational model for students and enthusiasts. The integration of MATLAB and Arduino pro- 3 vided a powerful and flexible environment for real-time data acquisition and computation, bridging the gap between theoretical understanding and practical implementation of power system analysis.

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