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FAST SUPER DECOUPLED STATE ESTIMATOR WITH VOLTAGE MAGNITUDE MEASUREMENTS

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ABSTRACT

This paper presents a new evaluation of the performance of the fast super decoupled state (FSDS) estimator when using voltage magnitude measurements as well as injection and flow measurements. The FSDS estimator is tested on different IEEE test systems with low R/X ratio lines and on distribution systems with high R/X ratio lines. Comparison is made with respect to the fast decoupled state (FDS) estimator. The results indicate that the FSDS estimator is capable of handling all type of measurements like injections, flows and voltage magnitudes. The FSDS estimator performs efficiently like the FDS estimator on systems with low R/X ratio lines. However, for systems with high R/X ratio lines, the FSDS estimator is superior to the FDS estimator.

Keywords

Fast decoupled state estimator, fast super decoupled state estimator, voltage magnitude measurements.

1. INTRODUCTION

Power system state estimation (SE) is a technique by which the state of a power system (usually magnitude and angle of bus voltages) is determined using raw measurements. The results of the state estimation are used for realtime security analysis, optimal power flow, etc. It is also exploited to filter redundant data, to eliminate incorrect measurements and to produce reliable state estimates. Most of the SE algorithms proposed in the literature have been based on weighted least-square (WLS) approach [1-3]. The need for an efficient algorithm that minimum memory and requires lower computational time has led to the

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development of fast decoupled state (FDS) estimator [4-6] based on P-Ө and Q-V decoupling used in fast decoupled power flow. The rate of convergence of the FDS estimator is strongly influenced by the coupling between P-Ө and Q-V mathematical models. This coupling increases with system loading levels and branch R/X ratios, and consequently the convergence rate decreases. The decoupled method either fails to provide a solution or results in oscillatory convergence on ill-conditioned power systems [7].

A fast super decoupled state (FSDS) estimator has been proposed in [8]. In this estimator, the functions describing the state and measurement are rotated in a direction such that the effects of low or high R/X ratios are eliminated. The rotation would reveal an automatic decoupling of the active and reactive equations, which lead to faster convergence than the FDS estimator for systems having high R/X ratio lines [8].

A fuzzy clustering and a pattern matching method, for power system state estimation has been generated based on the analog measurement vector in [9]. A complex artificial neural network has been used to adjust the link weighting in power system bad data analysis and estimation in [10]. An adaptive Kalman filter has been introduced for real-time power system state estimation in [11], but Kalman filter achieve optimal performance only when the system noise characteristics have known statistical properties [12]. A power system WLS state estimation method integrating a wide-area measurement system and SCADA technology has been proposed in [12].

The FSDS estimator has been proposed using complex measurements (injections and flows) only. However, the measurements vector includes injections and flows as well as voltage magnitudes. The performance of the FSDS estimator with voltage magnitude measurements is not precisely known. Also, best rotation angles for this method, for all systems, when using all type of measurements are not available in the literature. The performance of the FSDS estimator including voltage magnitude measurements is evaluated in this paper. The approach presented in this paper is simulated using the IEEE 30-bus, 57-bus and 118-bus transmission systems as well as 31-bus, 33-bus and 36-bus distribution systems. A comparison of the FSDS estimator with the FDS estimator is emphasized.

2. TRANSFORMATION TECHNIQUE

The complex conjugate of any measurement (injection, line flow) is:

$$Z_s = Z_{a-} jZ_r \tag{1}$$

Multiplying both sides of Eqn. (1) by a rotational operator $C_p = e^{j\Psi}$

$$Z_s e^{j\Psi} = (Z_{a-} jZ_r)(\cos\Psi + j\sin\Psi)$$

$$Z_s e^{j\Psi} = (Z_a \cos\Psi + Z_r \sin\Psi) - j(-Z_a \sin\Psi + Z_r \cos\Psi) \tag{2}$$

Concisely,

$$Z'_S = Z'_a - jZ'_r \tag{3}$$

From Eqns.(2) and (3), the transformed measurements are defined as:

$$Z'_a = Z_a \cos\Psi + Z_r \sin\Psi$$
$$Z'_r = -Z_a \sin\Psi + Z_r \cos\Psi \qquad (4)$$

Where,

Z'_S = transformed complex measurement

Z'_a = transformed active measurement

Z'_r = transformed reactive measurement

Ψ = rotation angle

3. THE MODIFIED FSDS ESTIMATOR

The FSDS estimator [8] is given by the following mathematical model:

$$[Y'^t_{aa}\ W_a Y'_{aa}]\ [\Delta\delta] = [Y'^t_{aa} W_a][\Delta Z'_a]$$
$$[Y'^t_{rr}\ W_r Y'_{rr}]\ [\Delta V] = [Y'^t_{rr} W_r][\Delta Z'_r] \qquad (5)$$

Where,

$\Delta\delta$, ΔV = voltage angle, magnitude corrections.

$\Delta Z'_a$, $\Delta Z'_r$ = transformed active and reactive measurement residuals.

Y'_{aa}, Y'_{rr} =Jacobian matrices.

The transformed active and reactive measurement residuals ($\Delta Z'_a$ and $\Delta Z'_r$) are given by (for injection measurements at node p):

$$\Delta Z'_a = (\Delta P_p \cos\Psi + \Delta Q_p \sin\Psi)/V_p$$
$$\Delta Z'_r = (-\Delta P_p \sin\Psi + \Delta Q_p \cos\Psi)/V_p \qquad (6)$$

Similarly, for line flow measurements between nodes p and q, the transformed active and reactive measurement residuals ($\Delta Z'_a$ and $\Delta Z'_r$) are given by:

$$\Delta Z'_a = (\Delta P_{pq} \cos\Psi + \Delta Q_{pq} \sin\Psi)/\sqrt{V_p V_q}$$
$$\Delta Z'_r = (-\Delta P_{pq} \sin\Psi + \Delta Q_{pq} \cos\Psi)/\sqrt{V_p V_q} \qquad (7)$$

Also, for voltage magnitude measurements at node p, the reactive measurements residual ($\Delta Z'_r$) is given by:

$$\Delta Z'_r = \Delta E_p \qquad (8)$$

The Jacobian matrices Y'_{aa} and Y'_{rr} are given by:

$$Y'_{aa}=\begin{bmatrix} Y_1 \\ Y_3 \end{bmatrix} \quad , \quad Y'_{rr}=\begin{bmatrix} Y_2 \\ Y_4 \\ Y_5 \end{bmatrix} \qquad (9)$$

The elements of the Jacobian submatrices Y_1, Y_2, Y_3, Y_4 and Y_5 are given as follows,

For injection measurements:

$$Y_1(p,q) = Y_2(p,q) = -Y_{pq}$$
$$Y_1(p,p) = Y_2(p,p) = \textstyle\sum_{q\neq p} Y_{pq} \qquad (10)$$

For line flow measurement:

$$Y_3(p,q)_q = Y_4(p,q)_q = -Y_{pq}$$
$$Y_3(p,q)_p = Y_4(p,q)_p = Y_{pq} \qquad (11)$$

For voltage magnitude measurements:

$$Y_5(p,q) = 0.0$$
$$Y_5(p,p) = 1.0 \qquad (12)$$

Where,

$Y_{pq} =$ amplitude of pqth element of nodal admittance matrix formed excluding shunts.

4. TEST RESULTS

4.1 Measurements System Configuration

Studies are carried out on six test systems. The first three are the IEEE 30-bus, 57-bus and 118-bus transmission systems with low R/X ratio lines [13]. The other systems are 31-bus, 33-bus and 36-bus distribution systems with high R/X ratio lines [14]. In the six test systems, injection measurements in all buses, except the reference bus, are considered. Five voltage magnitude measurements are considered for each system. Moreover, 53, 107, 229, 55, 59 and 65 line flow measurements are considered in the six systems, respectively. The standard deviations of the errors are set to 0.2% of the full-scale plus 1% of the true values for the power injection and flow measurements. The full-scale value of all the meters are assumed to be 1 p.u. A standard deviation of 0.1% of the true value has been set to voltage magnitude measurements. The FSDS and FDS estimators are tested with a redundancy of 2.0 for the six test systems. A tolerance of 0.0001 p.u. is used to terminate the execution in the two methods.

4.2 Performance Indices

The following two performances indices are used to judge the quality of estimates produced by the two estimators:

$$S_v = [\tfrac{1}{n}\textstyle\sum_{i=1}^{n}(\widehat{V}_i - V_{i(true)})^2]^{0.5}$$
$$S_\delta = [\tfrac{1}{n}\textstyle\sum_{i=1}^{n}(\widehat{\delta}_i - \delta_{i(true)})^2]^{0.5} \qquad (13)$$

a. Performance Evaluation of the FSDS and FDS Estimators

In Tables 1 and 2, the FDS and FSDS estimators are tested on the IEEE 30-bus, 57-bus and 118-bus systems with low R/X ratio lines. In Tables 3 and 4, the two estimators are tested on the 31-bus, 33-bus and 36-bus distribution systems with high R/X ratio lines.

The results of Tables 1-4 indicate that the FSDS estimator can be applied efficiently using voltage magnitude measurements as well as injection and flow measurements. The FSDS estimator performs efficiently like the FDS estimator for systems having low R/X ratio lines. However, the FSDS estimator is faster than the FDS estimator for systems having high R/X ratio lines as clear in Tables 3 and 4.

Table 1: Performance evaluation of the FDS estimator (systems having low R/X ratio lines)

	30-bus	57-bus	118-bus
No. of Iterations	4	5	8
Time	0.02	0.03	0.29
$S_v x10^4$	4.292	14.348	11.845
$S_\delta x10^4$	15.699	6.694	27.646

0.5 =half iteration for calculating ΔΘ or ΔV

Table 2: Performance evaluation of the FSDS estimator (systems having low R/X ratio lines)

	30-bus	57-bus	118-bus
No. of Iterations	4	4.5	5.5
Time	0.02	0.03	0.26
$S_v x10^4$	4.102	15.472	17.018
$S_\delta x10^4$	15.561	6.252	21.728

0.5 =half iteration for calculating ΔΘ or ΔV

Table 3: Performance evaluation of the FDS estimator (systems having high R/X ratio lines)

	31-bus	33-bus	36-bus
No. of Iterations	11	8.5	7
Time	0.03	0.02	0.02
$S_v x10^4$	1.541	6.997	1.101
$S_\delta x10^4$	0.944	4.489	0.787

0.5 =half iteration for calculating ΔΘ or ΔV

Table 4: Performance evaluation of the FSDS estimator (systems having high R/X ratio lines)

	31-bus	33-bus	36-bus
No. of Iterations	5	4	4
Time	0.01	0.01	0.01

$S_v x 10^4$	1.378	6.899	0.760
$S_\delta x 10^4$	1.405	4.579	0.853

0.5 =half iteration for calculating ΔΘ or ΔV

b. Best Rotation Angles For the FSDS Estimator

In the FSDS estimator, the Jacobian and gain matrices are made independent of the rotation angle which is involved in the iterative process as given in Eqns. 6 and 7. The effect of rotation angle on the convergence is shown in Tables 5 and 6 for systems having low and high R/X ratio lines, respectively. Tables 5 and 6 indicate that the convergence is sensitive to the rotation angle for all systems. Best convergence of the FSDS estimator is obtained when the rotation angle equals-15 degrees and -45 degrees for systems having low and high R/X ratio lines, respectively.

Table 5: Effect of the rotation angle
(Systems having low R/X ratio lines)

Rotation Angle (degree)	30-bus	57-bus	118-bus
	No. of iterations		
0	4.5	6	6
-5	4.5	5.5	6
-10	4	5	6
-15	4	4.5	5.5
-20	4	5	6
-25	4	5.5	6.5
-30	5	6	7
-35	5.5	6.5	7
-40	5.5	6.5	7.5
-45	7	8	7.5
-50	8.5	9.5	8.5

0.5 =half iteration for calculating ΔΘ or ΔV

Table 6: Effect of the rotation angle
(Systems having high R/X ratio lines)

Rotation Angle (degree)	31-bus	33-bus	36-bus
	No. of iterations		
-20	10.5	7	7
-25	9	6	6
-30	7.5	5.5	5.5

-35	6	5	4.5
-40	5.5	4	4
-45	5	4	4.5
-50	5	4	4.5
-55	5	4.5	5.5
-60	6	4.5	6
-65	6	5.5	6
-70	7.5	6	7.5

0.5 =half iteration for calculating ΔΘ or ΔV

5. CONCLUSIONS

The FSDS estimator is tested with voltage magnitude measurements as well as injection and flow measurements. The following conclusions can be drawn:

1) The FSDS estimator is efficient in handling all types of measurements like injections, flows and voltage magnitudes.

2) For systems having low R/X ratio lines, the FSDS estimator performs efficiently like the FDS estimator.

3) For systems having high R/X ratio lines, the FSDS estimator is faster than the FDS estimator.

4) Best convergence of the FSDS estimator is obtained when the rotation angle equals-15 degrees and -45 degrees for systems having low and high R/X ratio lines, respectively.

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