RESEARCH NOTE

ON LINE ELECTRIC POWER SYSTEMS STATE ESTIMATION USING KALMAN FILTERING

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Abstract In this paper principles of extended Kalman filtering theory is developed and applied to simulated on-line electric power systems state estimation in order to trace the operating condition changes through the redundant and noisy measurements. Test results on IEEE 14 - bus test system are included. Three case systems are tried; through the comparing of their results, it is concluded that the proposed dynamic estimator have great advantage over the static state estimation in its accuracy and real time implementation.

Key Words State Estimation, Kalman filter, Power Systems

چکیده در مقاله حاضر ابتدا مروری بر تخمین حالت دینامیکی و نظریه فیلتر کالمن صورت گرفته و سپس از نظریه فیلتر کالمن برای تخمین حالت دینامیکی سیستم های قدرت استفاده می گردد. در این مطالعه مشاهده می گردد که فیلتر کالمن نیاز شدیدی به اطلاعات صحیح در مورد ماتریس کوواریانس خطای روند Q و ماتریس کوواریانس خطای اندازه گیری R دارد. چگونگی دسیابی به این دو ماتریس به عنوان مجهولات مسئله تلقی گردیده و توسط روشهای مختلفی مورد بررسی قرار می گیرد. سپس نظریه تخمین حالت دینامیکی (فیلتر کالمن) در مورد سیستمهای قدرت خطی و غیرخطی توسعه داده شده ۱۴ با سه مورد آزمایش قرار گرفته و نتایج کامپیوتری مورد بررسی قرار می گیرد.

INTRODUCTION

In this paper statistical properties for the detection and identification of a power system are developed. The implementation aspects are presented together with experimental results from test results on simulation studies for the IEEE 14-bus test system. Three test case systems are tried. Comparing the results, it is concluded that the proposed dynamic estimator have great advantages over the static state estimation in it's accuracy and real time implementation. Furthermore, it is concluded that the line flow measurements are more suitable measurement sets than any other available measurement in the power system.

ELECTRIC POWER SYSTEMS STATE ESTIMATION BASED ON KALMAN FILTER

In application of Kalman filtering theory to power system state estimation problem, two mathematical models are required: a model of the time behavior of the system state and a model of the measurement system. Inherently the set of equations describing the power systems behavior are nonlinear. These equations are functions of the bus phase angles ($\underline{\delta} = [\delta_1, \delta_2, \ldots, \delta_n]^T$) and bus voltage magnitudes ($\underline{V} = [v_1, v_2, \ldots, v_n]^T$). The bus voltage angles and magnitudes are considered the network's state variables [1]. The knowledge of variables allows us to calculate other network's parameters. Thus, for an electric power system, with N buses, we introduce the (2N-2) state vector of $\underline{X}$ as follows [2,3]:

$$\underline{X} = \begin{bmatrix} \underline{\delta} \\ --- \\ \underline{V} \end{bmatrix} \tag{1}$$

In the utilization of the system equation within time interval of t_i to t_{i+1}, the state estimate and covariance matrix are reproduced to the following update equations

$$\underline{\hat{X}}^{-}_{i+} = \emptyset_i \underline{X}_i^{+} \tag{2}$$

and

$$P^{-}_{i+1} = \emptyset_i P^{+}_i \emptyset^{T}_i + Q_i \tag{3}$$

Where

$\underline{X}_i^{+}$ = the optimal state variables estimation just after time t_i,

$\underline{X}_i^{-}$ = A priori estimation of the state variables just before time t_i,

K_i = Kalman gain matrix,

P_i^{-} = the optimized value of a priori estimation error covariance matrix,

P_i^{+} = the optimized value of a posteriori estimation error covariance matrix.

for normal operating condition it is a reasonable assumption to consider the state transition matrix as a unity matrix. i.e.

$$\emptyset = I \tag{4}$$

thus

$$\underline{X}_{i+} = \underline{X}_i + \underline{\omega}_i \tag{5}$$

SIMULATION RESULTS

IEEE 14-bus system is selected for simulation purposes. The loads in the system are simulated such that they could change randomly. Then fast decoupled load flow is run as a base case. The measurement set can be selected arbitrarily from any combination of bus voltage magnitudes, bus injection powers, and line flow measurements. However, the three cases which are tested follows:

Case 1. All the bus voltage magnitudes are treated as measurements.

Case 2. All the line flows are treated as measurements.

Case 3. All the bus injection power (active and reactive) are treated as a measurement set.

Here not only all the measured variables are estimated, the unmeasured and/or unmeasurable variables are also estimated. Figure 1 shows the performance of the proposed estimator for typical bus from simulation system. From this figure it can be concluded that the line flow measurements are better measurements than injection bus power measurements and bus voltage magnitude measurements. Figure 2 shows phase angle of bus voltage which is the unmeasured parameter for simulation system. Again when line flow measurements are used, the unmeasurable or unmeasured parameters of the system can be estimated with more accuracy. The normalized residuals are calculated and the largest ones for each

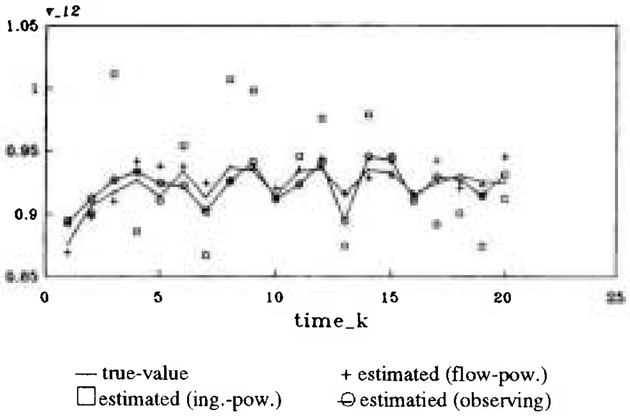

Figure 1. 14- Bus System Votage Magnitude Estimation.

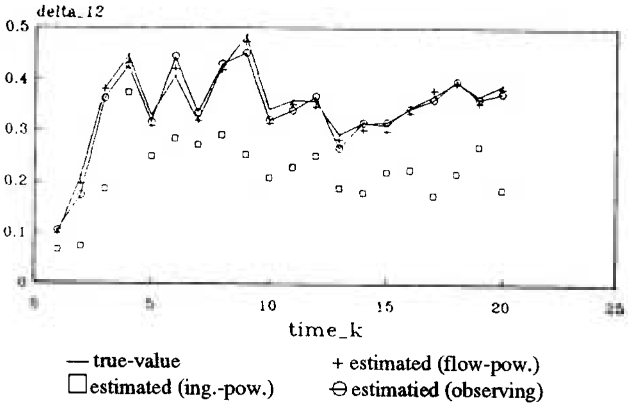

Figure 2. 14- Bus Phase Angle Estimation.

TABLE 1. Calculated Normalized Residuals for Test Case.

	Normalized Residual		
Test Case	**Case 1**	**Case 2**	**Case 3**
14 - Bus System	16.33	10.49	14.48

test systems are given in Table 1. The largest normalized residual corresponds to the bad data.

CONCLUSION

In this paper extended kalman filter method with more complete measurement model for power system estimation purposes and statistical properties for detection and identification of bad data measurements are presented. State estimation by extended kalman filter method has been demonstrated to be a powerful tool for accurately determining the values of system variables needed for operation. Hence the digital filtering is able to reduce the effects of random errors in power system measurements provided that it has an accurate model of the system.

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