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A multi-functional dynamic state estimator for error validation: measurement and parameter errors and sudden load changes

Key words: Dynamic state estimation, Kalman filter, Measurement errors, Branch parameter errors, Sudden load changes

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Motivation

- State estimation (SE) is one of the fundamental functions of an energy management system (EMS) which estimates the bus voltage magnitudes and phase angles as state variables.
- It has been shown that errors in the measurements and branch parameters as well as sudden load changes can have adverse impacts on SE results.
- Sudden changes in the power system operating conditions rarely occur and are due mainly to predictable events such as the disconnection of a large industrial consumer or component outages.

Motivation (Cont'd)

- From a practical point of view, these errors may exist in power systems at the same time.
- Obviously, the performance of SE depends on the accuracy of the measurements and branch parameters.
- To obtain a reliable SE, the simultaneous detection, identification, and estimation of measurement and branch parameter errors with high accuracy is a challenging task.

Main idea

- A DSE based on KF theory is proposed for the error processing problem.
- The proposed method can identify and correct errors in the measurements and branch parameters, simultaneously, and take account of sudden changes in the loads by using Lagrangian multiplier theory.
- Identification of sudden changes in a power system is impossible by normalized residual tests and an innovative test needs to be proposed for this problem.
- A new linear approximation approach is proposed to estimate erroneous variables at each sampling time.

Method

1. DSE uses the present and sometimes the previous states of a power system in addition to knowledge of the system’s physical model to predict the state vector for the next step time.
2. The following steps should be included in DSE :
    - ❑ Modelling
    - ❑ Forecasting
    - ❑ Innovation Analysis
    - ❑ Filtering
    - ❑ Residual Analysis

Method (Cont'd)

1. The proposed algorithm employs Lagrange multiplier analysis to identify errors in branch parameters and correct them.
2. all Lagrange multipliers are distributed according to a normal distribution with zero mean value and a non-zero covariance.
3. Erroneous measurements and branch parameters are corrected using a proposed linear approximation approach.
4. Not only are the erroneous measurements not deleted but also their corrected values are estimated by a corrective method.

Method (Cont'd)

1. The proposed dynamic state estimator algorithm applies the normalized residual, normalized innovation, and normalized Lagrange multiplier vectors for error processing.
2. Variation in the maximum elements of these vectors are presented in Table 1 in which c is the threshold for error processing.

Table 1 Variation in the maximum elements of normalized vectors by various errors

Vectors	Error type		
	Measurement error	Branch parameter error	Sudden load change
$\boldsymbol{v}_{k+1}$	$\max\{\boldsymbol{v}_{k+1}^N\} > c$	$\max\{\boldsymbol{v}_{k+1}^N\} > c$	$\max\{\boldsymbol{v}_{k+1}^N\} > c$
$\boldsymbol{r}_{k+1}$	$\max\{\boldsymbol{r}_{k+1}^N\} > c$	$\max\{\boldsymbol{r}_{k+1}^N\} > c$	$\max\{\boldsymbol{r}_{k+1}^N\} < c$
$\boldsymbol{\lambda}_{k+1}$	$\max\{\boldsymbol{\lambda}_{k+1}^N\} > c$	$\max\{\boldsymbol{\lambda}_{k+1}^N\} > c$	$\max\{\boldsymbol{\lambda}_{k+1}^N\} < c$

Method (Cont'd)

- The performance indices [15] at different stages are described as follows:

❑ Prediction index

$$\text{Index}_k^{\text{pre}} = \left| \frac{\tilde{\boldsymbol{x}}_k - \boldsymbol{x}_k^{\text{true}}}{\boldsymbol{x}_k^{\text{true}}} \right| \times 100\%.$$

❑ Estimation index

$$\text{Index}_k^{\text{est}} = \left| \frac{\hat{\boldsymbol{x}}_k - \boldsymbol{x}_k^{\text{true}}}{\boldsymbol{x}_k^{\text{true}}} \right| \times 100\%.$$

❑ Performance index

$$\text{Index}_k^{\text{performance}} = \frac{\sum_{i=1}^{m} \left| \hat{z}_k^i - z_k^{\text{ture},i} \right|}{\sum_{i=1}^{m} \left| z_k^i - z_k^{\text{ture},i} \right|},$$

Major results

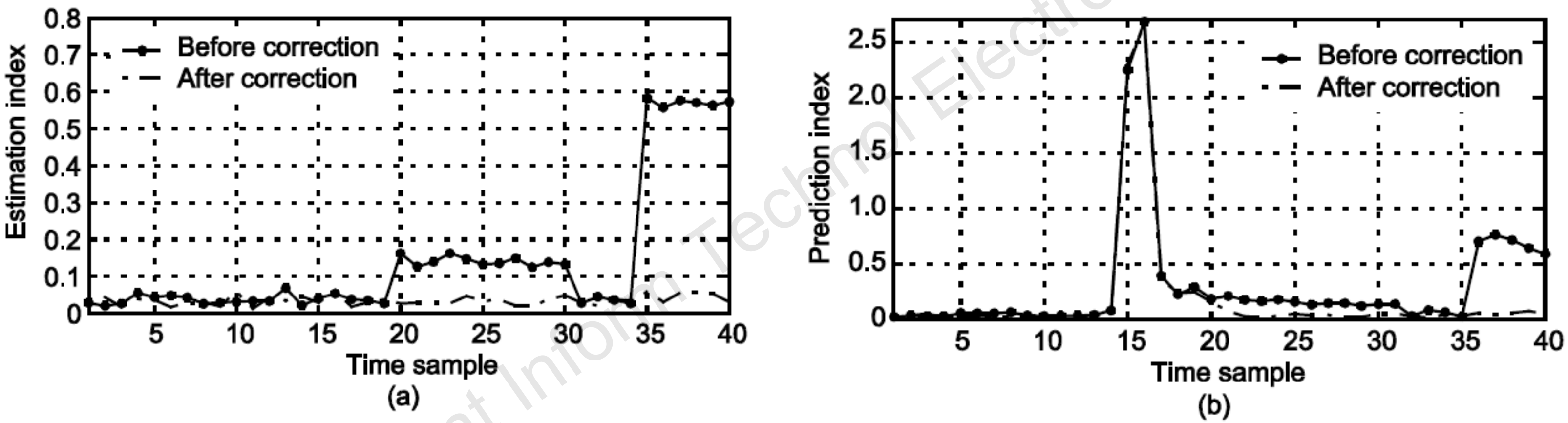
- The validity of proposed algorithm was evaluated on the IEEE 14-bus test system.
- Table 2 summarizes the simulated errors in the test system, including measurement error, branch parameter error, and a sudden load change.

Table 2 Simulated errors on the IEEE-14 bus test system

Time step k	Error type	Error information
30	Sudden load change	Bus 13 (Load completely cut off)
20–30	Measurement errors	$P_{13} = 0$ (True value = −0.135 p.u.) $Q_{13} = 0$ (True value = −0.058 p.u.)
30–40	Branch parameter error	$g_{1-2} = 7.5$ (True value = −4.990 p.u.)

Major results (Cont’d)

- The indexes from sampling time to and from to increased before using the proposed correction method.



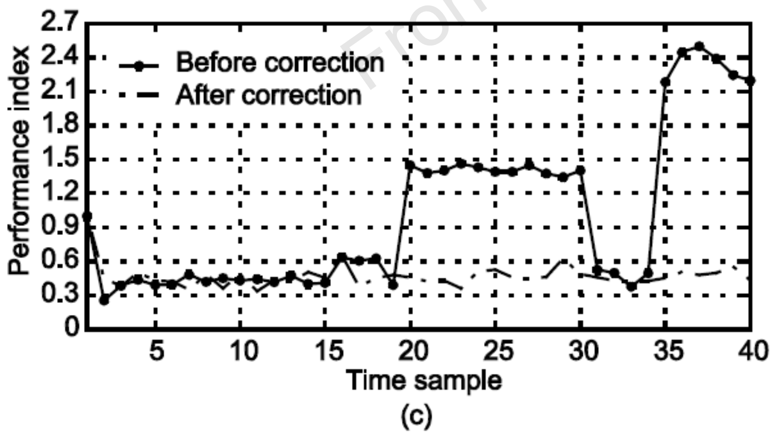


Fig. 2 Variation in evaluation indexes on an IEEE-14 bus test system, estimation index (a), prediction index (b), and performance index (c)

Major results (Cont'd)

- The proposed dynamic estimation algorithm performed appropriately and provided suitable corrections.

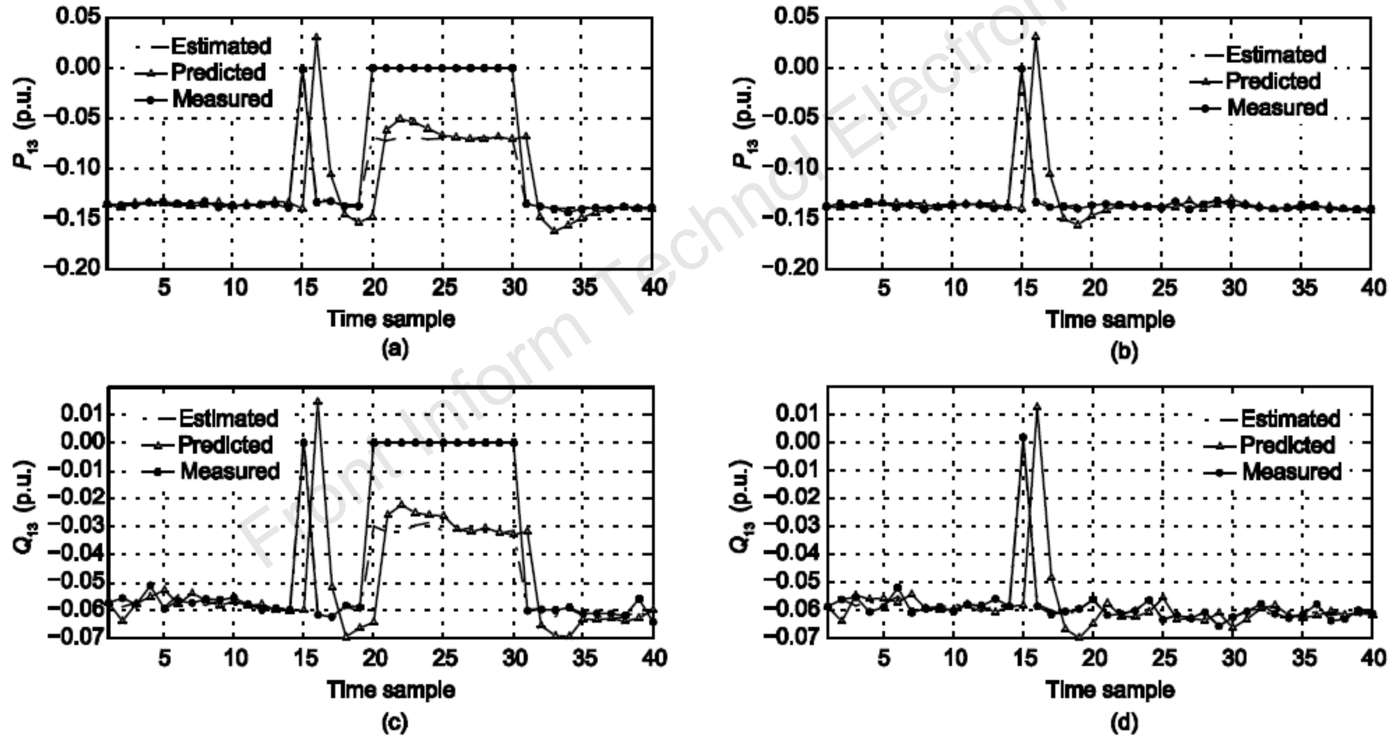


Fig. 3 Active and reactive power injection at bus 13: P_{13} before correction (a), P_{13} after correction (b), Q_{13} before correction (c), and Q_{13} after correction (d)

Major results (Cont'd)

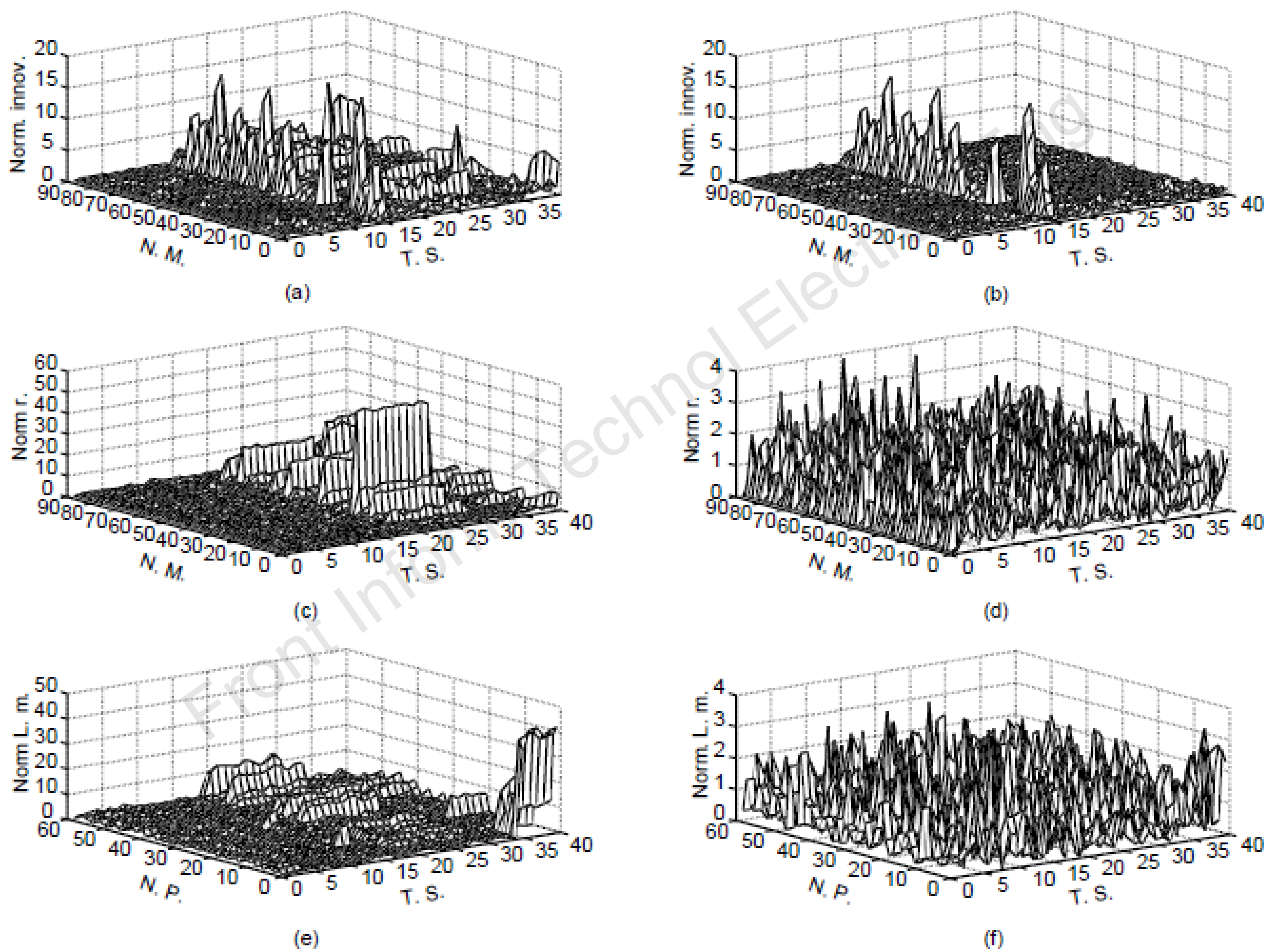


Fig. 4 Variations in normalized vectors: v_{k+1} before correction (a), v_{k+1} after correction (b), r_{k+1} before correction (c), r_{k+1} after correction (d), λ_{k+1} before correction (e), and λ_{k+1} after correction (f)

Norm. innov.: normalized innovation; Norm. r.: normalized residual; Norm. L. m.: normalized Lagrange multiplier vectors; N. M.: number of measurement, N. P.: number of parameter, T. S.: time sample

Conclusions

- A new algorithm for simultaneous validation of measurement and branch parameter errors is proposed based on the DSE algorithm and KF theory.
- The proposed correction methodology also successfully detected and identified sudden load changes.
- The proposed methodology applies three normalized vectors namely, measurement residual, Lagrange multiplier, and innovation vectors.
- The proposed method successfully processed the anomalies, with high accuracy.