# PROCESS DATA VALIDATION IN HV SYSTEMS OF POWER STATIONS

R. Procházka* and S. Bouček
Dep. of Electrical Power Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague, Czech Republic
*Email: <radek.prochazka@fel.cvut.cz>

**Abstract**: One of the conditions of safe and reliable operation in technologically complex systems is collection, processing and analysis of relevant objective and quality information about state values. Objectivity of gained procedural information is closely associated with activity of measuring chain. Monitoring of process quantities is necessary for both information gathering and for the control purposes and safety and emergency system decisions. The reliability of data acquisition can be ensured by redundancy principles together with diversification, but this approach can also bring a range of problems by means of security faults formation. This paper deals with the measured data validation by their significant errors selection, dispersion and systematic errors reduction. The principle of this method is based on a comparison of the measured process data with the data from a mathematical model that describes the physical link of parameters in measured HV system of power plant. In this case we use the linear static estimation as a method of data process estimation. Above mentioned method is looking for a vector which minimizes, in terms of selected criteria, deviations between the real process data and the values generated by a mathematical model. The practical measurements were realized on the physical model of power station electrical part.

## 1 INTRODUCTION

One way how to increase safety and reliability of power stations is in improving the quality of explicitness measured data and possible identification and localization of an errors in the measuring chains. The minimization of these errors (validation data respectively) is possible to do by several ways both in hardware area and in software area by using appropriate methods.

The software area used some well-known methods, like reduction of variance of random errors, correction of systematic errors, separation (or conditional correction) of outliers of measured values with their analysis which is useful for the fault identification in the measured or measuring systems. It is also determined by the development of procedures for normality testing of measured process variables and identifying outlying values which are based on selected criteria. These are applicable for the determination of weighting coefficients and identification of measurement chains error. The method of estimation process by linear or nonlinear estimation of state values is used in such cases [1]. The implementation of SW area can be advantageously performed through the methods of graphical programming.

The main principle of all the methods is based on a comparison of the measured process data with the data from mathematical models that describes the physical link of parameters in a measured system. Above mentioned method is looking for a vector which minimizes (in terms of selected criteria) deviations between the real process data and the values generated by a mathematical model. Large long term deviations between the outputs which overcame the selected boundary conditions can be used to detect failures of the measuring or measured system.

## 2 DATA VALIDATION BY ESTIMATION PROCESS

The validation of process data is realized by estimation system. For the building of estimation system the selection of state values must be done. The selected state values must fulfil the measurement equation [2, 3]:

$$\bar{m} = \bar{\Phi}(\bar{x}) + \bar{v} \qquad (1)$$

where: $\bar{m}$ is a vector of measured values
$\bar{x}$ is a vector of state values
$\bar{v}$ is an error vector
$\bar{\Phi}(\bar{x})$ is a vector function represents the relationships between the vector of measured values and vector of state values

The purpose of estimation process is to find the vector of state values $\bar{x}$ which best fits the vector of measured values $\bar{m}$. Such estimate $\tilde{x}$ can predict the modelled part $\bar{\Phi}(\bar{x})$ of $\bar{m}$. Then the error vector $\bar{v}$ includes both disturbing factors the noise and the modelling errors.
Together with the measurement equation (1) must exactly be hold the balance of the laws of mass conservation, energy conservation and conservation of momentum, both in individual

fragments and reciprocally between a fragments of technological system.

For the effective estimation process should be fulfilled the condition of sufficient data redundancy or higher vector dimension of measured values in compare to the vector dimension of state values. The higher is the ratio the preferential are conditions for validation.

All limiting conditions are included in the vector function $\overline{\Gamma}(\bar{x})$. Then from a mathematics point of view the estimation of the optimization process is the determination of vector $\tilde{x}$ (optimizer), which optimizes the selected criterion function $f(\bar{v})$ respecting the limiting conditions $\overline{\Gamma}(\bar{x})$.

### 2.1 Linear estimation

If the linear estimation is applied the vector function $\overline{\Phi}(\bar{x})$ has a linear form $\overline{\Phi}(\bar{x}) = [\Phi]\bar{x}$ which is obtained by linearizing the nonlinear equations at the point close to the operation point or within the operating range. The linear variant makes possible the use of wide mathematical tools for linear systems. However the results may lead to the worse results than in case of nonlinear variety. The solution is reached without iteration process according to the relationships in Table 1.

**Table 1:** Algorithm for linear estimation

| | |
|---|---|
| 1 | $\bar{v}(\bar{x}) = \bar{m} - [\Phi]\bar{x}$ |
| 2 | $\bar{r}(\bar{x}) = \sqrt{[W]}\bar{v}(\bar{x})$ *where [W] is known weight matrix* |
| 3 | $[K] = \{[\Phi^T][W][\Phi]\}^{-1}$ |
| 4 | $\tilde{x} = \arg\min\{\bar{r}^T\bar{r}\} = [K][\Phi^T][W]\bar{m}$ |

### 2.2 Nonlinear estimation

The nonlinear estimation approach covers relatively general case. Its prior assumption is the existence of only single optima. The resulting algorithm is iteration hence is more time and capacity-consuming. The example of algorithm for iteration process is approached in Table 2.

**Table 2:** Example of algorithm for nonlinear estimation

| | |
|---|---|
| 1 | $\bar{\xi} = [\tilde{x}_0, \bar{\lambda}_0] = \bar{\xi}^0$ *iniciation, k=0* |
| 2 | *calculation of* $\nabla\bar{L}^{(k)}$ |
| 3 | *If the control conditions are fulfilled then stop, otherwise 4* |
| 4 | $[\Omega^{(k)}] = \begin{bmatrix} [H^{(k)}] & [J_\Phi^{(k)T}] \\ [J_\Phi^{(k)}] & [0] \end{bmatrix}$ *ordered Hessian* |
| 5 | *Solution of equation* $[\Omega^{(k)}] \cdot \Delta\bar{\xi}^{(k)} = -\nabla\bar{L}^{(k)}$ |
| 6 | *Correction* $\bar{\xi}^{(k+1)} = \bar{\xi}^{(k)} + \Delta\bar{\xi}^{(k)}$ |
| 7 | $k = k + 1$ *return to 2* |

## 3 THE PHYSICAL MODEL OF POWER STATION

The verification of estimation system was performed on a physical model which is installed in the faculty laboratories at the Department of Electrical Power Engineering. The main parts of the model are short-circuit 3-phase synchronous alternator 0.4 kV, 16 kW mechanically coupled with the Ward-Leonard group DC motor. The dynamo is driven by the asynchronous motor. Alternator outlet can be connected via three-winding unit transformer to the internal grid of 0.5 kV laboratories, which is linked to the 22 kV substation through the further transformation. The model has standard equipment in terms of control, measurement, presentation and recording of operating parameters, synchronizing, management of energy supplies, de-excitation, etc.

**Figure 1:** Physical model of power station – outputs from measurement transformers (left), synchronous generator and DC motor (middle), control panel (right)

Figure 2 shows the electrical scheme of physical model. The voltages and currents are measured by instrument transformers in different points of physical model.

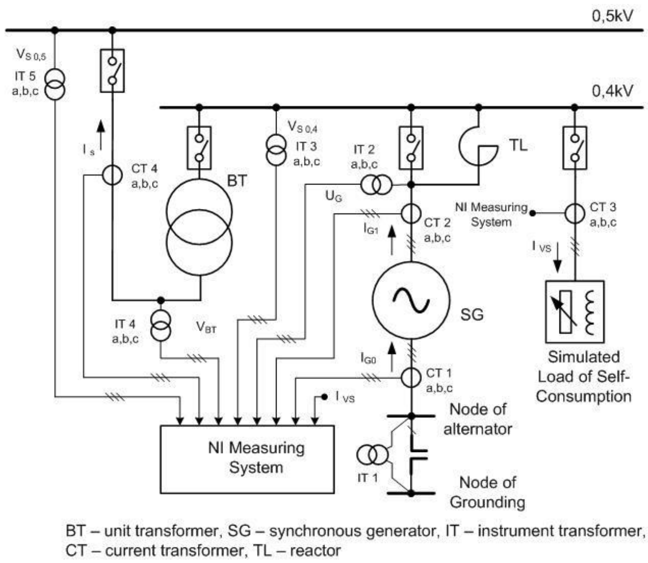


**Figure 2:** Electrical scheme of physical model of power station

Acquired signals are then converted by A/D units with current and voltage ranges of ± 15 A and ± 300 V and sampling frequency of 10 kHz. The final values are sending to consequent processes with frequency 500 Hz.

## 4 ESTIMATION SYSTEM

The example of estimation method application is shown on Figure 3 [4]. The process data are read from a technological process through the measuring channels. Acquired signals are then filtered in input modules. Consequently, the distribution of weights is performed depending on their quality. The module also loads from universal file containing the formulas which are valid between estimated values.

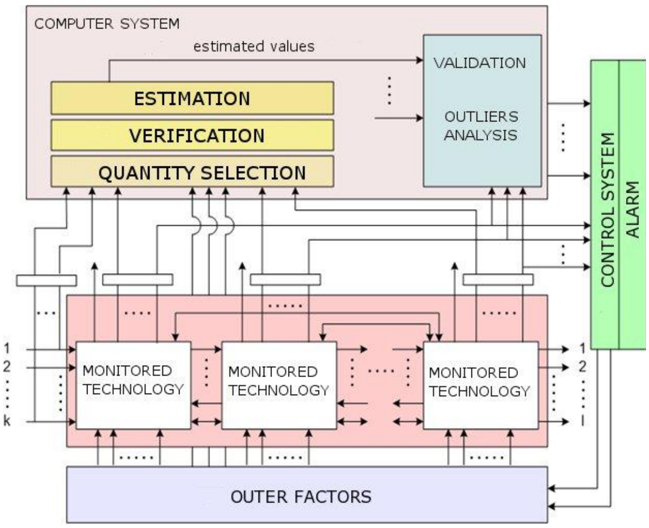


**Figure 4:** Block diagram of estimating system in technological process

After that follows the validation process of measured data by simple computing operations in verification module. This module is also able to eliminate gross errors of measurements.

In preliminary module the analysis model is compiled. The blocks of data are transformed into the measuring vectors and parameters. For each measurement the proportional errors are corrected depending on measurement quality. After that the estimation calculations are performed accordance with appropriate algorithm included calculations in accordance with measurement model equations which describe exact physical relations.

In output module a possible data with great error are recognized and the information about fault in measurement chain is then forwarded. The output file with estimated values is completed as well.

An example of HW solution for data aquisition and estimation system is shown on Figure 5. The program is compiled directly to the structure of field controlled gates. Computer programs are then faster than in case of universal processors.

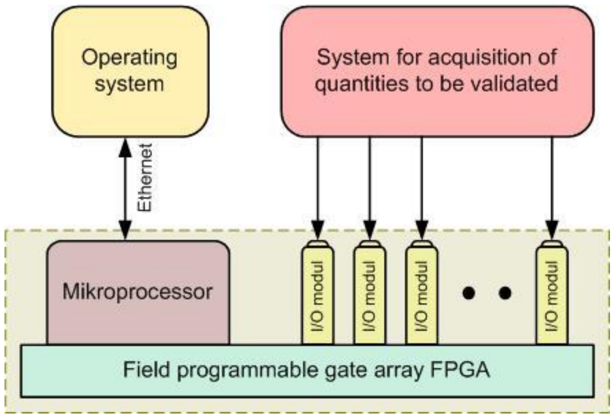


**Figure 5:** Example of HW solution for estimation system

## 5 VALIDATION OF ESTIMATION SYSTEM ON PHYSICAL MODEL OF POWER PLANT

The computer system is realized by using a facility of graphical programming. For the validation of the estimation system the simple case, when is assumed that the sum of currents in each node must be equal to zero, was chosen.

The current were measured in the following nodes (see Figure 2): node of alternator, output terminals of alternator, branch of simulated self-consumption and on terminal leads to outer grid. Then the mathematical model is given by Kirchhof's law. The self-consumption load was simulated by three power resistors in star connection which was supplied from unit busbar through autotransformer. The synchronous generator was during the data collection synchronized onto internal grid. Currents and their phase shifts were controlled by change of load angle and generator excitation. In case of self-consumption the change of currents was realized by adjustment of power resistors and autotransformer ratio.

The measurement uncertainty of current transformers was in all measured points the same. Possible decreasing of relative accuracy of measured current in unit self-consumption was not considered. That is why the weight matrix consists only from variance (normality test was applied before).

Some examples from the current measurements on the physical model of power station are shown on the figures below.

On the Figure 6 is comparison of probability density of measured data with artificially modulated noise (red line) with estimated output values (green line).

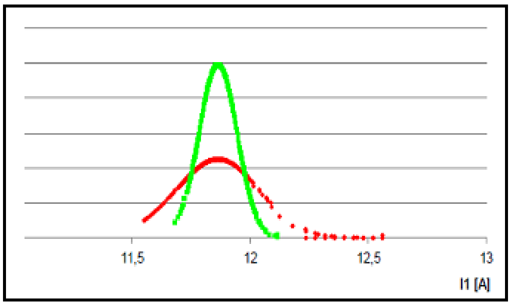


**Figure 6:** Artificially increased variance of data and their output after estimation process

On the Figure 7 is record of probability density of current in one phase of generator ($I_0$ – node current, $I_1$ – terminal current). It is evident that there is an error in measurement chain because the currents should be the same (capacitive currents are neglected). The estimation system makes both currents practically identical, but without any information which one is measured wrong, respective did not detect the error of measurement.

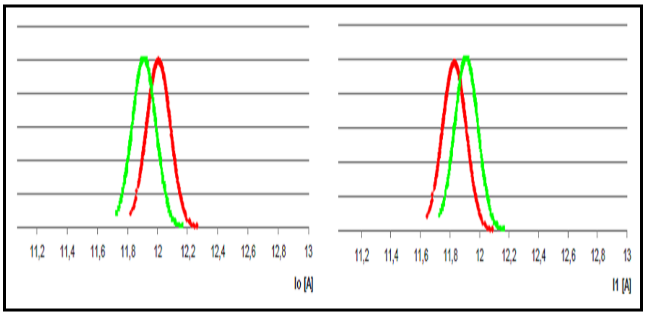


**Figure 7:** One phase current of alternator in node $I_0$ and at its terminal $I_1$. The confidence level for outlier test is low.

Figure 8 shows the record of probability density for the same currents as in previous figure but with confidence level for outlier test increased 10 times (from 2.5% to 25%). The system detect error in measurement of node current $I_0$. From the shape of estimated curves can be seen that the system assigned the higher weight to current $I_1$ (estimated values are closer here) and also the variance was decreased.

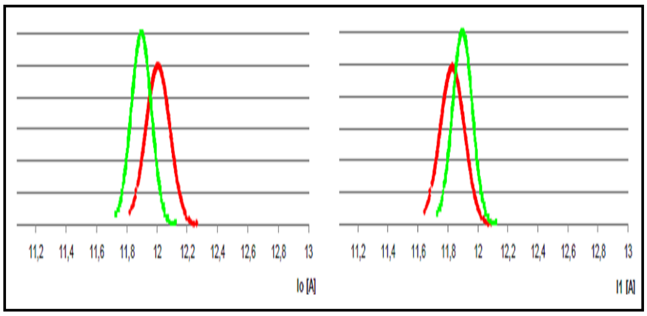


**Figure 8:** One phase current of alternator in node $I_0$ and at the terminal $I_1$. The confidence level for outlier test is higher.

Finally, on the Figure 9 is record of probability density for the same currents again but the confidence level of outlier test was decreased to original value (2.5%) and very strong parasitic signal with outlier values was added to the current $I_0$. Outlier values was corrected also at lower confidence level and estimation system correctly reduce the measurement error with higher weight set up on data with better quality i.e. current $I_1$.

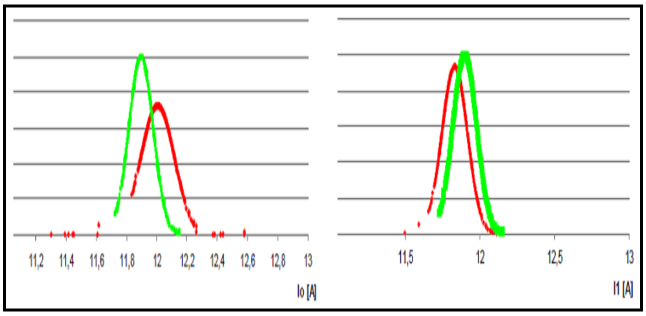


**Figure 9:** One phase current of alternator in node $I_0$ and at its terminal $I_1$. The confidence level for outlier test is low. The strong parasitic signal with outlier values was added to the current $I_0$.

## 6 CONCLUSION

The technological processes in power stations require measurements of state values which provide correct data with low uncertainty as possible. This is important assumption for reliable and safe operation especially in case of units with high power or nuclear power stations. The validation system which solves these requirements is needed.

Proposed method works with estimation system which consists from HW and SW layer. The HW has to ensure the acquisition of measured data and fast computation of estimated values and the SW includes all blocks for selection of quantities, filtration, statistical computation, data validation and estimation model.

From the presented results of verification process on physical model of power station and for the introduced simple case is evident that the tendency of estimation system is to decrease measurement error. For optimal results is necessary more redundant system of equations.

Proposed estimation system will be further improved and extended. The next step in the validation process will be the test on measured data from real power stations processes which should verified the system applicability under operation conditions.

## 7 ACKNOWLEDGMENTS

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