# THE EFFECT OF EXPERT EVALUATIONS ON THE EFFICIENCY OF DECISION PROCESSES IN POWER DISTRIBUTION SYSTEMS

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Abstract - The paper gives the results of tests carried out for utility operational staff (experts) to estimate the form and parameters of a probability density function of errors (which are committed by experts) in evaluation of peak loads at receiving buses. Special computer simulation studies were designed and executed to analyze the effects of load estimation errors on the results of power distribution systems performance calculations. From the results of simulation tests, probabilistic models of calculational errors made on the distribution systems were formulated.

Key Words: Error Probability Density Function, Experts Evaluation, Load Estimation

## I. INTRODUCTION

A basic factor in distribution system design and operation is power consumption at system nodes. A proper evaluation of loads is an essential point in correct calculations and analysis of power distribution systems [4]. The acquisition of this data is complex because of the large number of nodes. As a rule receiving nodes are not equipped with stationary measuring instruments so measurements of loads are only performed sporadically.

In operational practice in Poland [4] load data for the performance calculations and analysis of distribution circuits are acquired from the power utility operational staff (expert evaluations). The utility staff (experts) evaluate loads on the basis of possessed knowledge on results of sporadic (usually annual) measurements of receiving transformers peak loads and data on customers supplied from transformers. Those assessments are loaded by errors which influence on the accuracy of the system analysis.

This paper presents results obtained from measurement and simulation studies on the effect of expert evaluations of load on the efficiency of the decision processes in power distribution systems.

The next section presents outcomes of comparative tests between expert evaluations of peak load at receiving buses and measurement data. The simulation experiment designed to analyze the effect of unreliable load evaluation on the results of distribution system performance calculations is described in Section III. Section IV presents probabilistic models of calculation errors made on systems on the basis of load values estimated by experts. Conclusions and future directions are presented in Section V.

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## II. TEST DATA ACQUISITION

In order to evaluate the quality of load evaluation by experts in power distribution systems an experiment was designed and carried out. For an existing municipal 15 kV distribution system the measurement of daily peak load was taken at 26 randomly selected 15/0.4 kV receiving transformers. At the same time the experts were asked to evaluate the loads. Seven experts from the local power utility took part in the experiment. The expert evaluations were compared with measurement results. On this basis the percentage errors of expert judgments were calculated as given by

$$\delta_{Pi} = \frac{P_{ie} - P_{im}}{P_{im}} \times 100\% \qquad (1)$$

where:

$P_{ie}$ - expert evaluation of peak load at bus i,

$P_{im}$ - measured value of peak load at bus i.

The results of error calculations are presented in Table 1.

Table 1. Percentage errors ($\delta_P$) of expert evaluations of peak load

| Transformer Number | Percentage Errors | | | | | | |
|---|---|---|---|---|---|---|---|
| | Expert Number | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| | % | | | | | | |
| 1 | -56 | -13 | 16 | 16 | 45 | -13 | 16 |
| 2 | 51 | - | 145 | 2 | 2 | - | 23 |
| 3 | 21 | 0 | 5 | 47 | 5 | 5 | 47 |
| 4 | -46 | -33 | -7 | -71 | -54 | -33 | -75 |
| 5 | -11 | 100 | 270 | -56 | -41 | 122 | -41 |
| 6 | 170 | 187 | 272 | -49 | 1 | -32 | -32 |
| 7 | -24 | - | 16 | - | 42 | - | - |
| 8 | -41 | 32 | 150 | -77 | -38 | 134 | -53 |
| 9 | -38 | -40 | 44 | -39 | 22 | -36 | -52 |
| 10 | -15 | -20 | 70 | -47 | -15 | 6 | -26 |
| 11 | -16 | 30 | 83 | 63 | -35 | -19 | -51 |
| 12 | -27 | 13 | 87 | -58 | -55 | 21 | -62 |
| 13 | -69 | -8 | 29 | -71 | -63 | 10 | -70 |
| 14 | -44 | -15 | 15 | -73 | -67 | -4 | -73 |
| 15 | -31 | 192 | 137 | -18 | 28 | 83 | -9 |
| 16 | -53 | -26 | -19 | -60 | -33 | -19 | -60 |
| 17 | -2 | -32 | -1 | -32 | - | -14 | -37 |
| 18 | 14 | -32 | 14 | -69 | -53 | -17 | -74 |
| 19 | -13 | -45 | -8 | -40 | -27 | -27 | -36 |
| 20 | -8 | 3 | 81 | -55 | -23 | 29 | -48 |
| 21 | 25 | 318 | 262 | -39 | 39 | 25 | -44 |
| 22 | -79 | - | -42 | - | -65 | - | - |
| 23 | -61 | 186 | 119 | -75 | - | 45 | -66 |
| 24 | -18 | 2 | -25 | -73 | -46 | 2 | -66 |
| 25 | -47 | -45 | -45 | -76 | -72 | -59 | -79 |
| 26 | -38 | -5 | 27 | -81 | -55 | 8 | -78 |

Then, the statistical analysis of obtained results was made. In Figure 1 a histogram of observed errors is presented. The sample is characterized by the following parameters: mean value $\mu = -2.9\%$, standard deviation $\sigma = 73.4\%$, asymmetry coefficient $a = 4.0$. The above results indicate that a probability density function for the errors made by experts in peak load evaluations is asymmetrical and unimodal. A generalized beta distribution BT(a,b,p,q) [1] was chosen to represent the experimental data. It was assumed that the variable $\delta_{Pi}$ had a hypothetical beta distribution with following parameters:

$$f(\delta_{Pi}) = BT(-90,\ 900,\ 1.275,\ 12.75) \qquad (2)$$

The result of the approximation (2) was confirmed by using a Chi-square test with a significance level $\alpha = 0.05$ [1]. The probability density function for BT(-90, 900, 1.275, 12.75) distribution is shown in the same figure as the histogram of observed errors (Figure 1).

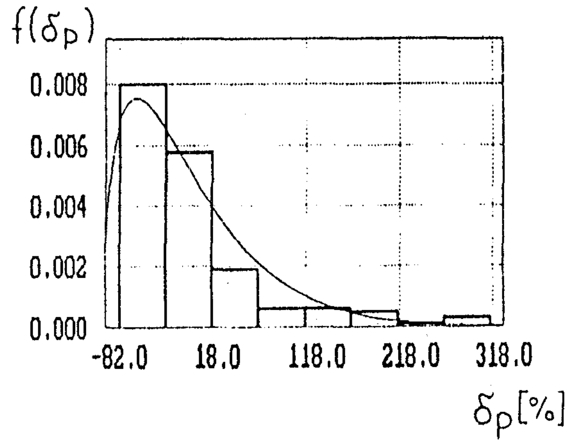



Figure 1. Histogram and probability density function for percentage errors of peak loads expert evaluations

The resulting model (2) was used to evaluate possible errors made in power distribution system computations.

## III. SIMULATION EXPERIMENTS

In order to investigate the effect of unreliable evaluation of loads on receiving buses on the results of system computations a special computer simulation experiment was designed and carried out. The goal of the simulation experiment was to determine forms and parameters of probability density functions for possible errors in calculations of basic quantities that characterize operating conditions of a power distribution system.

The simulation process consists of multiple repeated computations of power flows, bus voltages, voltage drops, power and energy losses for randomly changed values of peak loads on receiving buses:

$$P_i = \bar{P}_i(1 + \delta_{Pi}/100)$$
$$Q_i = \bar{P}_i(1 + \delta_{Pi}/100)\mathrm{tg}\varphi_i \qquad (3)$$

where:

$P_i$, $Q_i$ - random value of active and reactive peak load on bus i, respectively,

$\delta_{Pi}$ - random value of percentage error of load evaluation:

$f(\delta\ \ ) = BT(-90, 900, 1.275, 12.75)$,

$\bar{P}_i$ - average value of active peak load on bus i,

$\mathrm{tg}\bar{\varphi}_i$ - average value of power factor on bus i.

The simulation experiment was carried out for a numerical model [2] of an existing 15 kV, radially operated power distribution system [4]. The system supplies 65 receiving transformers of 15/0.4 kV. According to the results presented in Sections II the generalized beta distribution (2) was used as a probabilistic model of errors of load evaluations. Computations were repeated for an assumed number of $n_s$ = 250 runs. In each run, new values of peak loads on buses were selected according to equations (3). As a result, $n_s$ realizations of a vector of loads on system buses were obtained:

$$P^k = [P_1^k, P_2^k, \ldots, P_i^k, \ldots, P_n^k]^T \qquad (4)$$

where:
k - index for realization of simulation,
i - index for receiving bus,
n - number of receiving buses.

## IV. EXPERIMENT RESULTS

Lack of reliable load data on system buses makes it difficult to obtain likelihood results of operational and optimization computations made on distribution systems. To find out the effect of unreliable expert evaluations on the efficiency of the decision processes in a system simulation studies were performed.

For each realization of a load vector $P^k$ (4) power flow studies were made. As a result, $n_s$ realizations of a set of output quantities were obtained. The following quantities that characterize operating conditions of power distribution systems were analyzed: active and reactive peak load on the supplying bus, active power losses in lines, transformers and total, daily energy losses, and sum of voltage squared deviations on receiving buses for whole system and for one feeder, respectively (Table 2).

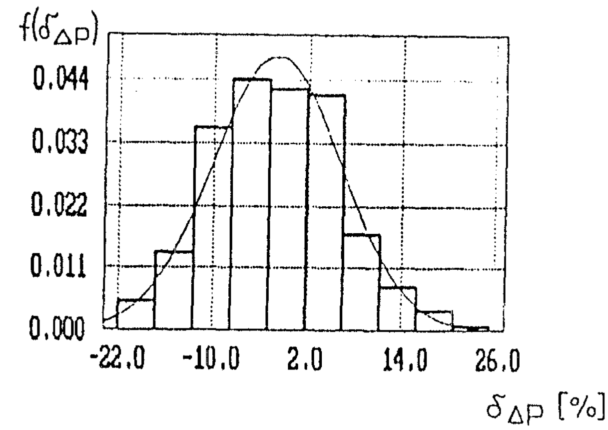
Table 2. Parameters of error distributions for selected output quantities

| Output Quantities | Error Distribution Parameters Average Value: m Standard Deviation: $\sigma$ | Object | |
|---|---|---|---|
| | | Whole System | One Feeder |
| | | % | |
| Active power on supplying bus: P | $m_P$<br>$\sigma_Q$ | -1.31<br>7.31 | 0.64<br>21.13 |
| Reactive power on supplying bus: Q | $m_Q$<br>$\sigma_Q$ | -3.35<br>19.13 | 0.61<br>23.16 |
| Total active power losses $\Delta P$ | $m_{\Delta P}$<br>$\sigma_{\Delta P}$ | -1.78<br>8.73 | 0.81<br>21.04 |
| Active power losses in lines $\Delta PL$ | $m_{\Delta PL}$<br>$\sigma_{\Delta PL}$ | -2.87<br>15.42 | 1.53<br>45.98 |
| Active power losses in trans-formers $\Delta PT$ | $m_{\Delta PT}$<br>$\sigma_{\Delta PT}$ | -1.20<br>6.45 | 0.74<br>18.92 |
| Daily energy losses $\Delta E$ | $m_{\Delta E}$<br>$\sigma_{\Delta E}$ | -1.23<br>7.67 | -0.03<br>11.35 |
| Sum of voltage square deviations on receiving buses $\Sigma\delta U^2$ | $m_{\Sigma\delta U^2}$<br>$\sigma_{\Sigma\delta U^2}$ | 14.10<br>4.5 | -<br>- |

Possible errors of calculations of investigated quantities on the basis of expert load evaluations were calculated in relation to values obtained from deterministic solutions of the power flow study for assumed average values of loads on receiving buses.

Data acquired in this way were used to formulate and confirm probabilistic models of the output quantities. On the basis of the premises of the central limit theorem [1], it was assumed that the probability distributions of the errors are normal. The statistical hypothesis was tested by the Kolmogorov-Smirnov test [1]. The results of the test showed that the probability distributions of the errors in most cases may be approximated by normal distributions. The estimated parameters of error distributions for the investigated output quantities are shown in Table 2. In Figure 2, histograms of observed errors and the approximating probability density functions are shown for selected quantities.

a)




b)

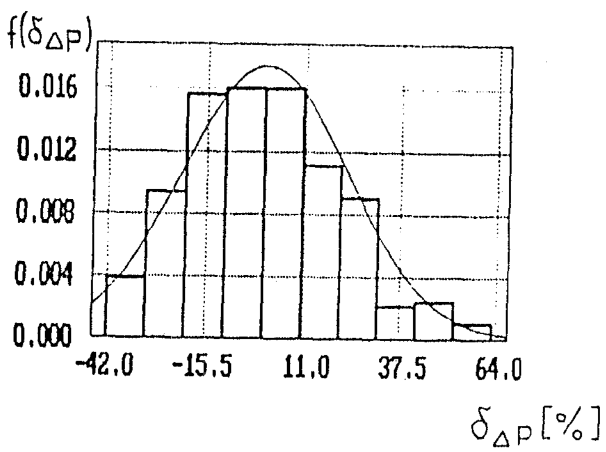



Figure 2. Histograms and probability density functions for percentage errors of calculations of total active losses a) for whole system, b) for one feeder.

## V. CONCLUSIONS

On the basis of statistical analysis of measurements and computer simulation experiment results the following conclusions were formulated:

1) Load evaluation errors existing today in operational practice in power distribution systems have a fundamental effect on theaccuracy of computations made on systems. As shown in Table 2, errors of operational calculations made on the basis of expert load evaluations my be significant. percentage.

2) As a rule, theoretical effects of optimization are contained in confidence area of calculations [2]. The results confirm the thesis that calculations used to optimize distribution system performance depend upon the load estimation. The implementation of proper load estimation is very important in distribution system calculation [4].

## REFERENCES

[1] Johnson N.L., Leone F.C.: Statistics and Experimental Design in engineering and Physical Sciences. John Wiley and Sons Ltd., New York 1977.

[2] Kujszczyk S.: Modern Methods of Power Distribution Systems Calculations. (In Polish). WNT, Warsaw 1984.

[3] Morgan M.G., Talugdar S.N.: Electric Power Load Management: Some Technical, Economic, Regulatory and Social Issues. Proceedings of the IEEE. Vol. 67, 1979, No 2.

[4] Nazarko J.: Power Distribution Systems State Estimation. (In Polish). Technica University of Bialystok, Bialystok (Poland) 1991.

## BIOGRAPHIES

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