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ESTIMATION OF THE UNCERTAINTY IN MEASUREMENT OF THE ELECTRIC ENERGY – ITALIAN-CROATIAN PROJECT

Mladen Boršić[1], Damir Ilić[1], Nadža Milanović[1], Luka Ferković[1], Pasquale Daponte[2], Aniello Cimitile[2], Sergio Rapuano[2], Mihail Marinov[2], Andrea Aiello[2], Gianpaolo Mercurio[2], Gioachino Truglia[2], Višnja Gašljević[3], and Roman Vulpe[3]

[1]Faculty Of Electrical Engineering and Computing, Zagreb, Croatia
[2]Università degli Studi del Sannio, Benevento, Italy
3Croatian Metrology Society, Zagreb, Croatia

Abstract − The Faculty of Electrical Engineering and Computing Science, University of Zagreb and the Faculty of Engineering University of Sannio signed, in the year 2001, the Agreement of Cooperation International Co-operation for the Research Doctorate in Information Technology with the aim at collaborating for the activation and the development of joint doctoral degree courses.

The President of the Province of Benevento and the President of the City Assembly of Zagreb signed, the same year, the Letter of intent for cooperation.

As the first step in this cooperation will be the realisation of the Italo-Croate project Estimation of the Uncertainty in Measurement of the Electric Energy funded by the Italian Ministry of Education, University and Research (Ministero dell'Istruzione, dell'Università e della Ricerca) and Croatian Ministry of Science and Technology (Ministarstvo znanosti i tehnologije).

The eolic electric energy, as a pure energy, becomes increasingly important in Italy. The high voltage to medium voltage transformer sub-stations in Montefalcone, having installed energy of about 180 MVA, will be the test stations to evaluate the uncertainty in measurement of electric energy generated by eolic generators. The result should be the fair and transparent energy rating.

The group of researchers from Faculty of Electrical Engineering and Computing, University of Zagreb, Croatian Metrology Society, Zagreb, and Università degli Studi del Sannio, Benevento will try to find all the sources of possible errors in measurements. At the end, two or three researchers will carry out internationally recognised doctorate dissertations.

Keywords: uncertainty, electrical energy measurement.

1. OBJECTIVES OF THE PROJECT

The objectives of the Project are:

A) To determine the mathematical model and to find the parameters which influence the uncertainty in measurement of the electric energy. The result should be to propose the correction measures. Concrete expected results:

- To estimate the uncertainty in measurement in sub-stations connecting the generators and transmission lines.
- To propose the measures to maintain the uncertainty in measurement between predetermined limits.

B) To establish, deepen, and develop bilateral, regional, and inter-university co-operation to encourage the strategy of sustainable development and to connect Croat research system to European Union system in the field of electric energy measurement.

2. MOTIVATION

Collaboration between the Faculty of Electrical Engineering and Computing, Zagreb, and Università degli Studi del Sannio, Benevento, exists from the year 1998 when Croat professor took lectures in Benevento. In the year, 2001 two Universities signed the Agreement of cooperation, which was the basis for the project. The primary goal is the cooperation in research projects and mutual recognition of the doctorial dissertations. Both universities offer their equipment and skilled staff. This specific research project is concerned with the estimation of the uncertainty in measurement of the electric energy produced by eolic generators situated near Montefalcone in south Italy. The eolic energy becomes increasingly important after the Kyoto protocol. On free market, the accounting of the energy must be transparent and based on the measurement results and other relevant data. The expression of result of measurement must be in accordance with internationally recognised document [1]. After analysing the parameters, which influence the uncertainty, and after in situ measurements, the proposal will be done for possible correction measures and for maintaining the limits of uncertainty in settled range.

3. PROCEDURE

The phases of the realisation of the project:

- Data acquisition of all relevant parameters (instrument transformers, electric energy counters, impedances of the instruments' transformers low voltage circuits, calibration reports);
- Mathematic modelling of the measurement system;

- In situ control of the equipment and measurement of the influence parameters;
- Calculation of the uncertainty;
- Possible corrective actions;
- Proposal how to maintain the uncertainty in settled range.

4. METHOD

The evaluation of uncertainty in measurement of electrical energy on high voltage transmission lines is made in accordance with the GUM (*Guide to the Expression of Uncertainty in Measurement*) [1]. The mathematical model includes voltage and current instrument transformer parameters, watt-hour meter parameters, and impedances of the low-voltage circuits of the instrument transformers.

The high voltage measurement facilities consist of measuring voltage and current transformers that reduce voltages and currents of the transmission lines on the level of reference voltage and current, and the active and reactive energy meters.

The basic equation for energy is:

$$W = \int_{t_2}^{t_1} ui \cdot \mathrm{d}t \qquad (1)$$

Supposing that voltage and current on high voltage transmission lines are sinusoidal, the equation (1) can be simplified to:

$$W_P = (UI\cos\varphi)\cdot t = Pt \qquad (2)$$

$$W_Q = (UI\sin\varphi)\cdot t = Qt \qquad (3)$$

where W_P is active energy, and W_Q is reactive energy, P and Q are active and reactive power, and t is time.

According to the equations (2) and (3), the input quantities are:

U – voltage of the high voltage transmission line;
I – current in the high voltage transmission line;
φ – phase shift between U and I
t – time.

A component of uncertainty due to time measurement is a part of uncertainty of energy meter constant.

4.1. Voltage

Voltage U_M on input terminals of energy meter is not equal to the voltage of the high voltage transmission line U divided with its rated transformation ratio K_n. The main reasons are:

– the actual transformation ratio is not equal to the rated transformation ratio K_n;

– voltages drop ΔU_V on the cable that connects the voltage instrument transformer and energy meter.

The phase difference between the primary voltage vector U and the voltage U_M vector exists too.

4.2. Voltage instrument transformer

Sources of uncertainty of the capacitive or inductive voltage transformer transformation ratio are: burdens, amplitude and frequency of the input voltage on the primary winding, ambient temperature etc. The bases for the estimation of standard uncertainty $u(U)$ are: supposed working conditions, verification data, producer's technical data, and the results of the *in situ* measurements of impedances of the low voltage instrument transformers' burdens and cables.

4.3. Cable impedance

The possible source of the systematic voltage error is cable impedance comprehending:

– impedance of connecting leads from voltage transformer low voltage terminals to the input meter terminals;

– impedance of the switch in the secondary circuit of the voltage instrument transformer (short-circuit protection).

4.4. Current I

The current I of an electricity meter is a secondary current of the current instrument transformer.

The current uncertainty, which a transformer introduces into the measurement of a current, consists of two components: current uncertainty (ratio uncertainty) and phase shift uncertainty.

Current uncertainty, and therefore components of uncertainty due to current ratio, depends on primary current, burden and burden's power factor. There are two ways to express the uncertainty $u(I)$:

– to choose fixed values of current, and then compute the standard uncertainties according to the error limits prescribed for accuracy class specified in relevant standards (i. e. IEC 185). The *a priori* rectangular distribution is supposed;

– to compute a mean of the uncertainty (variance) over the ranges of relevant parameters. It is a first step in the procedure of computing the mean variance of output quantities (active and reactive energy W_P, and W_Q) over the ranges of interesting parameters (current and power factor) with the aim to express the single value of standard uncertainty.

4.5. Phase angle φ between voltage and current vector

The phase angle φ is a difference in phase between the voltage and the current vectors. It is a value depending on the load of the electrical network. Since voltage and current are sinusoidal quantities, the phase angle is expressed by the power factor cosφ for active energy and sinφ for reactive energy for practical purposes.

The phase angle φ' between the voltage and the current vectors on the input terminals of the electricity meter is not equal to the phase angle φ between the voltage and the current vectors of the high voltage line because of the instrument transformers phase shifts.

The uncertainty $u(\varphi)$ of the phase angle $\Delta\varphi = \varphi' - \varphi$ is equal to the positive square root of a sum of the variances of variables voltage and current phase shifts:

$$u(\varphi) = \sqrt{u^2(\delta_U) + u^2(\delta_I)} \qquad (4)$$

where $u(\delta_U)$ and $u(\delta_I)$ are the uncertainties of the voltage and current instrument transformers phase shifts respectively.

4.6. Evaluation of combined standard uncertainty of active and reactive power

The first step in the evaluation of combined standard uncertainty of active and reactive energy is to find the combined uncertainty of active and reactive power. The combined standard uncertainty is the positive square root of combined variance $u^2(P)$ or $u^2(Q)$, which is given by the sum of estimated variances of the voltage, current and phase angle variables:

$$u^2(P) = \sum_{i=1}^{N} \left(\frac{\partial P}{\partial x_i} \right)^2 u^2(x_i) \tag{5}$$

$$u^2(Q) = \sum_{i=1}^{N} \left(\frac{\partial Q}{\partial x_i} \right)^2 u^2(x_i) \tag{6}$$

Expressed in relative ratio:

$$u(P)_{\%} = \sqrt{\left(u(U)_{\%}^2 + u(I)_{\%}^2 + (100 \tan\varphi \cdot u(\varphi))^2 \right)} \tag{7}$$

$$u(Q)_{\%} = \sqrt{\left(u(U)_{\%}^2 + u(I)_{\%}^2 + \left(100 \frac{u(\varphi)}{\tan\varphi} \right)^2 \right)} \tag{8}$$

Where $u(U)_{\%}$ is standard uncertainty of voltage expressed in percentage, $u(I)_{\%}$ standard uncertainty of current expressed in percentage, and $u(\varphi)$ standard uncertainty of phase angle expressed in radian.

4.7. Standard uncertainty of the electric energy meter

By evaluating components of uncertainty of meter, it is necessary to consider and include the following possible effects of:

- ambient temperature
- variation of voltage
- variation of frequency
- external magnetic field.

Standard uncertainty of the meter (u_m) is a variable. It depends on some parameters such as current through the meter and power factor. The specifications (standards, catalogues) specify only a few values of these parameters when specifying maximum permissible limits of errors. The maximum permissible limits of errors for other values of the parameters must be interpolated.

4.8. Expanded uncertainty U

It is a common practice to express uncertainty in the form of expanded uncertainty to provide a level of confidence that can be associated with a calculated uncertainty. Expanded uncertainty is obtained by multiplying the combined standard uncertainty by coverage factor k. The value of coverage factor k depends on level of confidence and assumed probability distribution of output quantity. It is possible to express expanded uncertainty only if it is proved that:

- the correlations between input quantities are negligible
- the nonlinearity between input and output quantities is negligible
- it is possible to find the resulting convolved distribution for measurand.

The central limit theorem helps in determining the form of the resulting convolved distribution for measurand Y. This theorem states that the distribution of Y will be approximately normal if input quantity are independent and the variance of Y is much larger than any single component from non-normally distributed X_i. The distributions of the most uncertainty components, in examined cases, are rectangular. Therefore, for all estimation it should be checked if the requirements of the central limit theorem are met. If they are, the expanded uncertainty for measurement active and reactive energy with a 95 % level of confidence is obtained by coverage factor $k = 2$ from following equations:

$$U_{95} = k\sqrt{u^2(P) + u_m^2} \tag{9}$$

$$U_{95} = k\sqrt{u^2(Q) + u_m^2} \tag{10}$$

When the requirements of the central limit theorem are not met, some analytical or numerical methods are required, or the result is expressed through the combined standard uncertainty.

4.9. Reporting the result

Correction and uncertainty of energy are variables. The parameters on which they depend are current and phase angle (power factor). The results of the calculations could be presented in the table form – the values of relative corrections and uncertainties over the range of possible values of parameters that influence them. Sometimes it is not appropriate to express the result for every possible current through the lines and for every possible power factor. For reducing the number of possible results, it is useful to find out interesting values of current and appropriate power factors for every measuring point.

The second possibility is to express a single mean correction and a single value of mean (expanded) uncertainty over the ranges of interesting parameters for every measuring point. It is important to find a reasonable interval of the parameters, and on that way to find few intervals that represent important working conditions.

5. CONCLUSION

The primary aim of project of estimation the uncertainties in measurement of electric energy on high voltage transmission lines is the improvement of quality of the measurement of electrical energy.

6. REFERENCE

[1] ISO (BIPM, IEC, IFCC, IUPAC, IUPAP, OIML): 1993: Guide to the expression of uncertainty in measurement, (GUM), 2nd edition, Genève, 1993

Authors: Prof. Dr. Mladen Boršić, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb, Croatia; phone: +385 1 61 29 600; fax: +385 1 61 29 616; Mladen.Borsic@fer.hr
Prof. Daponte, Pasquale; Università degli Studi del Sannio; Benevento, Italy; E-mail: dpnpql@amalficoast.it