Contribution of Impedance Imperfection of the V-type LISNs in Measurement Uncertainty of Conducted Disturbances

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***Abstract*—Method of uncertainty estimation due to impedance imperfection of the V-type Line Impedance Stabilisation Networks (LISNs) is presented. Elaboration is performed for two cases: for measured impedances of the LISN and for assumption of tolerances imposed on impedances. Estimation is illustrated with uncertainty calculation for two lines LISN. Uncertainty estimated with assumption of tolerances are presented in [2], [3] and [4]. Such uncertainty is much bigger than that estimated for LISN for which impedances are measured.**

Key words: Line Impedance Stabilisation Network (LISN), common mode, differential mode, Measurement Uncertainty (MU), mean value, standard uncertainty, random generator.

I. INTRODUCTION

Most of the standards require measurement of conducted disturbances emitted via cord to the mains. Frequency spectrum of these disturbances covers band A (from $9kHz$ to $150kHz$) and band B (from $150kHz$ to $30MHz$). For the benefit of measurements reproducibility the standards define so called V-type Line Impedances Stabilisation Network (LISN) which is inserted into the mains. Thanks to the LISN, coupling and decoupling impedances of the mains are stable by measurements.

Impedance imperfection of LISN is responsible for two contributions in measurement uncertainty. One is due to Voltage Division Factor (VDF). This contribution is elaborated in the previous publication of the authors [1]. The second contribution is due to deviation of LISN impedances from that of the reference LISN. Approach for estimation of this contribution is presented in [2] and [3]. Simplified EUT model with only one electromotoric force and only one impedance is considered there. In [4] and in [5] this approach is used for uncertainty estimation with assumption of impedance tolerances.

According to [4] and [5] maximal errors due to impedance imperfection are $(+3.1dB/-3.6dB)$ in band A and $(+2.6dB/-2.7dB)$ in band B. Triangular distributions is assumed there i.e. that divider which must be applied is equal to $\sqrt{6}$. Therefore standard uncertainty yields $(+1.27dB/-1.47dB)$ and $(+1.06dB/-1.1dB)$ in band A and B respectively. Despite unsymmetry of distribution, the mean value is not taken into account in these documents.

In this paper exhaustive elaboration of uncertainty due to impedance imperfection of LISN is presented. Complex EUT model with one differential mode source and two common mode sources is considered. Elaboration is accomplished with two following numerical estimations of measurement uncertainty of the two lines V-type LISN :

- for specific LISN for which impedances are measured with vector network analyser,
- with assumption of tolerances imposed on the LISN impedances.

II. REQUIREMENTS IMPOSED ON V-TYPE LISN

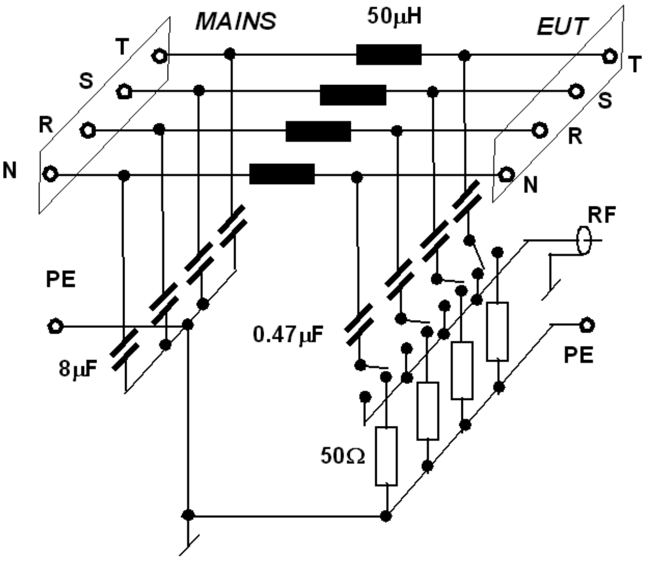

Fig. 1. Electrical scheme of the V-type LISN for disturbance measurement of four lines mains in band B.

Each LISN has three ports: EUT-port, Mains-port and RF-port on which measurement receiver with 50Ω input impedance is connected.

An example of such LISN intended for measurement in band B of four lines mains is shown in Fig.1.

Each coupling path has parallel connection of branches with 50Ω resistance and $50\mu H$ inductance. Moreover line inductances for separation of Mains-port and EUT-port are built in. For high current LISNs separation inductances place in the same time a role of coupling inductance, thanks capacitors connected in star to the PE.

Branches with 50Ω resistance have switches. In the line to be measured, switch is in such position that internal 50Ω resistance is switched off and 50Ω resistance of the receiver is inserted. In Fig.1 switches are in positions for disturbances to be measured in line T.

Tolerances for LISN impedances are given in [2]. They are $\pm 20\%$ for absolute value and $\pm 11.5^o$ for the phase, referred to parallel circuit $50\Omega \mid\mid 50\mu H$. This requirement is valid if 50Ω is inserted by the measurement receiver as well as if it is internal resistance.

Example of these impedances for two lines V-type LISN are shown in Fig.2. It should be noticed that there are slight differences between impedances of lines and for each line with internal and external 50Ω resistance. This results with different uncertainty for each line.

III. ESTIMATION OF UNCERTAINTY

Lets consider the circuit in which EUT is represented with delta mesh composed of one branch with differential voltage source $\mathcal{E}_{DM}$ and impedance Z_{DM} and two branches with common mode voltage sources $\mathcal{E}_{CM}$ and impedances Z_{CM}. LISN is represented with two branches with impedances Z_{IN} and Z_{EX}. Line with Z_{EX} means inserted 50Ω resistance of the measurement receiver. Such circiut is shown in Fig.3.

Infinitely large mains impedance is assumed in this presentation.

As the reference for uncertainty estimation, the idealised LISN with rated impedances $50\Omega \mid\mid 50\mu H$ in both lines is taken. These impedances are named Z_{RE}.

Reference voltage U_{RE} measured with receiver in such situation has two components: U_{RE}^{CM} form common mode sources

$$U_{RE}^{CM} = \frac{Z_{RE}}{Z_{RE} + Z_{CM}} \cdot \mathcal{E}_{CM} \tag{1}$$

and U_{RE}^{DM} from differential mode source

$$U_{RE}^{DM} = \frac{Z_{RE} \cdot Z_{CM}}{Z_{DM} \cdot Z_{RE} + 2 \cdot Z_{CM} \cdot Z_{RE} + Z_{DM} \cdot Z_{CM}} \cdot \mathcal{E}_{DM} \tag{2}$$

Reference voltage U_{RE} is function of five complex variables from which only Z_{RE} is determined. The rest over variables are random.

$$U_{RE}(\mathcal{E}_{CM}, \mathcal{E}_{DM}, Z_{CM}, Z_{DM}, Z_{RE}) = U_{RE}^{CM} + U_{RE}^{DM} \tag{3}$$

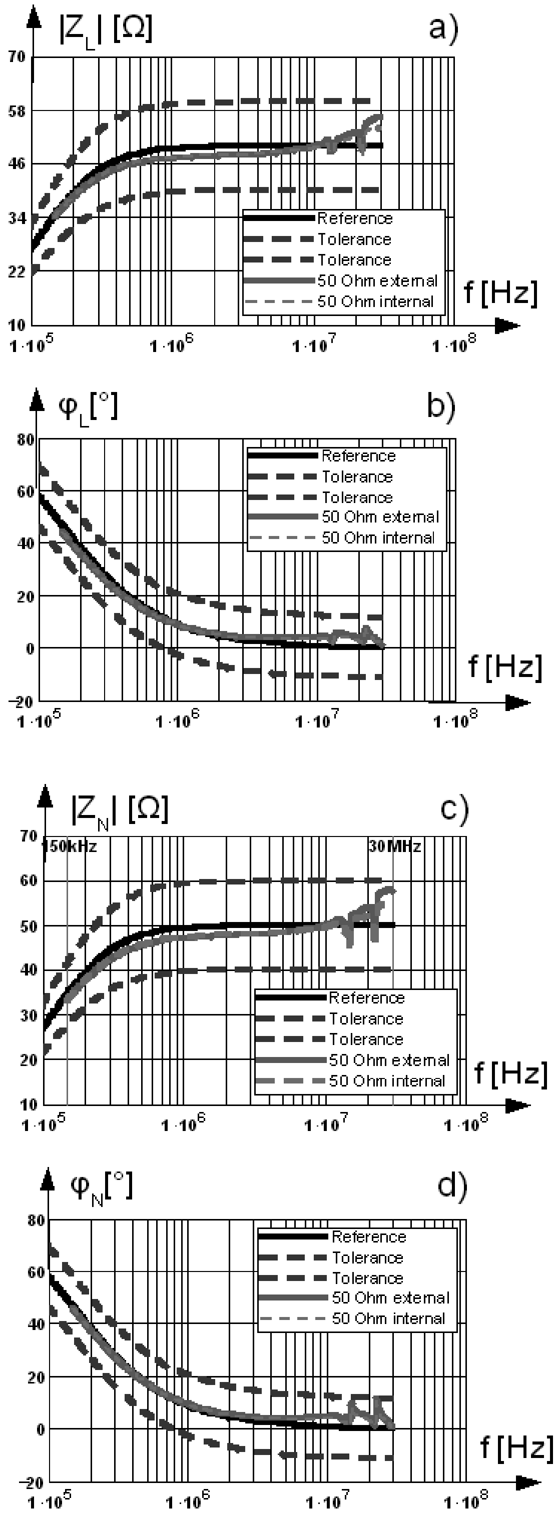

Fig. 2. An example of impedances of a true V-type LISN along with reference impedance and impedance tolerances: line magnitude a), line phase b), neutral magnitude c), neutral phase d).

U_{EX}^{CM} due to common mode sources of the EUT, in the circuit shown in Fig.3 is as follows. (Because of lack of space

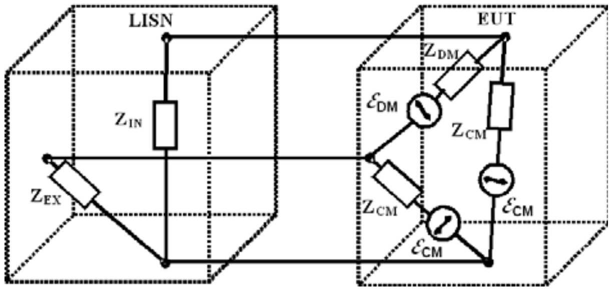

Fig. 3. Electrical circuit for uncertainty estimation of two lines EUT and the V-type LISN.

reciprocal of mentioned voltage is derived)

$$\frac{1}{U_{EX}^{CM}} = \frac{1}{(Z_{DM}Z_{IN}+2Z_{CM}Z_{IN}+Z_{DM}Z_{CM})\cdot Z_{EX}\cdot \mathcal{E}_{CM}}\cdot$$
$$(Z_{DM}Z_{IN}Z_{EX} + 2Z_{IN}Z_{CM}Z_{EX} + Z_{CM}Z_{DM}Z_{IN} +$$
$$+ Z_{CM}^2 Z_{IN} + Z_{CM}Z_{DM}Z_{EX} + Z_{CM}^2 Z_{EX} + Z_{DM}Z_{CM}^2) \tag{4}$$

U_{EX}^{DM} due to differential mode source in the EUT, in the circuit shown in Fig.3 is as follows

$$\frac{1}{U_{EX}^{DM}} = \frac{1}{(Z_{IN}+Z_{DM})\cdot Z_{CM}\cdot Z_{EX}\cdot \mathcal{E}_{CM}}\cdot$$
$$(Z_{DM}Z_{IN}Z_{EX} + 2Z_{IN}Z_{CM}Z_{EX} + Z_{CM}Z_{DM}Z_{IN} +$$
$$+ Z_{CM}^2 Z_{IN} + Z_{CM}Z_{DM}Z_{EX} + Z_{CM}^2 Z_{EX} + Z_{DM}Z_{CM}^2) \tag{5}$$

True voltage U_{EX} is a function of six complex variables from which only two: Z_{IN} and Z_{EX} are determined. The rest over variables are random.

$$U_{EX}(\mathcal{E}_{CM}, \mathcal{E}_{DM}, Z_{CM}, Z_{DM}, Z_{EX}, Z_{IN}) = U_{EX}^{CM} + U_{EX}^{DM} \tag{6}$$

Error δ is defined as relation of absolute values of Eq.(6) and Eq.(3)

$$\delta = 20\log\frac{|U_{EX}|}{|U_{RE}|} \tag{7}$$

It means that error δ is a function of eight random variables: two absolute values of electromotoric forces: common mode $|\mathcal{E}_{CM}|$ and differential mode $|\mathcal{E}_{DM}|$, their phases ψ_{CM}, ψ_{DM} and two absolute values of impedances: common mode $|Z_{CM}|$ and differential mode $|Z_{DM}|$ and their phases φ_{CM}, φ_{DM}. It can be estimated only numerically.

This estimation has been performed for range of variation of electromotoric forces $|\mathcal{E}_{CM}|$ and $|\mathcal{E}_{DM}|$ from $0V$ to $100V$, their phases ψ_{CM}, ψ_{DM} from 0 rad to 2π rad, for absolute values of impedances $|Z_{CM}|$, $|Z_{DM}|$ from 0Ω to $100k\Omega$ and their phases φ_{CM}, φ_{DM} from $-\pi/2$ rad to $\pi/2$ rad. Values have been chosen by random generator. For each frequency $3'000'000$ samples with rectangular probability distribution have been taken.

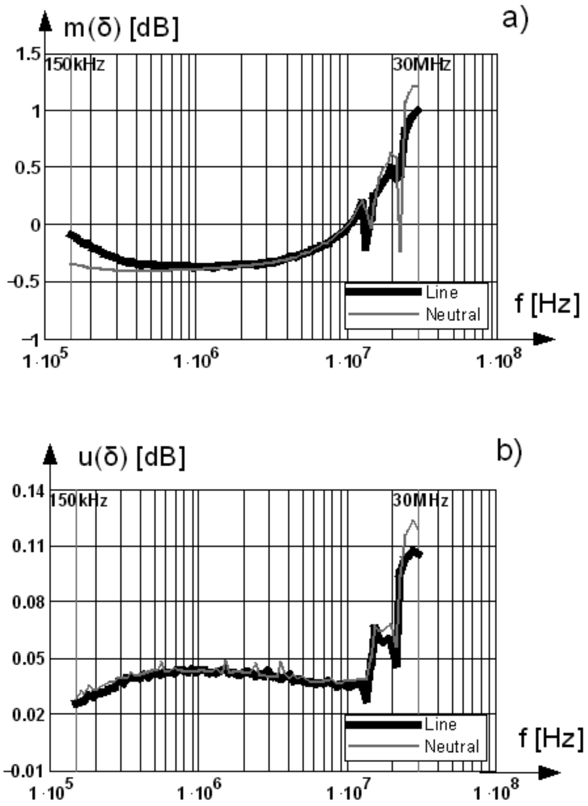

Fig. 4. Error due to impedance imperfection of the V-type LISN versus frequency: mean value a), standard uncertainty b).

Results of this estimation are shown in Fig.4. This distribution is approaching normal distribution with mean value $m(\delta)$ unequal to zero.

It must be noticed that distributions for Line and Neutral are slightly different.

The worst case standard uncertainty is equal to $u = 0.13dB$. This is for Neutral by frequency about $28MHz$.

Additionally, by reffering the measurement result to the standard limit, the minimal mean value which is equal to $m = -0.41dB$, must be taken into account with opposite sign. This value is again for Neutral, by frequency about $310kHz$. Rational for this is smaller measurement result obtained with the true LISN than with the reference LISN.

The same estimation has been done with assumption of tolerances for LISN impedance i.e. $\pm 20\%$ for absolute values and $\pm 11.5^o$ for phases. This has approximately rectangular distribution. The mean value and standard uncertainty are almost independent on frequency. The same situation is reported for T-type ISN (see [6]).

Obtained minimal mean value is $m = -0.06dB$ and maximal standard uncertainty $u = 1.0dB$.

IV. CONCLUSIONS

Method of uncertainty estimation of the V-type LISNs due to impedance imperfection is presented. It is illustrated with calculation for the two lines LISN intended for measurement in band B.

Calculation is performed in two cases: for measured impedances of the LISN and for assumption of tolerances imposed on the LISN impedances. Obtained uncertainties are $\pm 0.13dB$ and $\pm 1.00dB$ respectively. Advantage of uncertainty calculation for individually measured LISN impedances, compared with application of the impedance tolerances is obvious.

Because of big number of random variables, which are moreover frequency dependent, this estimation can be done only numerically.

Uncertainty obtained for simplified EUT model and tolerances of impedances, presented in [4] and in [5] $(+1.06dB/-1.1dB$ in band B) are practically the same as obtained in this paper ($\pm 1.00dB$ for impedance tolerances). This is however misleading because in [4] and in [5] triangular distribution is assumed. Investigation of the authors shows that such distribution is almost rectangular i.e. that divider equal to $\sqrt{3}$ must be applied. Therefore standard uncertainty for maximal errors $(+3.1dB/-3.6dB)$ in band A and $(+2.6dB/-2.7dB)$ in band B should be $(+1.79dB/-2.08dB)$ and $(+1.5dB/-1.56dB)$ respectively.

Investigation of the authors shows that results of uncertainty estimation can contain mean value unequal to zero. In documents [4] and in [5] this fact is ignored. It is recommended there to symmetrise the range of variation in case of unsymmetry.

In opinion of the authors results for two lines LISN cannot be extrapolated for four lines LISN. Investigation of this case is necessary and will be carried out by the authors.

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