Design of Three-Phase Line Impedance Stabilization Networks for EMC Pre-compliance Testing Laboratories

Conference Paper · May 2013

DOI: 10.1109/ECTICon.2013.6559466

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***Abstract*- In this paper, the design procedure of three-phase line impedance stabilization networks (LISN) for EMC pre-compliance testing laboratories is proposed. The three-phase LISN schematics and the detail of its components are provided. Finally, the experimental results demonstrating the performances of proposed three-phase LISN are given.**

I. Introduction

To comply with the conducted electromagnetic interference (EMI) standards, the Line Impedance Stabilization Networks (LISN) or Artificial Mains Networks (AMN) is normally used in conducted emission measurements, where a designed LISN must be complied with the performance requirements specified by CISPR 16-1 standard. Generally, the main functions of LISN are to perform [1-5]:

- Stable and normalized impedance at main supplies over the frequency range of interest e.g. 50 Ω at the output ports of LISN over 150 kHz – 30 MHz (for conduced EMI measurement).
- Incoming EMI disturbance prevention from main supplies.
- Provide matched 50 Ω EMI measurement ports connecting to EMI receivers.

In [6-8], the design procedure of low-cost single-phase LISN 50 Ω/50 µH + 5 Ω v-networks suitable for EMC and power electronics laboratories was proposed. Although, the proposed single-phase LISN of [6-8] can successfully fulfilled the CISPR 16-1 requirements with minimum cost, it can be applied for a single-phase equipment under test (EUT) only. In this paper, the concept of [6-8] is extended to three-phase EUT systems.

II. Design Of Proposed Three-Phase Line Impedance Stabilization Network

A. *Three-phase LISN Schematic*

Fig.1 (a) shows the schematic of proposed three-phase LISN components. According to CISPR 16-1 [1], the 50 Ω/50 µH + 5 Ω V-NETWORK is chosen to stabilize the impedance of power line to be equal to 50 Ω in each line-to-ground (L_1-G, L_2-G, L_3-G and N-G). The actual designed three-phase LISN is shown in Figs. 1 (b)-(c).

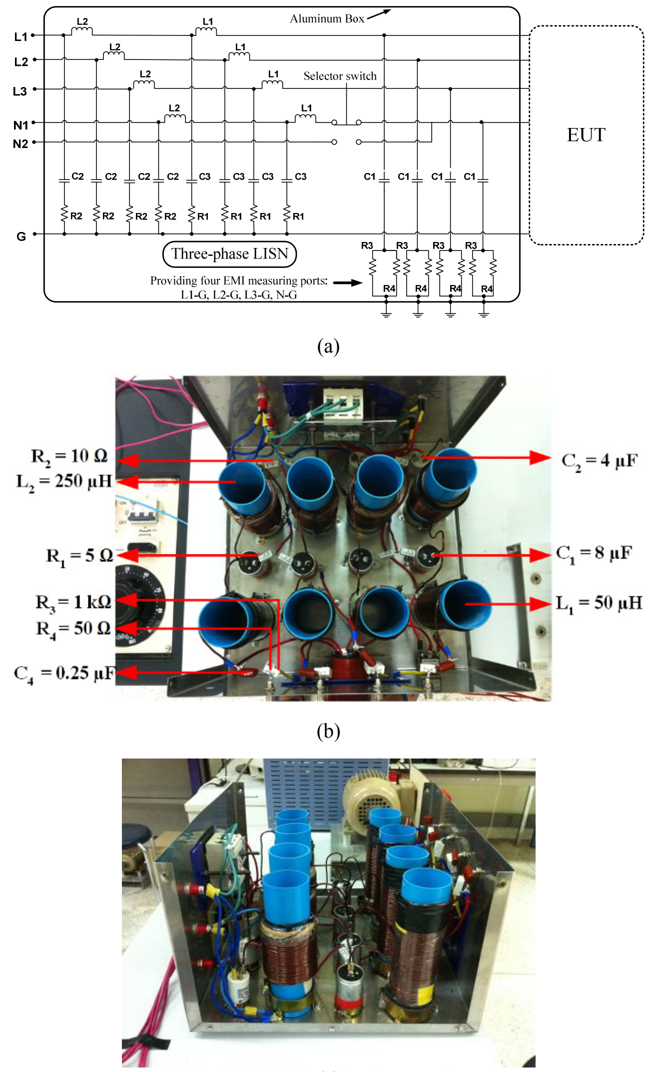


Fig. 1. Designed three-phase LISN: (a) schematic (b) top view(c) side view.

B. Three-phase LISN Components

The list of LISN components in each line-to-ground circuits can be summarized as shown in Table I.

TABLE I
PROPOSED THREE-PHASE LISN COMPONENTS
(50 Ω/50 μH + 5 Ω V-NETWORK) [1], [6]

COMPONENT	VALUE	TYPE	RATED
R_1	5 Ω	Wire wound	5 W
R_2	10 Ω	Carbon film	1/2 W
R_3	1,000 Ω	Carbon film	1/2 W
R_4	50 Ω	Carbon film	1/2 W
C_1	8 μF	metallized polypropylene film	450 Vac
C_2	4 μF	metallized polypropylene film	450 Vac
C_3	0.25 μF	matallized polyester film	275 Vac
L_1	50 μH	AWG#11 wound on PVC (single-layer winding)	12 A
L_2	250 μH	AWG#11 wound on PVC (three-layer winding)	12 A

It should be noted that the designed three-phase LISN is covered with the metal box with the size of 400x4000250 mm in order to prevent the radiated EMI emission [4-5].

III. DESIGN OF LISN INDUCTORS

Generally, to avoid saturation of magnetic core due to high current, a LISN inductor is an air-core inductor where its coil winding is wound around a non-magnetic, non-flammable, and insulating material e.g. Bakelite. However, the price of such core is costly affecting to the cost of a LISN. In order to lower the cost of LISN, the unplasticized polyvinyl chloride (PVC) water pipe is applied to be a core of LISN inductors where the effectiveness of this concept has already proved experimentally in [6-8]. It can provide the stable 50 Ω impedance over the conducted EMI frequency range. Using the same concept of single-phase LISN [6-8] to design the three-phase LISN inductors, it can be concluded as follows.

A. Design procedure for 50 μH LISN Inductor

For 50 μH LISN Inductor (L_1), the chosen length, diameter and maximum operating temperature of PVC forming cores are: 200 mm, 27.5 mm and 60 °C, respectively. The single-layer winding configuration with AWG#11 is chosen as copper windings which has maximum current for power transmission up to 12 A. The number of turns for 50 μH LISN Inductor (L_1) is approximated using Eq. (1).

$$N = \sqrt{\frac{L l_m}{A_c \mu_0}} \tag{1}$$

where N is the total number of turns (turns)
L is the required inductance (H)
l_m is the coil length (m)
A_C is the cross section of PVC core (m^2)
μ_0 is the permeability of air (H/m).

Using Eq. (1), the approximated number of turns for L_1 is

$$N_{50\mu H} = \sqrt{\frac{50\times10^{-6}\cdot 0.2}{\pi\cdot(27.5\times10^{-3})^2\cdot 4\pi\cdot10^{-7}}} \simeq 57 \text{ turns.}$$

B. Design procedure for 250 μH LISN Inductor

In case of 250 μH LISN Inductor (L_2), the chosen length, diameter and maximum operating temperature of PVC forming cores are the same as that of L_1. However, in order to use the same PVC core size of L_1, L_2 must be wound with multi-layer winding configuration. The number of turns for 250 μH LISN Inductor (L_2) can be calculated using Wheeler air core coil formula as shown in Eqs. (2)-(3) where the definition of parameters used in Eq. (2) is provided in Fig. 2 (c).

$$L(\mu H) = \frac{31.6\cdot N^2\cdot (R)^2}{6\cdot(R)+9l+10(B)} \tag{2}$$

$$R = \frac{r_1 + r_2}{2} \tag{2a}$$

$$B = r_2 - r_1 \tag{2b}$$

where R is the average winding radius (m)
B is the different between r_2 and r_1 (m)
r_1 is the inner core radius (m)
r_2 is the outer core radius including the width of copper winding (m)

$$N_1 = \frac{N + (N_2/2)}{N_2} \tag{3}$$

where N_1 is number of turns per layer (turns)
N_2 is the number of layers (layers)

Since the diameter of copper winding (AWG#11) is 2.3 mm and three-layers winding configuration is chosen, the number of turns per layer can be determined as follows.

$$R = \frac{27.5\times10^{-3} + \left[27.5\times10^{-3} + \left(3\cdot\frac{2.337\times10^{-3}}{2}\right)\right]}{2}$$

$$= 29.25\times10^{-3} \text{ m}$$

$$B = r_2 - r_1 = 31\times10^{-3} - 27.5\times10^{-3} = 3.5\times10^{-3} \text{ m}$$

Substituting required inductance (250 µH), coil length (l_m = 200 mm) and calculated R and B into Eq. (2) yields

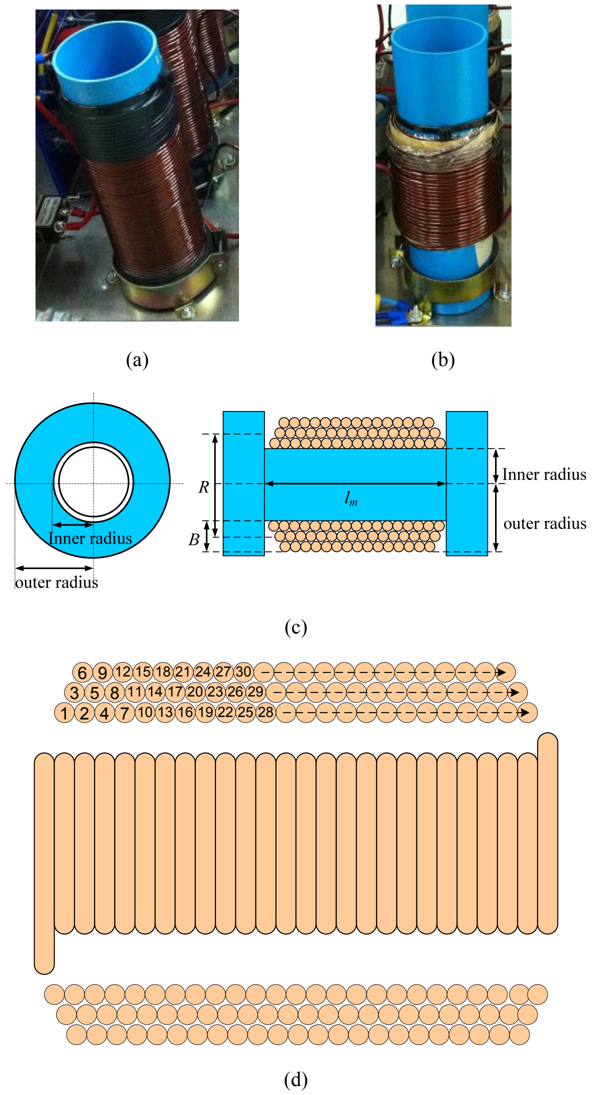


Fig. 2. LISN Inductors: (a) actual designed 50 µH inductor (single-layer winding) (b) actual designed 250 µH inductor (three-layer winding) (c) dimension of 250 µH inductor (d) 3 layer winding diagram.

$$N = \sqrt{\frac{L(\mu H)\left[6\cdot(R)+9l_m+10(B)\right]}{31.6(R)^2}}$$

$$= \sqrt{\frac{250\left[6\cdot\left(29.25\times10^{-3}\right)+9\left(200\times10^{-3}\right)+10(3.5\times10^{-3})\right]}{31.6\left(29.25\times10^{-3}\right)^2}}$$

$$\simeq 136.57 \text{ turns}$$

With the chosen three layer winding configuration (N_2 = 3), the number of turns per layer (N_1) can be calculated by substituting N and N_2 into Eq. (3).

$$\mathrm{N}_1 = \frac{N+(N_2/2)}{N_2} = \frac{136.57+(3/2)}{3} \simeq 46 \text{ turns per layer}$$

where the three-layer winding diagram is shown in Fig. 2 (d). It should be noted that, to minimize the stray capacitances of multi-layer winding configuration, a winding coil should be wound in a manner of progressive winding and widely separates the starting and ending points of a winding [3]. Figs. 2 (a) and (b) show the actual designed LISN inductor of single-layer winding configuration (50 µH) and three-layer winding configuration (250 µH), respectively.

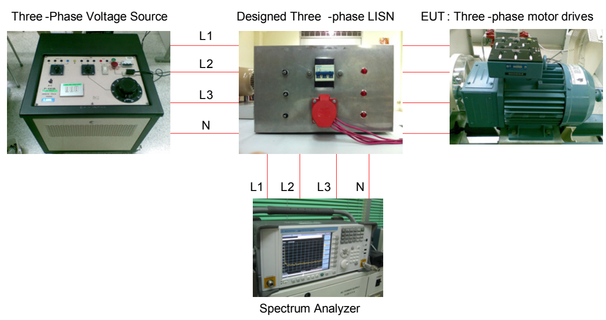
IV. Experimental Verifications

A. Stabilized 50 Ω Impedance verification

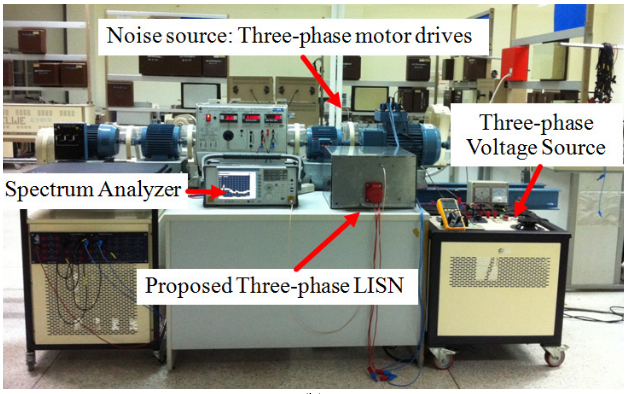
Referring to the experimental verification of stabilized 50 Ω impedances in single-phase LISN [6-8], it shows a good agreement with CISPR 16-1 standard for both phase-to-ground and neutral-to-ground (L-G and N-G). In this paper, the same concept of [6-8] is employed, but it is extended to each line-to-ground and neutral-to-ground of three-phase LISN (L_1-G, L_2-G, L_3-G and N_1-G). As a result, the experimental verification of stabilized impedance is not repeated here.

B. Conducted EMI measurement verifications

To verify the effectiveness of measuring conducted EMI using proposed three-phase LISN, the measurement setup as shown in Figs. 3 (a)-(b) is demonstrated. The three-phase motor drives are used being as a noise source which is connected at the output port of LISN where the input ports of LISN is connected to three-phase voltage source. The spectrum analyzer is used as a measuring conducted EMI equipment. The conducted EMI is measured and compared in case of running three-phase motor drives at: no load, half-load (2.8 A), and full-load (rated). Figs. 4 (a)-(d) show the conducted EMI comparison results measuring at L_1-G, L_2-G, L_3-G and N-G, respectively. From the experimental results, it shows that conducted EMI measuring at ports L_1-G, L_2-G, L_3-G is minimum at the no-load condition and maximum at full-load condition that matches well with the theoretical ones [2-3]. However, the measuring conducted EMI at port N_1-G giving unchanged results because the three-phase motor is connected in star connection with balanced three-phase load.

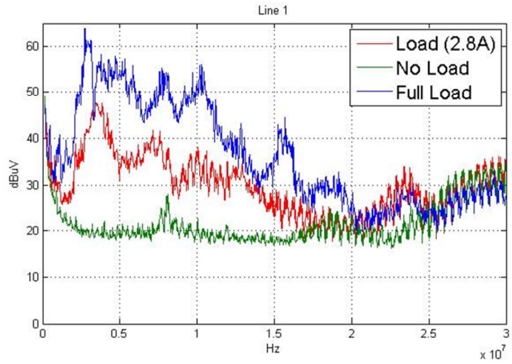


(a)

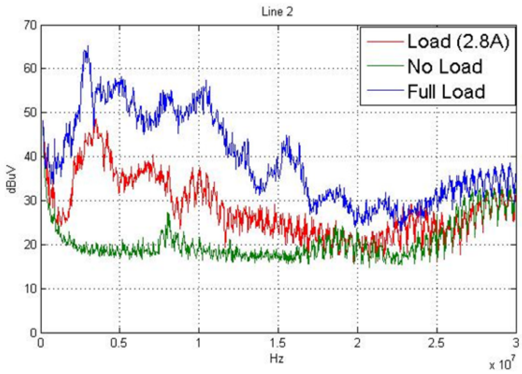


(b)

Fig. 3. Measurement verification of proposed three-phase LISN: (a) testing block diagram (b) experimental testing verification



(a)



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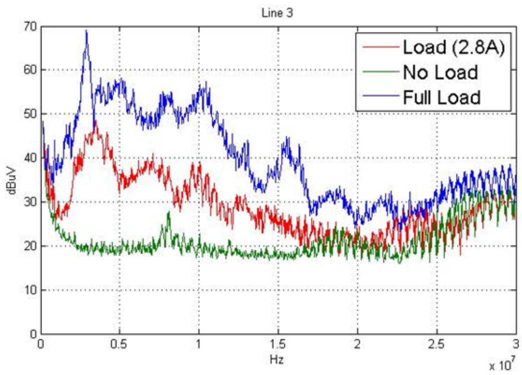
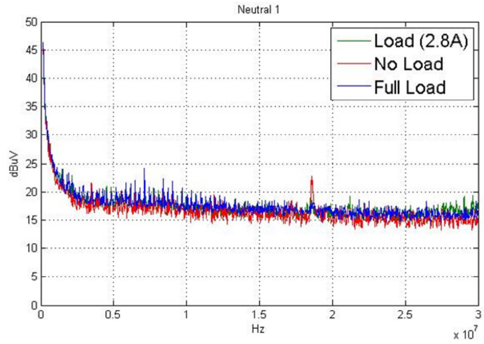


(c)



(d)

Fig. 4. Comparison of conducted EMI measurements: (a) L1-G (b) L2-G (c) L3-G (d) N1-G.

IV. CONCLUSTIONS

The main idea of this paper is to lower the cost of three-phase LISN by using PVC as a forming winding core of LISN inductors where the advantages of using PVC as winding cores for single-phase LISN have already proved in [6-8]. Using the concept of [6-8] to lower the inductor construction cost of LISN, the in-house three-phase LISN for EMC pre-compliance testing laboratories is experimentally demonstrated. The design procedure of three-phase line impedance stabilization networks (LISN), especially LISN inductors, is presented step-by-step. The three-phase LISN schematics and the list of usage components are also provided. From the experimental verifications of designed three-phase LISN, it shows the good agreement between the measured results and theoretical ones.

ACKNOWLEDGMENT

Author would like to thank Mr. Wanatsakorn Sirivatpong, Mr. Chatchai Borikappakul, and Mr. Chanin Sornbunthong for the experimental demonstrations.

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