

Comparative Analysis Between Two Proposed Uses of The Line Inter-phase Transformer In 12 Pulse Three Phase Rectifiers.

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Abstract:

In this paper it is presented a comparative study between two proposed uses of the Line Inter-phase Transformer (LIT), as a passive solution to improve the input current shape in very high power three phase systems.

By using the LIT, in 12 pulse operations, an input current shaping without the 5th and 7th harmonics is obtained.

Experimental results, theoretical analysis and numerical simulation are presented to accomplish the comparison.

INTRODUCTION:

A passive technique to reduce the Total Harmonic Distortion (THD), and the output voltage

ripple in very high power three phase rectifiers, consists in increasing the rectifier operations pulses, (12 or more). To achieve this, an special three-phase transformer connection is necessary, e.g. the typical connection in HVDC is $Y\Delta Y$ [1]. By using this technique in a three-phase system with balanced voltage and without distortion, the line input current shaping does not present 5th and 7th harmonic components. The reference [2], (Fig 1) (LIT1), presented other types of special three-phase transformer connections. This technique applies when isolation is not necessary. This option carries advantages as little volume, but has some problems like displacement factor and poor output voltage regulation. The cause of these problems is the necessary input filter reactor to reduce the high THD. A simple modification, the placement of input AC reactor into to the DC side (Fig 2), avoids these problems [3].

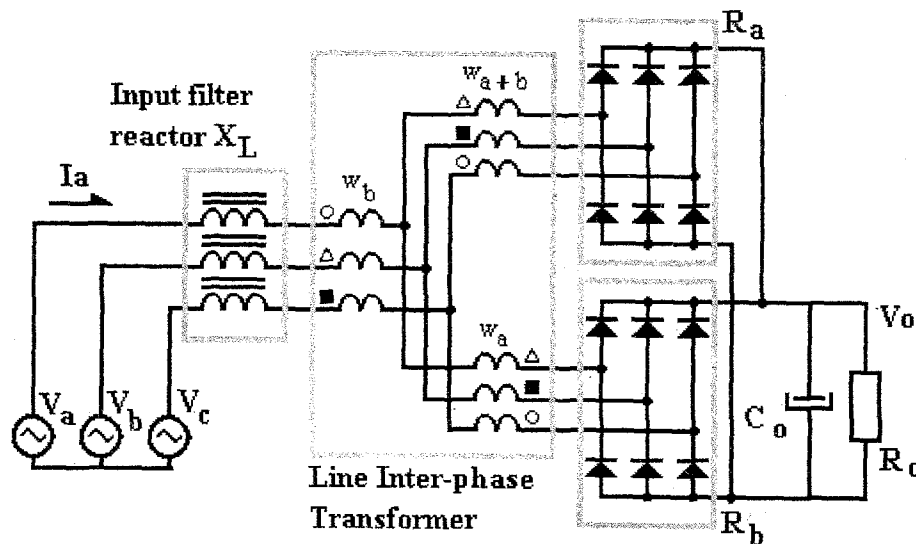


Fig 1 Special transformer connection from [2] (LIT1)

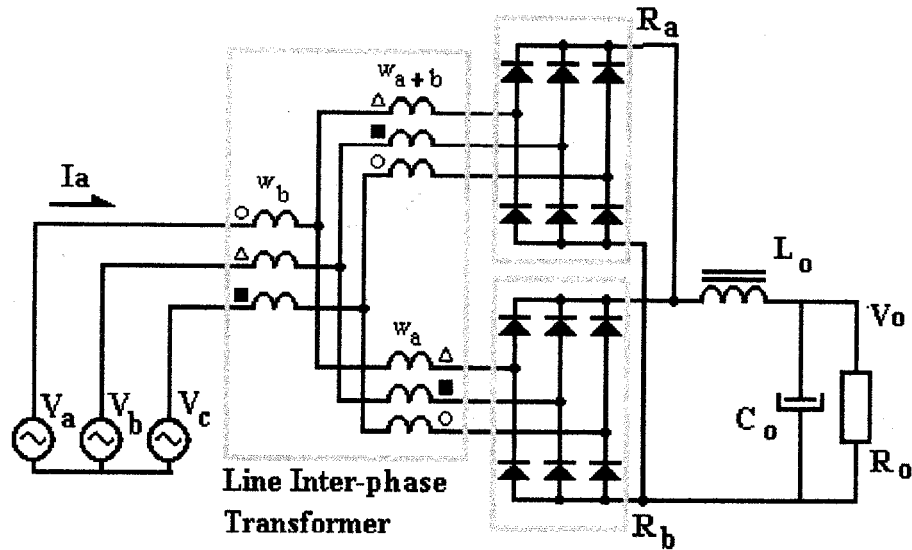


Fig 2 Modification from circuit of Fig 1 [3] (LIT2).

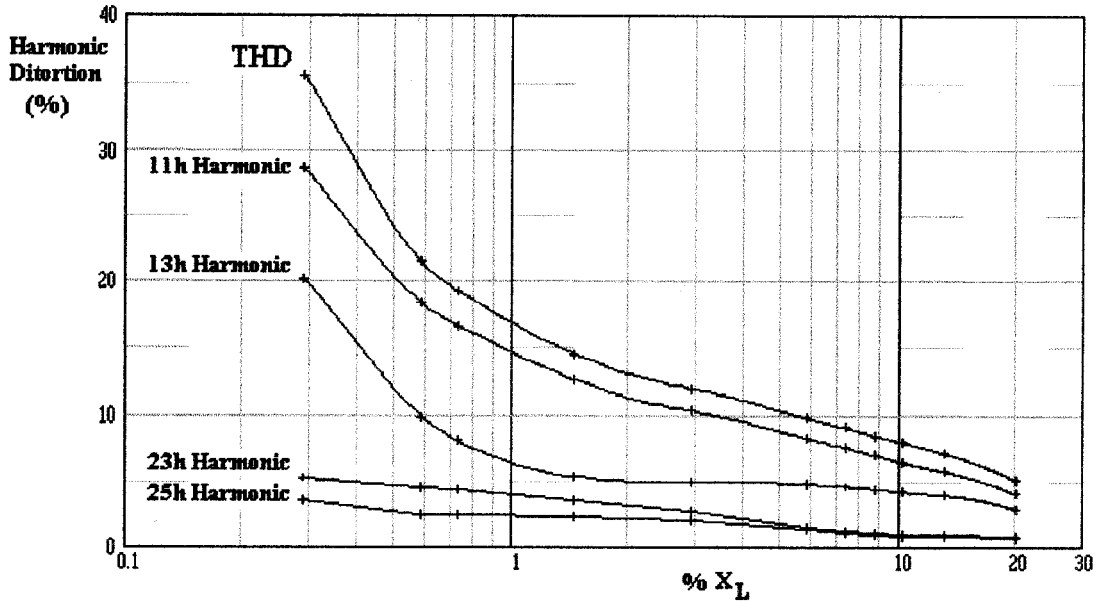


Fig 3 Relative values of THD and main harmonic components of the LIT1, for full load.

This paper presents a comparison between both alternatives, studying their performances for PF, THD, efficiency, volume, etc. In order to perform these comparisons some experimental prototype results and numerical and theoretical analyses are carried out.

BASIC RELATIONS:

It is possible to obtain the similar characteristics of multiple pulse (12 or more) rectifier operation using the LIT. For 12 pulse system, (Fig 1), the LIT's windings turns-ratio is given by:

$$\frac{W_b}{W_a} = 0.366 \quad (1)$$

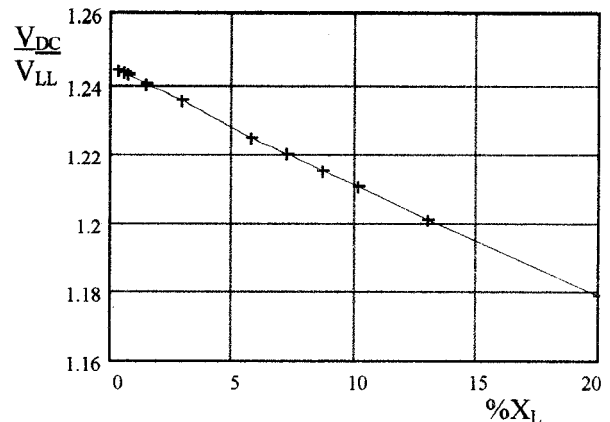


Fig 4 Relative output voltage vs. relative line impedance, for full load.

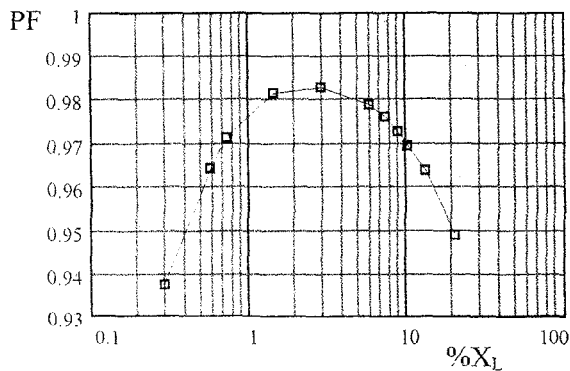


Fig 5 PF vs. %X_L for the LIT1.

For ideal diodes and neglecting the inductive and resistive voltage drops, the DC voltage is given by:

$$V_{DC} = 1.25 \cdot V_{LL} \quad (2)$$

Other specific design guidelines can be found in Fig.3, Fig.4 and Fig 5 and in [2].

For the circuit of Fig 1 (LIT1) the THD and PF depend on input impedance as shown in Fig.3 and Fig. 5. Also, the output voltage depends on the input impedance as shown in Fig. 4. However, in the circuit of Fig. 2 (LIT2), the input impedance has been neglected, then the theoretic THD is fixed to 15%, therefore the PF is fixed to 0.99 as shown in [3]. The theoretic output voltage does not present variation with the load. All the graphical results from Fig. 3 to Fig. 6 were obtained by numerical simulations.

The output filter design of LIT2 is classical. It needs to attenuate 12xfr and 3.6%V_{DC}. The LIT's design is the same for both cases.

$$\%X_L = \frac{X_L \cdot P_O \cdot 100}{V_{LL}^2} \quad (3)$$

Where: X_L= Line impedance
V_{LL}= Line input voltage
P_O= Power output

CONSIDERATION IN THE COMPARATIVE ANALYSIS:

In order to carry out the comparative analysis, it is necessary to make some considerations:

- The LIT1's input filter reactor was chosen to have low THD. Experimental value used was 12%.
 - The LIT2's output filter was chosen to reduce problems with line voltage imperfections (as low frequency harmonics).
 - The output capacitor is the same for both cases.
- For numerical simulations:
- Ideal utility network was used.

- Ohmic voltage drops were neglected.

Keeping in mind the aspects mentioned before, computer simulations and experimental prototypes were developed.

The following values were used :

V_{LL}= 220 V 60 Hz P_O= 6kW P_{LIT}= 0,8 kVA

For the LIT1 an impedance of 12% was used, then:

L= 2.5 mH and C= 3200 uF

For the LIT2: L=7.5 mH and C= 3200 uF

COMPARATIVE ANALYSIS:

PF, THD and output voltage regulation results for both circuits are shown in Figs 6 to 16. Through these results, it is possible to observe:

- It has little differences between numerical and experimental results. The differences are due to the ohmic drops, transformer leakage and ac mains impedances.

- The LIT1 circuit has low PF behavior although the THD is low.

- The LIT2 circuit has relative high THD but good PF.

- As shown in Fig.5, the optimal LIT1's PF is obtained to 3% of X_L, but it is still low when compared with the LIT2 behaviors. The main cause of low PF is the Displacement Factor (DF) introduced by the input filter reactor.

- Other interesting aspect of comparison is the output voltage regulation. The results show that the output regulation is good for both circuits. Nevertheless, the circuit LIT1 has a little worse output voltage regulation, (2% against 6%).

- The LIT2's circuit has better efficiency.

- The final volume and weight obtained were the same for both circuits. If the line voltage used has good quality, it is possible to obtain an important reduction in volume and weight of the output filter for the LIT2 circuit.

- When the load is low, the performances in both circuits present a deterioration, which is greater in the LIT1 circuit. The main cause is that the THD becomes more relevant, and the magnetizing current of the transformer becomes representative, then the line current exhibits low harmonics components, 5th and 7th.

- The harmonic current spectrum, for full load in both circuits, showed components of low frequency (3th, 5th and 7th) with low amplitude; this is due to ac mains imperfections, like unbalanced voltage and voltage distortion.

- It is possible to perform IEEE Std. 519 using the LIT1 circuit for systems with ratios of the short-circuit current (RSC) available at the point of common

Numerical Results:

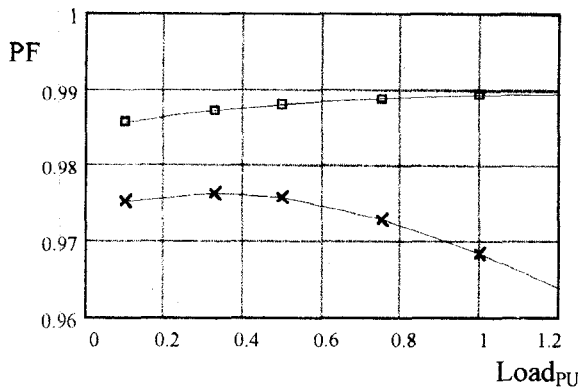


Fig 6 PF vs. Load in per unit.

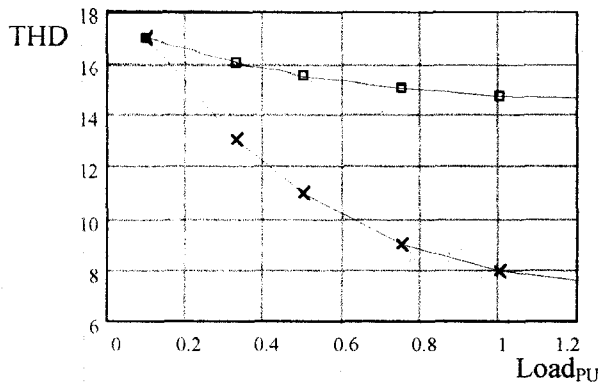


Fig 7 THD vs. Load for the LIT1 and LIT2 circuits

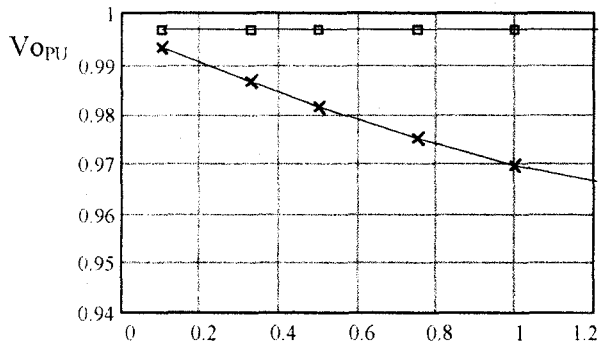


Fig 8 Output Voltage regulation

Box mark refer to LIT2
 Plus mark refer to LIT1

coupling (PCC) better than 50. For the LIT2 circuit it is necessary to put an input filter to reduce the amplitude of the 11th current harmonic component. If any filter is used the RSC must be better than 1000.

- The audible noise in the LIT1 is larger than in LIT2. This is due to the larger variations of the magnetic flux in the input filter reactor.

Experimental Results:

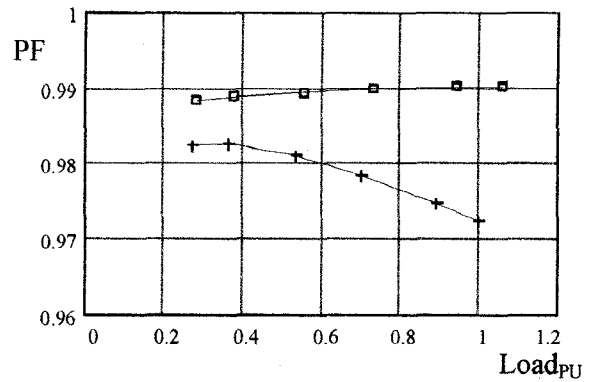


Fig 9 PF vs. Load in per unit.

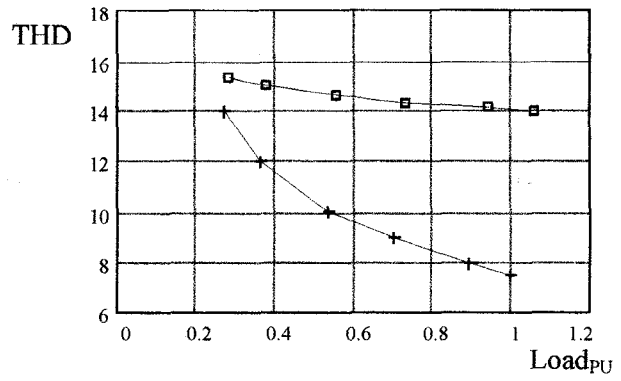


Fig 10 THD vs. Load for the LIT1 and LIT2 circuits

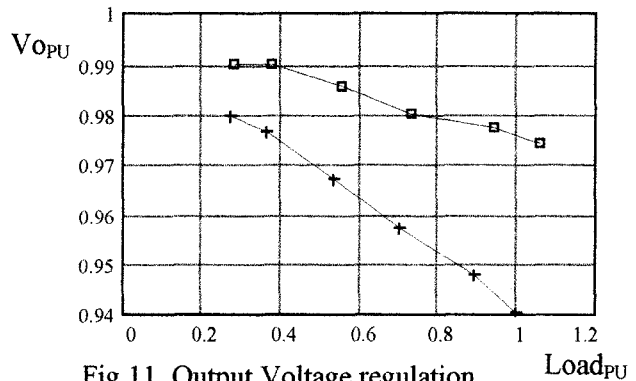


Fig 11 Output Voltage regulation

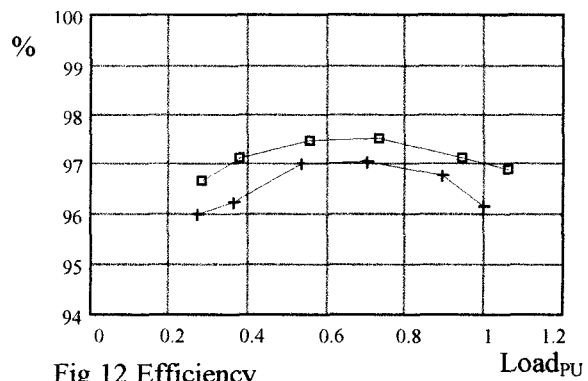


Fig 12 Efficiency

CONCLUSION:

This paper presented a comparison between two applications of LIT transformer in 12 pulse operation.

The graphical behaviors of numerical and experimental results are similar.

Both circuits have similar characteristics, the main difference is the THD. The LIT1 could accomplish the new harmonic standard restrictions, but with the increase of the input filter reactor. This implies in an increase in the DF and voltage regulation problems. If tuned filter is used to reduce 11th harmonic, the LIT2 circuit could accomplish the new harmonics restrictions without the LIT1 problems.

The LIT2's output filter needs to be designed to avoid resonance with the low harmonic voltage frequency carried by ac mains imperfections.

The results presented here are a good guideline for the circuit design.

REFERENCES:

- [1] Rex. M. Davis, "Power Diode and Thyristor Circuits", IEE Monograph Series 7, Peter Peregrinus Ltd.,UK, 1976.
- [2] Clemens Niermann, "New rectifier circuits with low mains pollution and additional low cost inverter for energy recovery" EPE'89, pp 1131-1136
- [3] Carlos Muñoz and Ivo Barbi "A New Approach To The Three-Phase Power Factor Passive Correction Using The Line Inter-Phase Transformer" COBEP'95, Brazil, pp 315-319
- [4] IEEE Std. 519-1992 Recommended Practices and Requeriments for Harmonic Control in Electrical Power Systems.

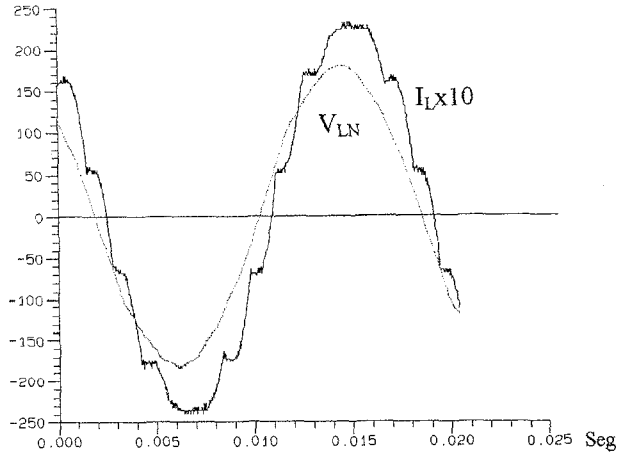


Fig 13 Experimental result, line current and phase voltage of LIT1 at full load.

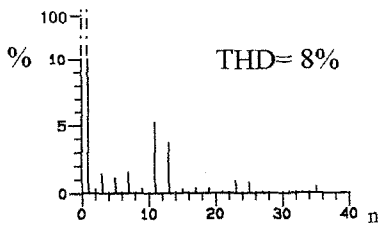


Fig 14 Harmonic line current spectrum of LIT1.

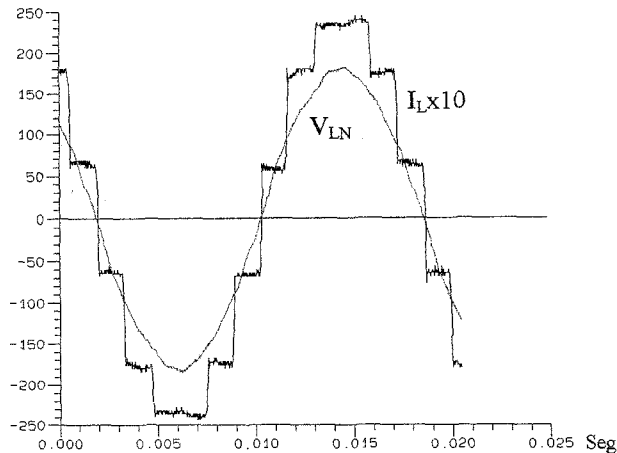


Fig 15 Experimental result, line current and phase voltage of LIT2 at full load.

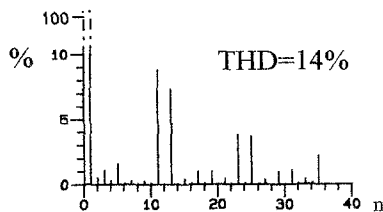


Fig 16 Harmonic line current spectrum of LIT2.