Effects of Distorted Source on Operating a Load-Balancing Transformer in a Distribution Network

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***Abstract*- A Load balancing transformer was suggested for improving the three-phase unbalanced currents in distribution networks. On the other hand, magnitude and phase unbalance commonly occur in power grid networks. This paper investigates the impacts of a distorted source on the operation of a Load-balancing transformer as well as the proposed Load-balancing transformer in this paper. The proposed and original Load-balancing transformers are simulated with MATLAB and the effects of simultaneous unbalanced voltage and harmonics are analyzed under different circumstances and the results are discussed.**

***Keywords*: unbalanced voltage, unbalanced current, Load balancing transformer**

I. INTRODUCTION

Unbalance load is a concern in distribution networks. It causes one phase of transformer to reach its rated value earlier, while there is unused capacity in the other phases. This is the reason for increase in manufacturing cost of transformer. Unbalancing in distribution networks also increases the losses in the conductors, brings in losses and produces voltage in the natural wire, and finally results in voltage drop in the network. However, some techniques have been previously proposed to reduce the unbalancing and its lateral effects. One of them is using of Load-balancing transformer, on the other hand magnitude and phase commonly occur in power networks. The main causes of unbalance are single phase loads present in power systems, unbalanced impedances of transmission lines and transformers, and non-uniform compensation of three-phases with capacitor banks. In additional the increased use of solid state converters produces harmonics in the supply current and voltage waveforms. Nonlinear loads, including adjustable speed drives, UPS, switch mode power converters, microprocessor controls, robotics, fax machines and laser printers create harmonics. These devices also tend to be the most sensitive to malfunction from harmonic distortion. The harmonic currents generated by these non-linear loads do not only cause additional heating of power system components, but at the same time they flow through the system impedance and current harmonics create voltage drops at their respective harmonic frequencies distorting the voltage waveform.

This paper compares the proposed and original Load-balancing transformers which are supplied with unbalanced voltage. A proposed Load-balancing transformer can be simply obtained with a little change in the distribution transformer without any need additional instruments, while it is practical and inexpensive for being implemented in distribution systems.

II. BACK GROUND OF LOAD BALANCING TRANSFORMERS

In [1] a special transformer was suggested for improving the three-phase unbalanced currents, where each phase including one extra pair of coupling windings in addition to the primary and secondary windings of transformer. One coupling winding from each phase in series with one coupling winding from the second phase is reversely paralleled with the secondary winding of the third phase. Under unbalance condition, the unbalanced currents are distributed between the coupling and secondary windings that are supplied through different phases (shown in Fig 1).

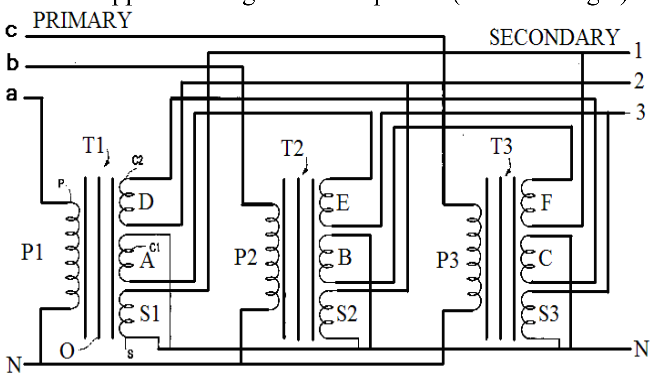

Fig 1.Original Load balancing transformer

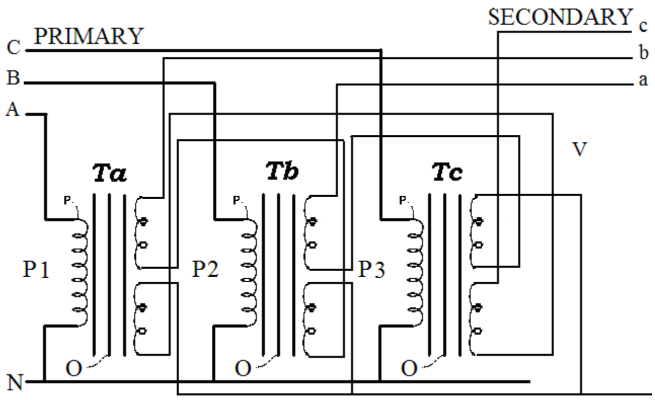

Fig 2.proposed Load balancing transformer

The proposed Load-balancing transformer is a three-phase transformer which has an additional coupling winding in the secondary-side of each phase. The coupling winding from each phase is reversely seriesed with the secodary winding of the another phase. Under unbalanced condition, the unbalanced current flows through the coupling and secondary windings that each winding is fed from primary by using a separate phase. In this way, part of excess current

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of one phase is transferred to the other phaes (shown in Fig 2).

III. THE EFFESCTS OF UNBALANCED VOLTAGES ON THE LOAD BALANCING TRANSFORMER

In many European countries, according to the European voltage characteristic standard EN 50160 [2], the permissible long-term voltage deviation is ±10%, and the ratio of the negative-sequence voltage component and the positive-sequence voltage component should not exceed 2%. The standard also says that in some power systems the ratio is ‘‘up to about 3%”. In this part the unbalance in the phase and the magnitude of the voltage has been considered.

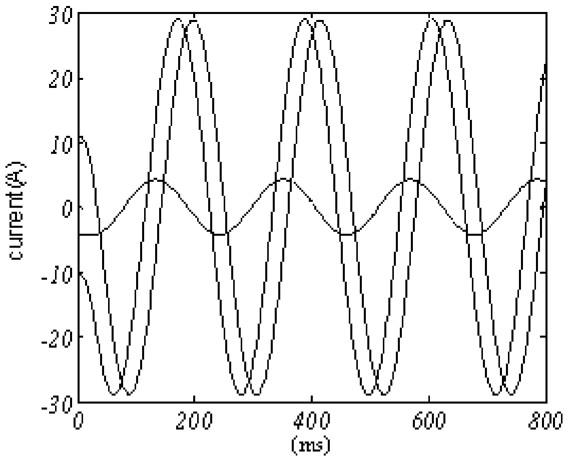

Fig 3.The current of primery-side of Original Load balancing transformer (unbalance factor is 1%)

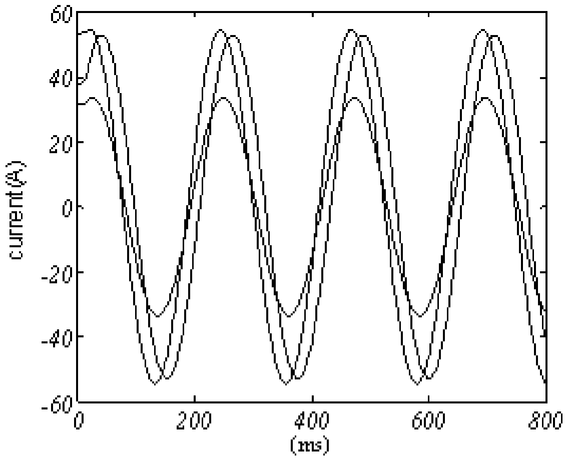

Fig 4.The current of primery-side of Original Load balancing transformer (unbalance factor is 2.5%)

A. Unbalance in the Voltage Magnitude

In this case the Load-balancing transformer is operating with an unbalance voltage at its terminals. So, the value of the voltages for phases A, B and C would be as follows: V_{AB}=200, V_{BC}=198, V_{CA}=202, So the average is 200, and the maximum deviation from the average is 2, so the percent unbalance factor is 1 % (based on NEMA definition), unbalanced loads are connected to the secondary-side of original and proposed Load-balancing transformer. Now assume three phase voltages having of 205,195 and 200, the average is 200 and the maximum deviation from the average is 5, so the percent unbalance factor is 2.5 %.

Figure 3 and 4 show an increase in the magnitude unbalance at the terminal of original one can increase unbalance current in the primary-side more than secondary-side. For an unbalanced factory higher than 1 %, the increase of the unbalanced current in the primary side is considerable.

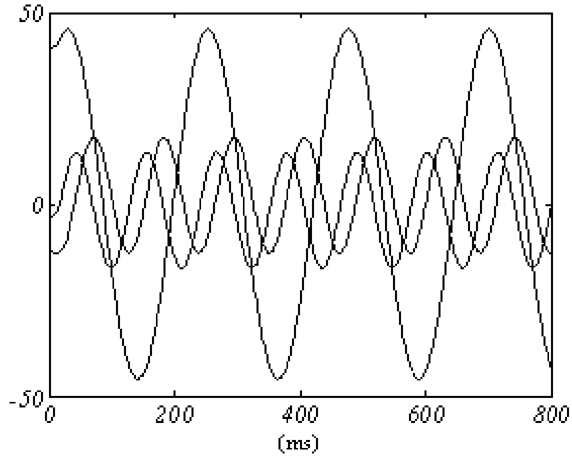

Fig 5. d,q,0 form of current in primery-side of Orginal Load balancing transformer (unbalance factor is 1%)

In this part an unbalance of 10% is assumed for the phase of applied voltages of phase B and C. these voltages are supplied proposed Load-balancing transformer. It can be seen (Fig 3-5) a large amount of phase difference is produced by the Original design of the Load-balancing transformer. However, the proposed Load-balancing transformer which is supplied with unbalanced voltage is capable of moving towards balancing the unbalanced load both in magnitude and in phase (Shown in Fig 6).

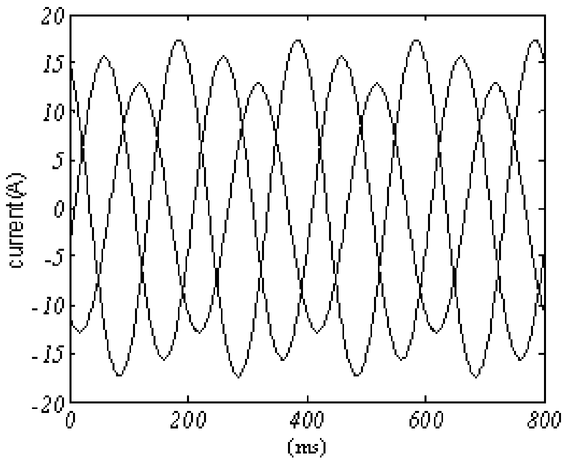

Fig 6. The current of primery-side of Proposed Load balancing transformer (unbalance factor is 10%)

B. Unbalance in the Voltage Phase

The impacts of unbalanced voltage on a Load-balancing transformer can be analyzed with symmetrical components, negative and positive sequence components. Their ratio, known as the **V**oltage **U**nbalance **F**actor (**VUF**) describes the voltage unbalance percentage (although other definitions of voltage unbalance percentage are commonly used):

$$VUF = \frac{|U_-|}{|U_+|} \times 100\% \qquad (1)$$

Where $\mathbf{U}_-$ is negative sequence voltage component and $\mathbf{U}_+$ is positive sequence voltage component. In this part an unbalance of 1% is assumed for the phase of applied voltages, the applied three phase voltages are as follows: $V_A=200\angle 0$, $V_B=200\angle 242$, $V_C=200\angle 122$. It can be seen (Fig. 7) a large amount of phase difference is produced by the Original design of the Load-balancing transformer in the primary side.

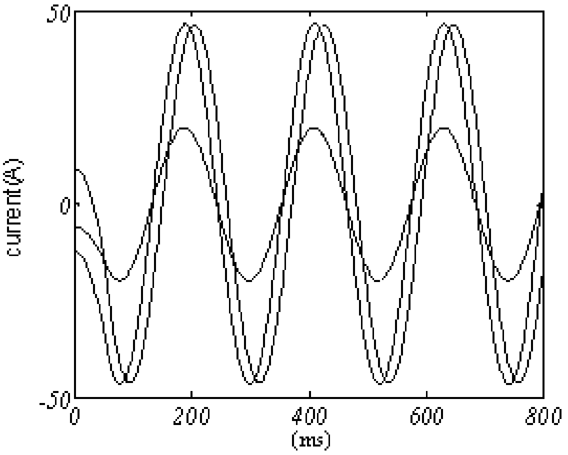

Fig 7.the current of primery-side of Original Load balancing transformer (VUF=1%)

Now in this part an unbalance of VUF=10% is assumed for the phase of applied voltages, these voltages are supplied proposed Load-balancing transformer. $V_A=200\angle 0$, $V_B=200\angle 216$, $V_C=200\angle 132$. According to Fig.8 a proposed Load-balancing transformer is capable of moving towards balancing the unbalanced load both in magnitude and in phase.

If the supplied voltage unbalanced in phase and magnitude similarly through unsuccessful compensates generating a lot of amount of zero component current in the primary side of original one, so it is concerning power quality in public networks. However the proposed Load balancing transformer can compensate the unbalanced load successfully and the zero component of current at the primary-side is zero. Therefore use of the Original Load-balancing transformer connected to an unbalanced voltage is not normally allowed.

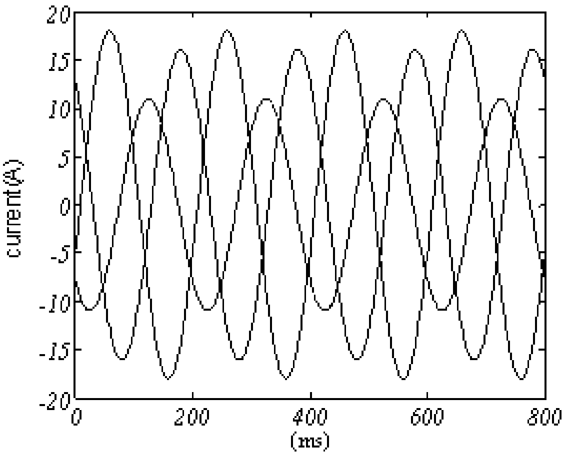

Fig 8. The current of primery-side of Proposed Load balancing transformer (VUF=10%)

IV. HARMONIC ANALYSIS

Harmonic distortion can be caused by both active and passive non-linear devices in a power system. The power transformer, for example, generates a magnetization current with third-order and higher odd harmonics. In the past, these passive devices were the primary source of harmonics. Today, most harmonic distortion is generated by input stage of (active) electronic power converters. In this part three major harmonics namely, 3rd, 5th, and 7th harmonics are introduced to the model. Moreover, a combination of these harmonics is considered as well. The Load-balancing transformer has been supplied with the rated voltage and the harmonics are injected in the voltage source. The applied voltage can be written as:

$$V(t) = \underbrace{V_1 \sin(2\pi f t)}_{fundamental} + \underbrace{\sum_{k=3,5,7} V_k \sin(2\pi k f t + \theta_k)}_{Harmonics} \qquad (2)$$

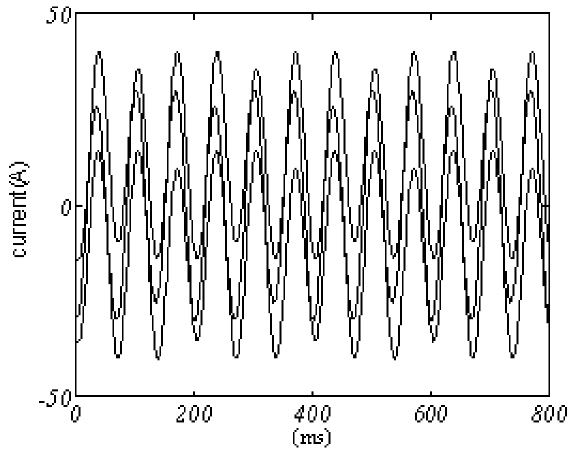

Fig 9.The current of primery-side of Original Load balancing transformer when 3rd harmonic is injected

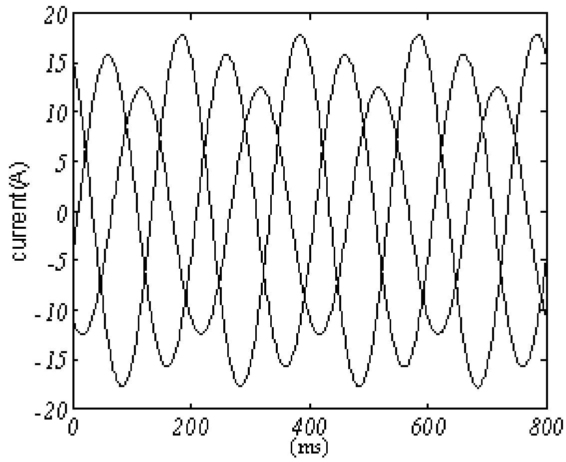

Fig 10.The current of primery-side of Proposed Load balancing transformer when 3rd harmonic is injected

A. 3rd Harmonic

In this case the 3rd harmonic is injected into the voltage sources. As the main frequency of the voltage source is 50Hz the harmonic frequency is 150Hz. According to the standards the magnitude of the harmonics should be less than 5% [22] of the main frequency magnitude. The magnitude of the main frequency voltage is 200 (V) so the magnitude of the voltage harmonic should be less than 10(v). Two cases are assumed here. In the first case the Original Load-balancing transformer but in the second case the proposed Load-balancing transformer. The voltages that are applied to the transformer three phases are as follows:

$$\begin{aligned} V_C &= 200\sin(2\pi 50t + 120) + 5\sin(3\times 2\pi 50t) \\ V_B &= 200\sin(2\pi 50t + 240) + 5\sin(3\times 2\pi 50t) \qquad (3) \\ V_A &= 200\sin(2\pi 50t) + 5\sin(3\times 2\pi 50t) \end{aligned}$$

Figure 9 and 10 show the current of primary-side after compensation by Original and proposed design respectively. The proposed Load balancing transformer is capable of balancing an unbalance load, but the original compensator is not.

B. 5th Harmonic

In this case the 5th harmonic is injected into the voltage sources. As the main frequency of the voltage source is 50Hz the harmonic frequency is 250Hz. According to the standards the magnitude of the harmonics should be less than 5% of the main frequency magnitude. Fig. 11, 12 show the current primary-side after compensation by the Original and proposed design respectively.

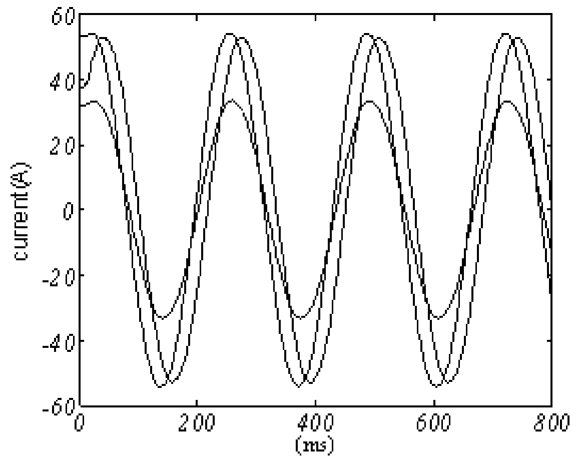

Fig 11.The current of primery-side of Original Load balancing transformer when 5th harmonic is injected

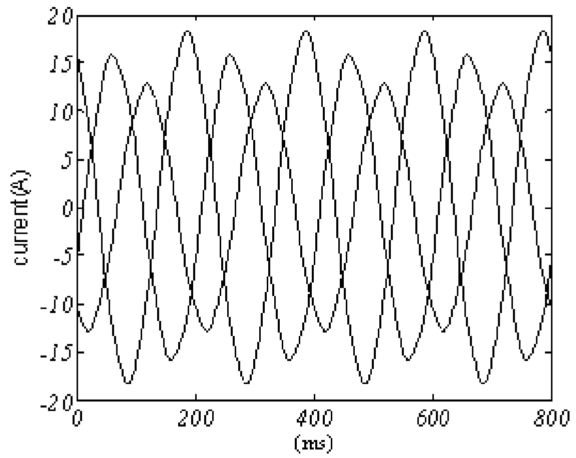

Fig 12.The current in primery-side of Proposed Load balancing transformer when 5th harmonic is injected

C. 7th Harmonic

In this case the 7th harmonic is injected into the voltage sources. As the main frequency of the voltage source is 50Hz the harmonic frequency is 350Hz. The magnitude of the main frequency voltage is 200(v) so the magnitude of the voltage harmonic is 5(v). Fig. 13 and 14 show the current of primary-side after compensation by the Original and proposed design respectively.

The proposed Load balancing transformer has been simulated under unbalance load and compared with the original transformer. The performance of the both of them has been considered with several of harmonic voltage distortion. According to these figures (9-14) the current of primary-side of original load balancing transformer is more unbalanced than the current of secondary side (load). In additional through unsuccessful compensates generating lots of amount of zero component current in distribution network and concerning power quality in public networks.

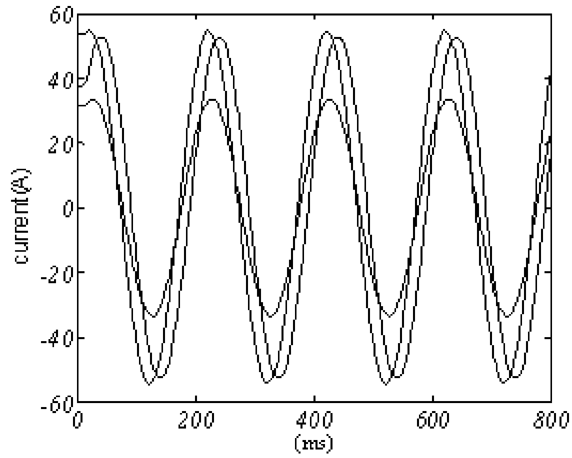

Fig 13. The current of primery-side of Original Load balancing transformer when 7th harmonic is injected

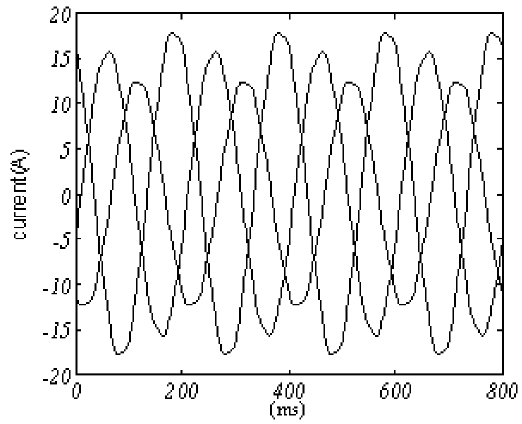

Fig 14. The current of primery-side of Proposed Load balancing transformer when 7th harmonic is injected

V. CONCLUSION

In this paper for balancing of the load in distribution network, a transformer has been proposed which can be simply provided with a little change in the ordinary distribution transformer without any need to the additional special instruments. Finally for improving the performance of this transformer which supplied with unbalanced voltage and harmonic voltage distortion in the Load-balancing, a method has been proposed and simulated using MATLAB and the results have been compared. With respect to low cost of implementation of the proposed idea, and the problems brought in the network by the unbalanced loads, it is recommended to use this transformer instead of the ordinary distribution transformer.

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