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A Comprehensive Comparison between Three Practical Topologies of the Load-Balancing Transformers

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***Abstract*— Load-balancing transformer is a three-phase transformer which has a pair of additional coupling winding in the secondary-side of each phase. One of the coupling windings from each phase is in series with that of the other phase and the set of these two windings is reversely paralleled with the secondary winding of the third 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 of one phase is transferred to the other phases. In this paper based on the original load-balancing transformer, two new load-balancing transformers are presented. Two proposed and original load-balancing transformers are simulated with *MATLAB* and the results are discussed.**

Keywords- Load-balancing, load-balancing transformer, power quality, unbalanced current

I. INTRODUCTION

Unbalanced 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 neutral wire, and finally results in voltage drop in the network.

Due to random behavior of connection and disconnection of single phase loads to the network, and that single phase loads are not uniformly distributed over the network, it is nearly impossible to establish a complete balance in distribution network. However, some techniques have been previously proposed to reduce the unbalancing and its lateral effects. One of them is using of admittance compensative network [1]. Switching the single phase loads on and off, constantly changes the network admittance, so using this method in distribution networks is expensive and impractical. Using the rotating balancers such as synchronous condensers and induction motors to absorb negative component of current, is another approach which is not economical due to high cost and losses. Using the FACTS controllers is another technique that recently has made prominent progress in theory [3-7]. Using these controllers and dealing with problems such as harmonic capability, efficiency and implementation, relies on advances of technology. Along this, active filters [2], [8], [9] or combinations of FACTS controllers and active filters [10] has been proposed which are expensive, and have complication in design, control and implementation.

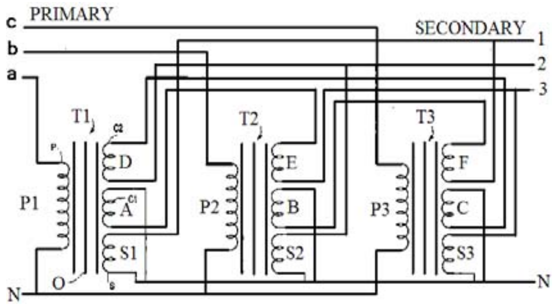

Fig. 1. Orginal Load balancing transformer

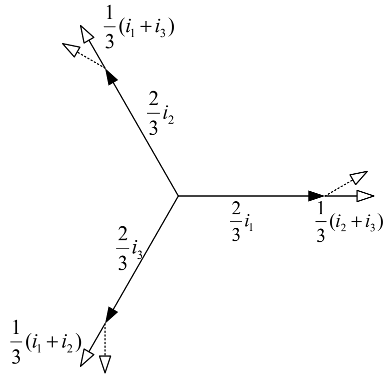

Fig. 2. Current distribution in the ordinary load balancing transformer

In this paper, in addition to evaluation of Load-balancing transformer, some modifications are proposed. These modifications have been applied in order to reduce unbalance and to make complete and effective use of transformer capacity. Both the proposed Load-balancing transformers and originally load balancing transformer can be simply obtained with a little change in the distribution transformer without any need to additional instruments, while it is practical and inexpensive for being implemented in distribution systems.

II. ANALYSIS OF THE LOAD-BALANCING TRANSFORMER

In [11] a particular transformer has been used in order to balance the consumer-side load. In this transformer, the secondary windings are connected together in a special way as shown in Fig. 1. This connection is so arranged that one winding of column T_1 (A) is in series with a winding of column T_2 (E) and finally is paralleled with a winding of column (S_3). In this kind of transformer, two-third of the load current is obtained by a winding which is reversely paralleled with a set of two series windings and one-third of it supplied by two series windings. For example, according to Fig. 1, two-third of the load current for phase 3 of the secondary-side is supplied by winding S_3 and one-third by two coupling windings A and E. So, the primary-side current of each phase is not equally supplied by three secondary phases according to the equivalent circuit given by Fig. 3.

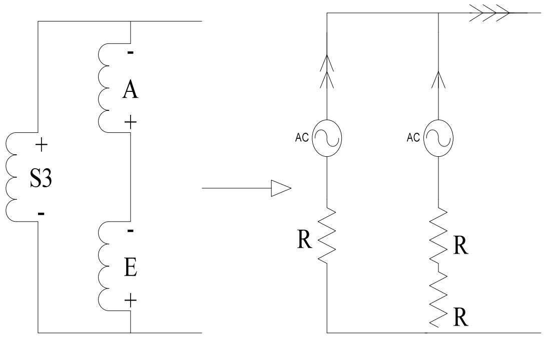

Fig. 3. Original load-balancing equivalent circuit for each secondary phase

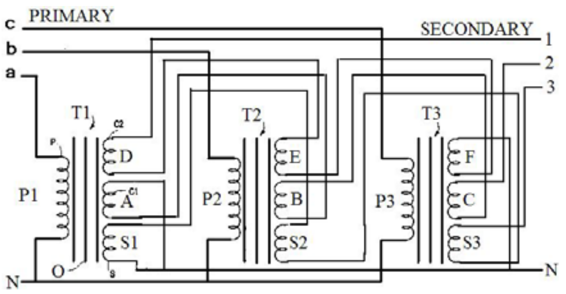

Fig. 4. First proposed Load balancing transformer

A. Transformer primary side current

Primary side current of each phase of transformer is obtained from vector summation of secondary-side three-phase currents using unequal coefficients. For example, in phase T_1 shown in Fig.1, the current i_a, is equal to the summation of $-\frac{1}{3}(i_2+i_3)$ and $\frac{2}{3}(i_1)$. As shown in Fig. 3, if the load is unbalanced, this current unbalance is somehow distributed among three-phases of the primary-side. This way, amplitude and phase of transformer's primary-side currents can be considerably balanced. Thus, the primary-side currents are introduced as follows:

$$
\begin{aligned}
I_A &= \frac{2}{3}i_1 - \frac{1}{3}(i_2+i_3) \\
I_B &= \frac{2}{3}i_2 - \frac{1}{3}(i_1+i_3) \\
I_C &= \frac{2}{3}i_3 - \frac{1}{3}(i_1+i_2)
\end{aligned}
\quad (1)
$$

This paper proposes two new topologies in order to select the best possible connections of windings of load-balancing transformer.

III. PROPOSED LOAD-BALANCING TRANSFORMER

At first one of these Load balancing transformers proposed as shown in Fig. 4, it has a secondary winding and two coupling windings in each phase. The secondary windings of this transformer (see Fig. 4) are connected together in a special way, so under unbalanced condition, the unbalanced current flows through the couplings and secondary winding that each winding is fed from primary by using a separate phase. This connection is so arranged that one winding of column T_1 (A) is in series with a winding of column T_2 (B) and with a winding of column T_3 (C). In this kind of transformer, the load current is obtained by three series windings. The advantage of this transformer is the ratio of the number of turns in the secondary side to the number of turns in the primary side is 228 to 20000; however the number of turns in the secondary side to the number of turns in the primary side of the original load balancing transformer is 380 to 20000.

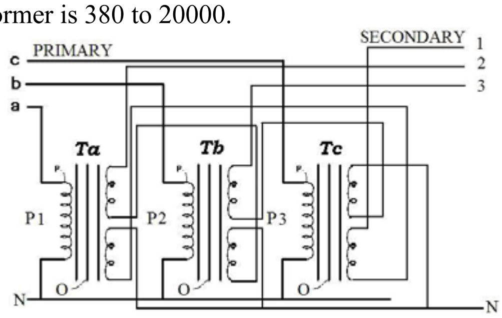

Fig. 5. Second suggested Load balancing transformer

Any way, another suggested Load balancing transformer is shown in Fig. 5. It has a secondary winding and a coupling winding in each phase. The secondary windings of this transformer (see Fig. 5) are connected together in a special way, so under unbalanced condition, the unbalanced current flows through the coupling and secondary winding that each winding is fed from primary by using a separate phase. In this kind of transformer, the load current is obtained by two series windings. The advantage of this transformer is the ratio of the number of turns in the secondary side to the number of turns in the primary side is 228 to 20000 and it has two windings in the secondary side in each phase; however the first proposed and original load balancing transformer has three windings in the secondary side in each phase.

IV. SIMULATION RESULT

The proposed and suggested load balancing transformers have been simulated under unbalanced load and compared with the original load balancing transformer. Figure 6(a) shows the unbalanced load currents and fig 7(a) shows Symmetrical components of three-phase unbalance load. Also, Figs. 6, 7 present the three-phase primary currents and its symmetrical components for the original load-balancing transformer, the first proposed load-balancing transformer and the second suggested load balancing transformer, respectively. It can be seen that in spite of balancing the amplitude, a large amount of phase difference is produced by the original and first proposed design of the load-balancing transformer. However, the second suggested load-balancing transformer is capable of moving towards balancing the unbalanced load both in amplitude and in phase. But according to the IEEE definition the calculated unbalance percents show some facts in comparison with the load unbalance percent:

- The original load balancing transformer cancels zero sequence currents, having no effect on the negative sequence component.
- The first proposed load balancing transformer reduces zero sequence currents and having no effect on the negative sequence component, so makes the unbalance worse than the original design.

- The second suggested load balancing transformer cancels zero sequence currents and having no effect on the negative sequence component as well as the original design, so the magnitude of the IEEE unbalance percent for the second suggested and the original load balancing transformer is better than the other case. But the number of secondary and coupling windings of the second suggested load balancing transformer is fewer than the original design as well as the ratio of the number of turns in the secondary side to the number of turns in the primary side.

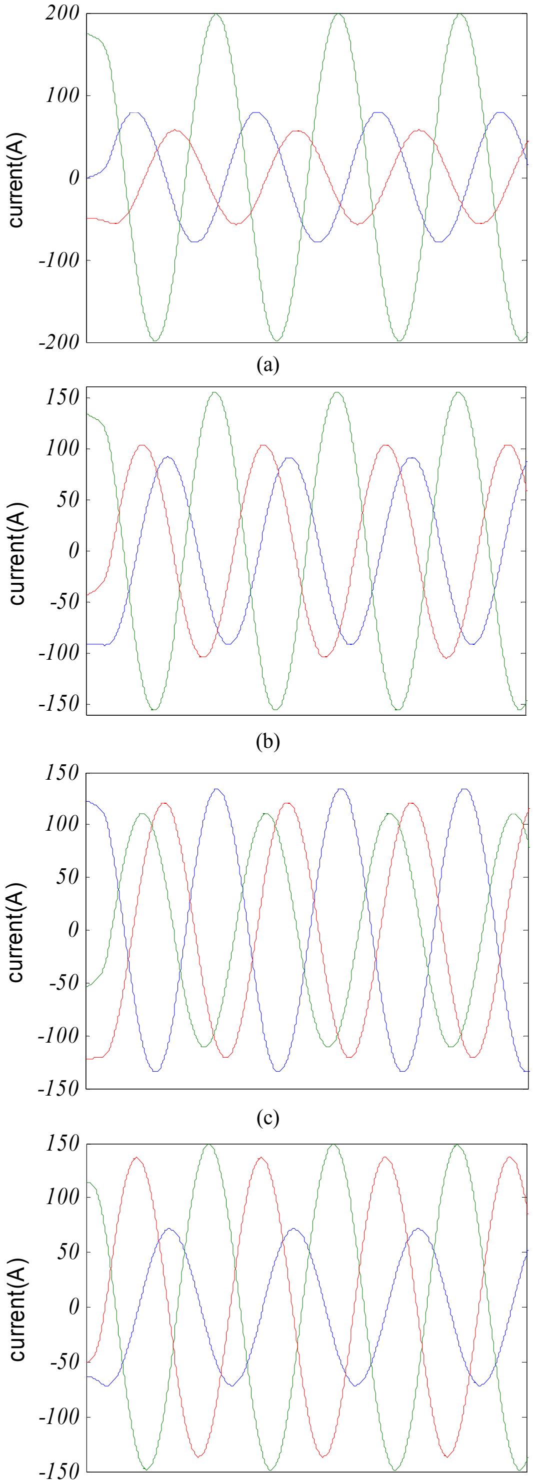

Fig. 6. (a) Simulated secondary-side unbalanced load currents, and resultant primary currents using three different proposed load balancing transformer topologies: (b) original load balancing transformer (see Fig.1); (c) First porposed load balancing transformer (see Fig. 4); (d) Second suggested transformer (seeFig. 5)

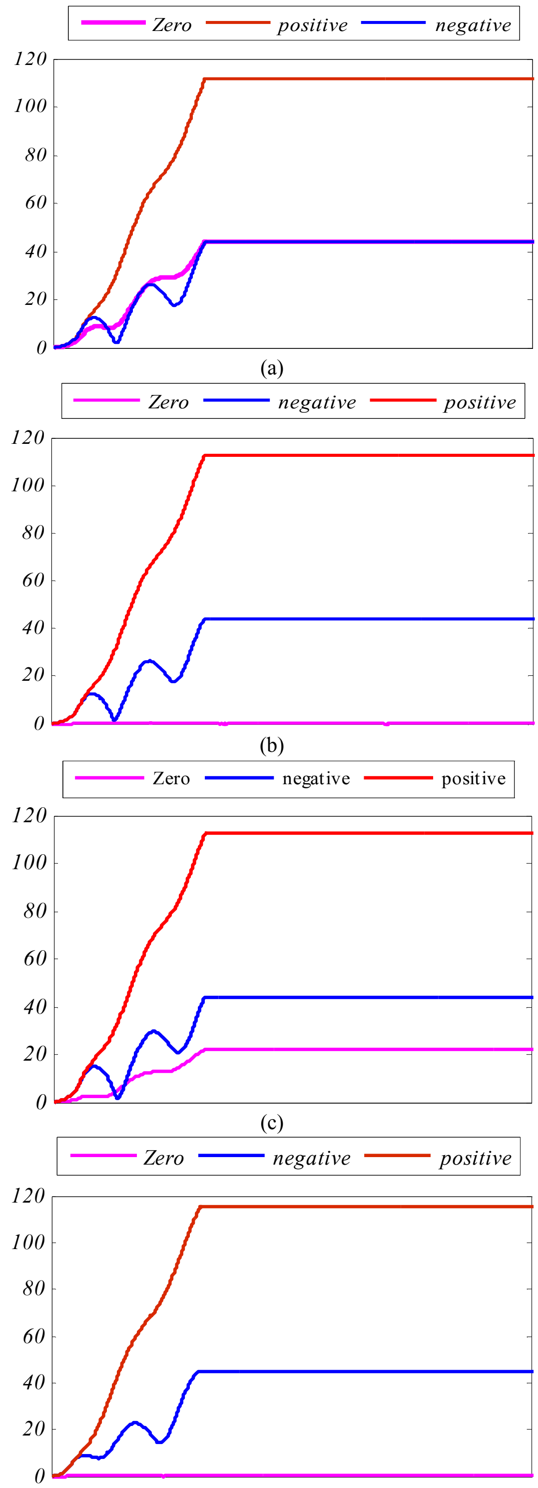

Fig. 7. Symmetrical components of the (a) Simulated secondary-side unbalanced load currents, (b) Current of primery side of the original load balancing transformer (see Fig.1); (c) Current of primery side of the first porposed load balancing transformer (see Fig. 4); (d) Current of primery side of the second suggested transformer (seeFig. 5)

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 in the Load-balancing, two topologies have 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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