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Modified Distribution Transformer for Enhancing Power Quality in Distribution Systems

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ABSTRACT

The percentage of non-linear loads in the power distribution sector is increasing day by day. Harmonics injected by these non-linear loads circulate in the delta windings of the conventional distribution transformer thereby increasing the temperature and losses. This reduces the efficiency and life of the transformers. In a modified distribution transformer configuration proposed recently, called star-star-delta_utilized configuration (YYD_utilized), the harmonics circulating in the delta winding was utilized and the drainage power thus recovered was used to power auxiliary loads. This paper presents the experimental studies conducted on YYD_utilized distribution transformer. When compared to conventional star-star, delta-star and star-star-delta transformers, the new configuration of YYD_utilized transformer has shown considerable improvement in transformer efficiency. The results obtained show that when the power from the circulating harmonics is recovered and utilized, it not only improves transformer efficiency but also improves the power factor and reduces the harmonic distortions at the primary side of the transformer. The results obtained also suggest the existence of maximum power point or an optimum loading for the recovered harmonic power.

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1. INTRODUCTION

Conventionally, two winding delta-star transformers are used for electric power distribution. The primary delta winding of the transformer provides a closed circulating path for the harmonic currents which are injected due to the non-linear loading of the transformer secondary [1]. These circulating harmonics result in loss of energy as heat and eventually reduce the transformer life [2]-[5]. The power which is usually wasted due to the circulating triplen harmonics in the delta winding of a distribution transformer is termed as drainage power.

Recently, a new scheme for ac power distribution using three winding transformer is proposed by the authors [6]. Figure 1 shows the configuration for modified ac distribution. The primary and secondary windings of the transformer are star connected. The third winding is a tertiary winding connected in delta configuration to allow path for circulating currents. The difference between the new configuration and conventional three winding configuration is the way in which the tertiary winding is loaded [7]-[8]. In the new configuration, auxiliary loads are connected across the fundamental frequency zero potential terminals of the tertiary winding. This ensures that the auxiliary load is powered only by the harmonic power or drainage power and not by the fundamental frequency power [9].

The triplen harmonics circulating in the tertiary delta will depend on the severity of non-linear loads connected to transformer secondary. The recovered power output from the opened delta terminals, which depends on the level of harmonics could be rectified and used for purposes like charging of batteries or power conditioned and fed back to grid as power quality ac. This new configuration is termed as star-star-delta_utilized configuration (YYD_utilized) [9]. This configuration helps in recovering and utilizing the drainage power which is usually wasted as circulating harmonics in the delta winding.

This paper present the results of experimental studies conducted on YYD_utilized transformer. The effects of the new configuration on system power quality and transformer efficiency is analyzed. The new configuration is compared with conventional star-star, delta-star and star-star-delta transformers and the results obtained show that a significant improvement in transformer efficiency and power quality can be achieved by recovering and utilizing the drainage power.

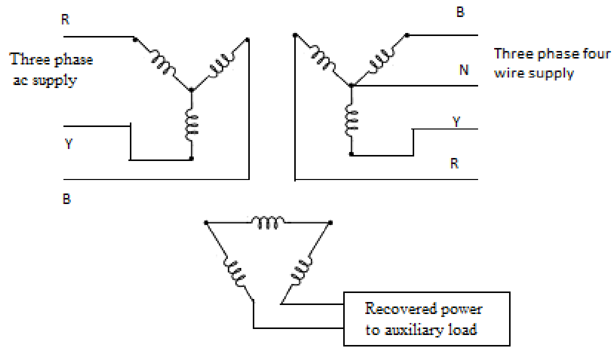


Figure 1. Modified ac distribution

2. EXPERIMENTAL STUDIES

Experimental studies are conducted in a prototype model of 3kVA, 415 V, 1:1:1 three phase transformer. The transformer secondary is connected to non-linear loads and the various winding configurations like delta-star, star-star, star-star-delta closed and star-star-delta_utilized are analyzed. Depending on the type of loads and percentage of loading, four cases are considered. For each case study, balanced loading is ensured in transformer secondary, so that the recovered power has only triplen harmonics.
Case 1: Loading Transformer secondary nearly to 50% of full load using computer load.
Case 2: Loading transformer secondary nearly to 100% using computer load parallel to rectifier load.
Case 3: Loading Transformer nearly to 50% of full load using rectifier load.
Case 4: Loading transformer nearly to 100% using rectifier load.

3. RESULTS AND ANALYSIS

Table 1 shows the primary, secondary and tertiary power of various configurations of transformer for all the four cases (loading conditions). The secondary load is kept constant while experimenting with different configurations for a specific case. For e.g., for case 1, the transformer secondary is connected to computer loads so that the transformer is loaded to nearly 50%. With the transformer in YY, the power obtained at primary and secondary sides are noted. Now without changing the number of computers on the secondary side, the transformer is reconnected in delta-star and again the readings are obtained. This is repeated for all the configurations. This gives the first four rows of Table 1 for case study 1. Similarly the procedure is repeated for all cases. The objective of the experiment is to analyze the effectiveness of the new configuration compared to conventional configurations for a constant secondary load.

For case 1, (i.e., 50% loading with computer loads) the power drawn from the primary side is found to be lesser in the case of YYD_utilized configuration (1480W) followed by star-star-delta, delta-star and star-star configurations (1520W, 1530W, 1550W respectively). Same effect is visible in all the case studies. This shows that for meeting the same load, the power drawn from the primary is the least for YYD_utilzed configuration.

Another interesting observation is that the fundamental component of the secondary power is remaining the same for a particular case irrespective of the winding configuration. For example, for case 1, the fundamental power is constant at 1360 W for all the configurations. But the total secondary power is different and is found to be the least for YYD_utilized configuration. This is due to the lower harmonic power requirement at the secondary side, for YYD_utilized transformer.

Figure 2 shows the efficiency obtained for different configurations for all the four cases. It can be observed that the YYD_utilized configuration is giving the highest efficiency, followed by YYD, DY and YY respectively. For example, for case 1 (50% loading with computer load), the efficiency for YYD_utilized transformer is 0.934. YYD transformer shows an efficiency of 0.90, followed by DY with an efficiency of 0.897. The efficiency of YY is the least with 0.89.

Table 1. Primary, Secondary and Tertiary Powers of Various Transformer Configurations

Case study	Configuration	Primary Total power (Watts)	Primary Fundamental component of total power (Watts)	Secondary Total power (A) (Watts)	Secondary Fundamental component of total power (Watts)	Tertiary Recovered power (B) (Watts)	Total output power (A+B) (Watts)
1	YY	1550	1510	1380	1360	0	1380
	DY	1530	1500	1372	1360	0	1372
	YYD	1520	1495	1370	1360	0	1370
	YYD_ utilized	1480	1475	1365	1360	18	1383
2	YY	2840	2630	2500	2480	0	2500
	DY	2625	2600	2495	2480	0	2495
	YYD	2620	2580	2488	2480	0	2488
	YYD_ utilized	2600	2595	2483	2480	43	2526
3	YY	1480	1440	1320	1300	0	1320
	DY	1460	1430	1312	1300	0	1312
	YYD	1450	1425	1310	1300	0	1310
	YYD_ utilized	1410	1405	1305	1300	24	1329
4	YY	2840	2630	2445	2400	0	2445
	DY	2625	2600	2440	2400	0	2440
	YYD	2620	2580	2435	2400	0	2435
	YYD_ utilized	2595	2560	2430	2400	58	2488

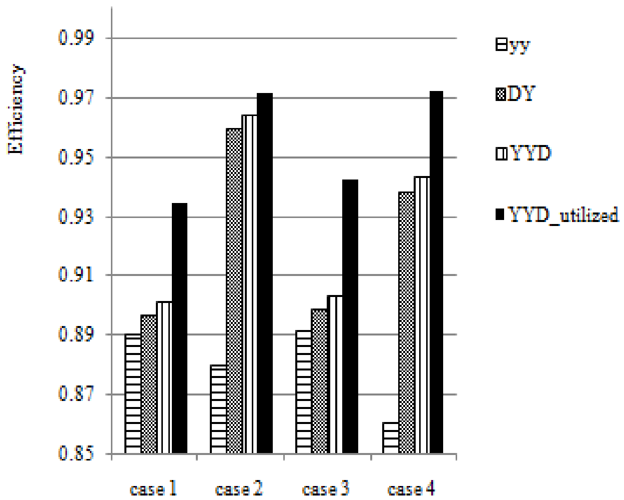


Figure 2. Comparison of efficiency for different configurations

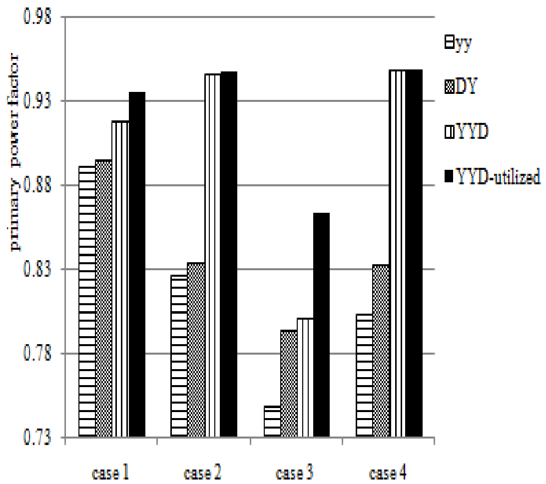
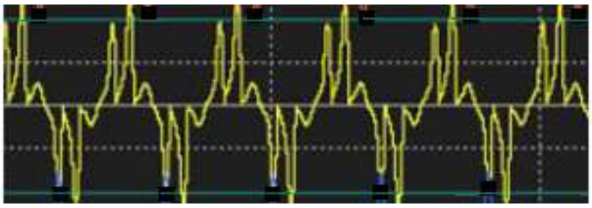


Figure 3. Comparison of power factor for different configurations

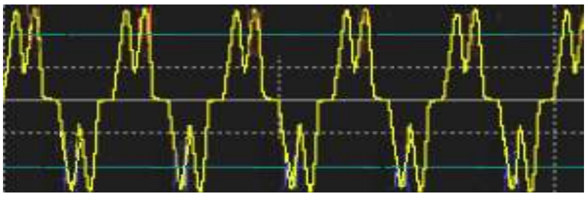
The same pattern of variation is observed for all the four cases. The high efficiency of YYD_utilized connection is obvious since with the new configuration, the power which is usually wasted in the delta winding is being recovered and utilized. Figure 3 shows the primary power factor of all configurations for all cases. It is found that the power factor also follows a pattern similar to efficiency, the highest being for YYD_utilized and lowest for YY configuration. This is because of the better wave-shaping of the current for the new configuration which is resulting in better power factor. Figure 4 represents the input line current waveforms for different configurations for the fourth case (100% loading with rectifier load).

Current waveform shown in Figure 4(d) is the least distorted compared to others. This proves that YYD_utlized configuration gives a better approximated sinusoidal waveform, and hence lowest THD.

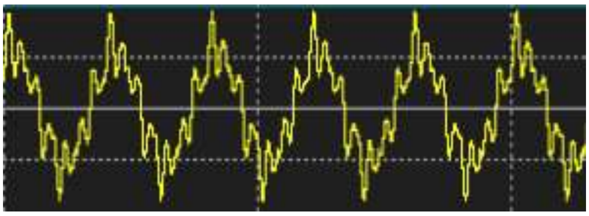
Figure 5 shows the harmonic distortions in the line current for the primary of the transformer. All the different cases are considered and for each case, all the four configurations are compared. From the Figure it can be observed that the THD is the highest for YY and the least for YYD_utilized.



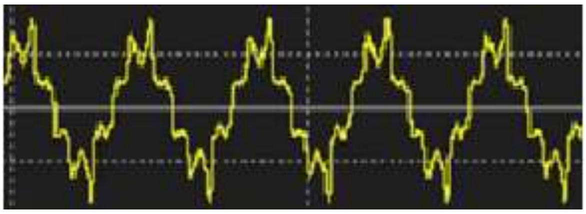
4(a) Input current for YY transformer



4(b) Input current for DY transformer



4(c) Input current for YYD transformer



4(d) Input current for YYD transformer

Figure 4. Input line current waveforms for different configurations

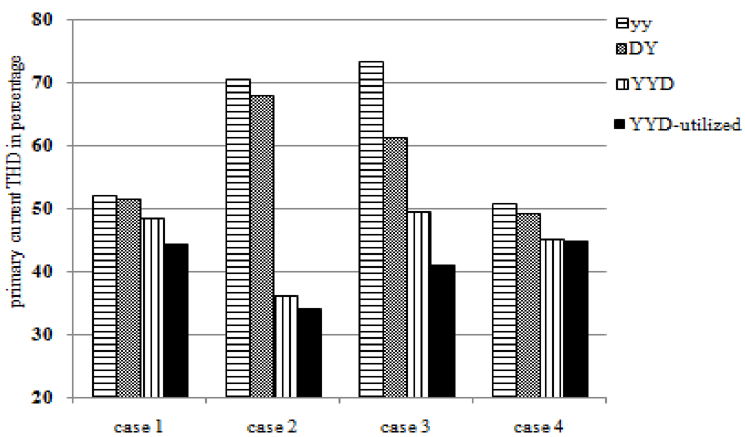


Figure 5. Comparison of current THD for different configurations

Table 2 shows the variations in the primary and the secondary power as the tertiary recovered power is varied. Keeping the non-linear load at the transformer secondary as constant, when the tertiary load is varied for YYD_utilized transformer, the recovered power also changes. The recovered power reaches a maximum of 24 W and then starts decreasing as the tertiary load resistance is increased. Both primary and secondary fundamental power remains same but the harmonic power differs as the recovered power changes.

Table 2. Effect of Varying Recovered Power

Tertiary recovered power in Watts, C		18	20	23	24	22	16
Prim. power (Watt)	Total, A	1415	1413	1411	1410	1408	1406
	Fundamental	1405	1405	1405	1405	1405	1405
Sec. power (Watt)	Total, B	1308	1306	1304	1305	1303	1301
	Fundamental	1300	1300	1300	1300	1300	1300
Total output power in Watts, B+C		1326	1326	1327	1329	1325	1317
Efficiency in %, [B+C]/A		93.7	93.8	94.0	94.3	94.1	93.7

Figure 6 shows the variation of the transformer efficiency with tertiary recovered power. The efficiency is found to be the maximum for a recovered power of 24W. Further attempts to increase the drainage power by changing the tertiary load resistance resulted in a reduction in the tertiary power. This shows that there exists an optimum loading for the recovered harmonic power for every loading condition of the transformer secondary. Maximum power extraction techniques can be used to operate the transformer at its possible maximum efficiency. Table 3 shows the harmonics present in the circulating current of tertiary delta winding for the proposed configuration. It is seen that the magnitude of fundamental frequency component is negligible (0.02 A).

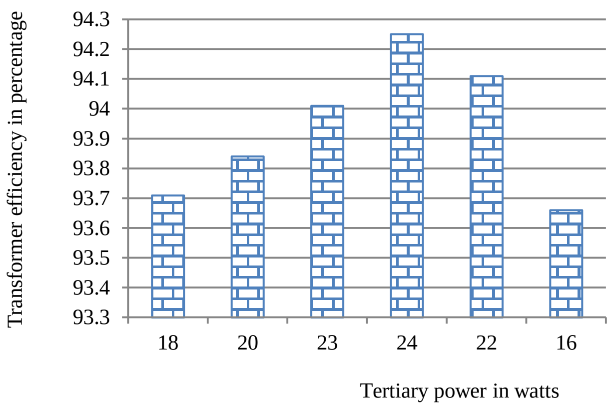


Figure 6. Variation of transformer efficiency with recovered power

The major harmonic components present are triplen harmonics i.e., third harmonic component of 0.62 A and ninth harmonic component of 0.52 A and fifteenth harmonic component of 0.37 A This is the current which powers the load connected across the terminals of the tertiary winding. This proves that the power recovered is harmonic power and not the fundamental frequency power.

On comparing the modified distribution transforner configuration (YYD_utilized) with conventional configurations, it is found that the new configuration results in better transformer efficiency and better supply power factor. Moreover the harmonicdistortions at the line side of the transformer is reduced and the supply current distortions are less for the new configuration. The new scheme can recover and utilize the power which is usually wasted as circulating harmonics in delta winding of the distribution transformer. The results obtaiened show that there exists an optimum loading for the harmonic recovered power and maximum power extraction methods can be used for better system operation. FFT analysis of the current to the auxiliary tertiary load shows the predominance of triplen harmonics which proves that the power recovered is harmonic power and not the fundamental frequency power.

Table 3. Harmonics in the Tertiary Delta Winding

Order of harmonics	Magnitude (A)	Order of harmonics	Magnitude (A)
1	0.02	9	0.52
2	0.04	10	0.03
3	0.62	11	0.02
4	0.04	12	0.03
5	0.02	13	0.03
6	0.03	14	0.03
7	0.02	15	0.37
8	0.03	16	0.02

4. CONCLUSIONS

This paper compares the performance of star-star-delta_utilized configuration of distribution transformer with other existing configurations like star-star, delta-star and star-star-delta configurations. Modifying the existing DY distribution transformer to YYD_utilized configuration requires an additional tertiary winding. But this additional winding needs to have only a fractional capacity of main windings and hence the increase in cost of transformer is only marginal. In the case of a conventional distribution transformer supplying modern non-linear loads, the pay-back period need only be a few months. The scheme could be more cost effective if the recovered power can be directly utilized (without any conversion) for purposes like street lighting of nearby localities of the distribution transformer. The results of the laboratory experiments conducted on a three kVA transformer shows that when the tertiary delta harmonic power is recovered and utilized, the transformer efficiency increases. The star-star-delta_utilized configuration also results in better power factor and reduced distortions (current THD) compared to other configurations. The implementation of this scheme will lead to better distribution system which will give better energy efficiency and improved power factor for the power network. The scheme can reduce harmonic losses in the power grid and can improve the efficiency and life of the distribution transformers.

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