Power Quality Improvement in Distribution System using Active Filter Technology

Praveen Kumar Joshi, R. P Singh, Chava Sunil Kumar

Abstract: Power distribution systems are crucial for growth of industries and pave way for economic growth as well. In such systems, flaws in distribution leads to deteriorated quality distribution. Active Power Filter (APF) is the device which is capable of eliminating both lower order and higher order harmonics in distribution systems. Distribution networks bestow a great job in supplying power to different kinds of non-linear loads. For instance, it can supply power to high power industrial electrolysis and three phase rectifier fed motor drives. In the rectifiers and inverter stations converter transformers are used. Converter transformer plays an important role in distribution systems. Traditional converter transformers in the presence of non-linear loads harmonic components can cause affect winding of the transformer. This in turn reduces the life time of transformer besides brining many power quality problems to the distribution networks. To overcome these drawbacks, this paper proposes a converter transformer with APF to leverage benefits of APF and improve power quality improvement in distribution systems. The filter circuit is associated with the secondary common winding and secondary prolonged winding provided a tap at the connecting point of these two. When secondary prolonged winding encounters harmonic current, common winding associated with the new converter transformer is able to cause contrasting harmonic current in order to balance it. This is made possible with the secondary common winding with zero impendence design. Thus in the new converter transformer, the primary winding does not have any induced harmonic current. The proposed APF is evaluated with simulation study that showed power quality enhancement in distribution when compared with state of the art shunt active power filtering.

Index Terms: Distribution systems, converter transformer, novel active power filter, current control

I. INTRODUCTION

Electric power distribution is an essential phenomenon which serves the purpose of distributing power to consumers of different kinds. There are different types of distribution systems. However, they are meant for delivering power to required consumers. From the transmission system to the consumers the power is distributed with a systematic approach. Towards, this end there are networks of power distribution in the real world. Power distribution networks are using applications based on power electronics. There are issues related to harmonic components in presence of non-liner loads. In case of non-linear loads, the power distribution systems exhibit power quality problems.

With respect to HVDC transmission system, it has converter station at both ends integrated by a DC link. The converts produce wide range of harmonics in the conversion process. Thus the quality of power distribution system is deteriorated. Therefore, it is essential to have mechanisms to reduce the harmonics produced by the converters present on both sides of converter station of HVDC transmission system. In the traditional converter transformer, the transformer will be affected by harmonics that cause many issues like vibration, heat, noise and losses due to harmonics. In order to overcome such problems some solutions are found in the literature. Out of them filtering techniques are there [5], [6], [7], [8], [10]. From the literature it is found that quality in power distributions is an open problem that needs continuous effort in improving it.

In this paper, the aforementioned problems are addressed a new converter transformer is designed with a novel APF technique. This approach is able to prevent reactive and harmonic power components that may flow into primary windings associated with the converter transformer. Thus the proposed method can solve the power quality problems of distribution system. The remainder of the paper is structured as follows. Section 2 reviews literature on on power quality improvement in distribution systems. Section 3 provides problem definition. Section 4 proposes a new converter transformer with active filtering technology. Section 5 gives details of the configuration of the proposed system and results. Section 6 concludes the paper and provides future scope of the research.

II. RELATED WORK

Different techniques are found in the literature on power quality improvement in distribution systems. Satyanarayana et al. [1] studied hybrid fuzzy controlled Improved Power Quality Conditioner (IPQC) to have an active filter and found that to be useful under different loads. Bouzid et al. [2] studied different ways of controlling power distribution with respect to micro grid applications. It is also suitable for renewable energy sources. They studied inner control loops for Distributed Power Generation Systems (DPGS). Georgilakis [3] proposed an Optimal Distributed Generation Placement (ODGP) to bestow best sizes and locations of DGs in order to improve the quality of power distribution systems. Li et al. [4] investigated on the reduction

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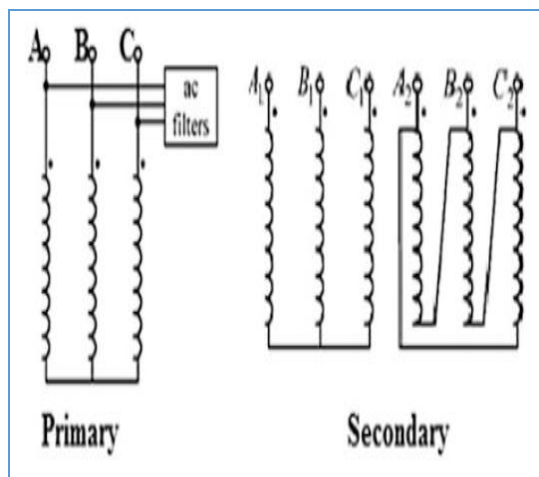
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Figure 1: Shows converter transformer with passive filters

As mentioned above, the HVDC system is using traditional converter transformer with associated passive filters. In this context, resonance occurs between the passive filters and the system impedance. This resonance will cause increase in the harmonic currents and voltages. It can also lead to damager of filters and other closely associated equipment. This is the problem to be addressed. Even modifying frequency of filters will not solve the problem as it may lead to suboptimal performance of passive filters. Therefore, it is essential to overcome this problem by designing a novel converter transformer with active filter technology.

IV. PROPOSING A NEW CONVERTER TRANSFORMER WITH ACTIVE FILTERING TECHNOLOGY

A new converter transformer is proposed along with a novel active filtering technology. Prolonged delta connection is implemented in its secondary winding. The secondary prolonged winding is denoted as Ai-ai, Bi-bi, Ci-ci (i = 1, 2). Figure 2 (b) shows this arrangement.
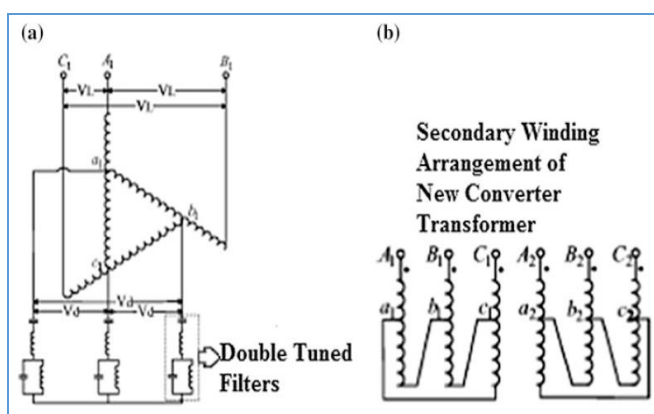
Figure 2: Illustrates wiring of new converter transformer

The winding denoted as a1-b1, b1-c1, c1-a1, a2-c2, b2-a2, c2-a2 is known as secondary common winding. The filters are shown in Figure 2 (a). At the connecting point of common winding and secondary prolonged winding there are double tuned filters. There is the notion of self-coupling accomplishment that is associated with the common winding

and secondary prolonged winding. It is related to something known as autotransformer series. The winding arrangement of the new converter transformer is shown in Figure 3.
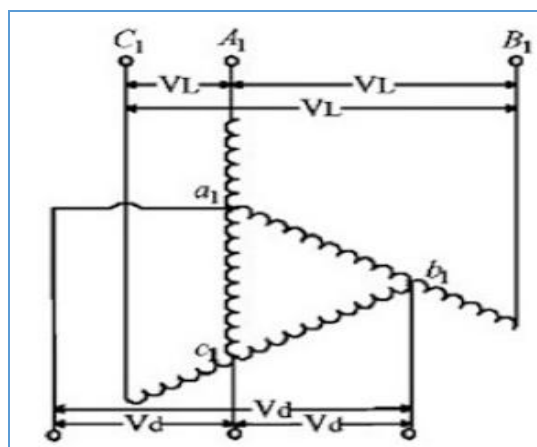
Figure 3: The new converter transformer's winding arrangement

As presented in Figure 3, it is evident that there is winding arrangement of the new converter transformer. There are many variables associated with this. The common notations used in the modelling are shown in Table 1.

Table 1: Shows notations used in the proposed model

Notation	Description
V_e	Voltage of secondary prolonged winding
V_d	Voltage of secondary common winding
V_L	Line-voltage
I_e	Prolonged winding's RMS value of current.
I_d	RMS value of current of the common winding
I_o	Output current
S_e	Electromagnetic capacity
S_o	Output capacity
α	Coefficient ratio
W_1	Turns number of the primary winding
W_2	Turns number of the secondary prolonged winding
W_3	Turns number of the secondary common winding
Z_{12}, Z_{13}, Z_{23}	Short-circuit impedances
I_h	Harmonic current source
I_{h1}	Primary winding's harmonic current.
I_{h3}	The harmonic current of secondary common winding

As shown in Table 1, there are many notations used and their description is provided.

With respect to Figure 3, the line-voltage is denoted as V_L and voltage of secondary prolonged winding is denoted as V_e and the voltage of second common winding is denoted as V_d. Thus it is possible to obtain voltage phasor diagram. The output line voltage, as per cosine rule, is as in Eq. 1.

$$V_L{}^2 = (V_e + V_d)^2 + V_e{}^2 - 2V_e(V_e+)\cos\frac{2\pi}{3}$$
(1)

Here the output line voltage is denoted as $V_L{}^2$. The voltage of secondary prolonged winding is obtained using Eq. 2.

$$V_e = -V_d\frac{V_L{}^2}{3} + \sqrt{\frac{V_L{}^2}{3} - \frac{V_d{}^2}{12}}$$

As shown in Eq. 2, there is the usage of output line voltage computed in Eq. 1 as well. The new converter transformer is electromagnetically coupled with common winding and secondary prolonged winding. That is associated with a series and commonly used winding of autotransformer. Where there is magnetic force equilibrium arrived between common winding and secondary prolonged winding it leads to the relation shown in Eq. 3.

$$V_e I_e = V_d I_d$$
(3)

Here RMS value of the current of common winding and prolonged winding are denoted as I_d, I_e respectively. The output current denoted as I_o is equal to the current of secondary prolonged winding I_e. Then its electromagnetic capacity can be computed as in Eq. 4.

$$S_e = 3V_e I_o$$
(4)

In the same fashion, the output capacity is computed as in Eq. 5.

$$S_o = \sqrt{3}V_L I_o$$
(5)

The material utilization of ratio of the transformer can be analysed with coefficient ratio which is computed as in Eq. 6.

$$\alpha = \frac{S_e}{S_o} = \frac{\sqrt{3}V_e}{V_L}$$
(6)

Thus new converter transformer's ratio coefficient is computed to have the proposed filtering mechanism. Figure 4 shows new converter transformer designed with single-phase harmonic model. This model is effectively used to analyse filtering phenomenon in the new converter transformer.
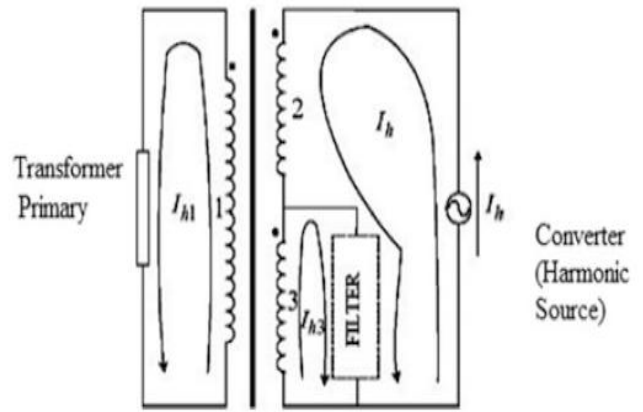
Figure 4: New converter transformer's single phase harmonic model

As shown in Figure 4, there are many notations used. The source of harmonic current is denoted as I_h. It also reflects harmonic current of the secondary prolonged winding. The harmonic current of secondary common winding and the primary winding are denoted as I_{h3}, I_{h1} respectively. The I_h which denotes harmonic current in secondary prolonged winding is capable of inducing harmonic currents I_{h3}, I_{h1} in secondary common winding and primary winding respectively. To balance I_h, these currents are utilized. As per the ampere turn method, it is possible to get a relation as shown in Eq. 7.

$$W_2 I_h = W_1 I_{h1} + W_3 I_{h3}$$
(7)

The turns number associated with primary winding, secondary prolonged winding and the secondary common winding are denoted as W_1, W_2 and W_3 respectively. From the relation in Eq. 7, it is understood that if there is balance between common winding and secondary prolonged winding a value zero is associated with I_{h1}. At the same time, it is known that no induced harmonic current is found in primary winding. Thus it is evident that the harmonic currents flow through secondary winding associated with the transformer.

Figure 5: Wiring arrangement of single-phase model

In order to know the proposed active filter technology, it is required to have full tuning of filter and also zero impendence design pertaining to the common winding of the transformer. This analysis is made with

the wiring arrangement of single-phase model shown in Figure 5. From the short circuit test [31] the impendences denoted as Z12, Z13 and Z23 that are nothing but short-circuit impendences, Eq. 8 is used to get impendence value.

$$Z_1 = 0.5(Z_{12} + Z_{13} - Z'_{23})$$
$$Z'_2 = 0.5(Z_{12} + Z'_{23} - Z_{13})$$
$$Z'_3 = 0.5(Z_{13} + Z'_{23} - Z_{12})$$

$$(8)$$

As per the winding arrangement made in Figure 5, the secondary common winding shows impendence that is almost zero when the value of resistance is ignored. This is the reason why harmonic current flows in the branch of common winding. It does mean that no induced harmonic currents are associated with primary winding. The equivalent circuit model is shown in Figure 6.
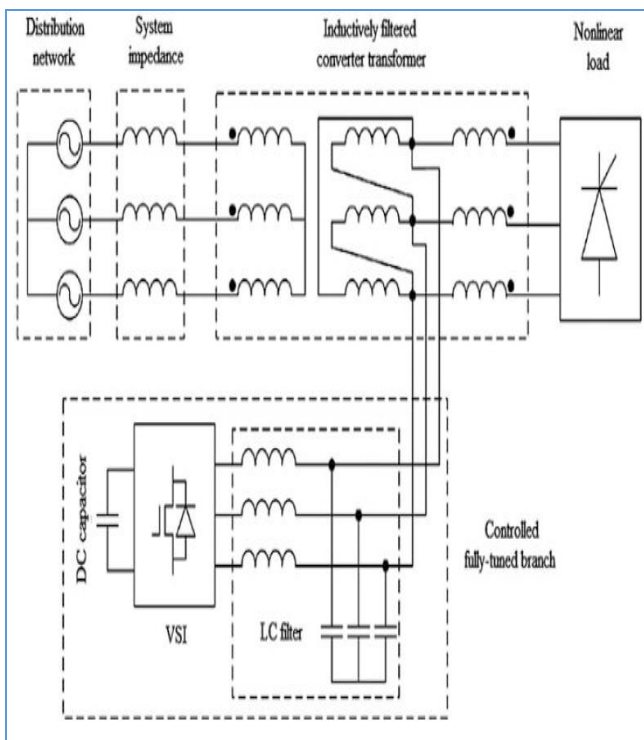

Figure 6: Shows wiring model of the proposed active filter technology

The common winding and prolonged winding are at the secondary side. Tuned filter is connected in such a way that there is connection phase that couples the two windings involved. The secondary design is specifically made to have balance of harmonic potential. This will effectively prevent the possibility of harmonic currents in the primary winding.

V. CONFIGURATION OF THE PROPOSED SYSTEM

There is difference between the configuration of traditional APF and the proposed novel active filter technology. It is shown in Figure 7. As shown in Figure 7 (a), the harmonic load current is flowing into PCC. The traditional converter transformer suffers from reactive power

and harmonic components associated with load current. Thus it results in noise, vibration, increase in temperature and losses. When the active filter is connected in parallel, the rectifier gets affected due to impendence. This is the reason why power quality problems exist when traditional converter transformed is used.

As shown in Figure 7 (b), between the non-linear load and the source, the new converter transformer is connected. The linking position between prolonged winding and common winding is used to connect the active filter. This arrangement helps in avoiding harmonics. The harmonics flows into secondary of the common winding and prolonged winding. Due to the strategic position of the filter, it is able to draw harmonic components into secondary side only. This will ensure that the primary winding is devoid of harmonics. Thus there is suppression of harmonic components at the very nearer of the non-linear load. In other words, the path of harmonic flows is confined to some area which gets rid of effects of harmonics in the power distribution systems.
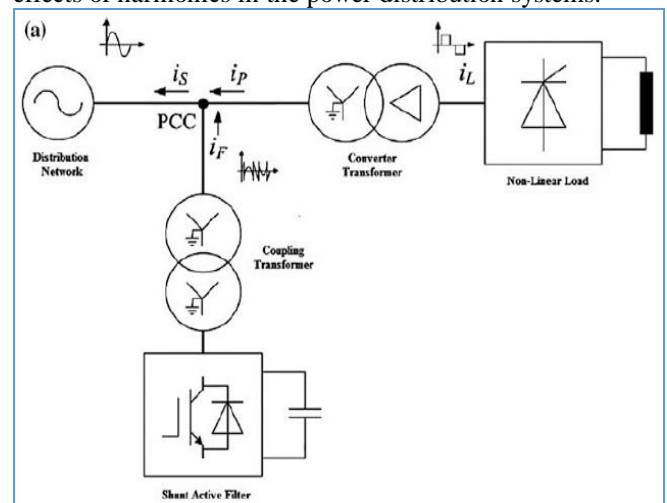

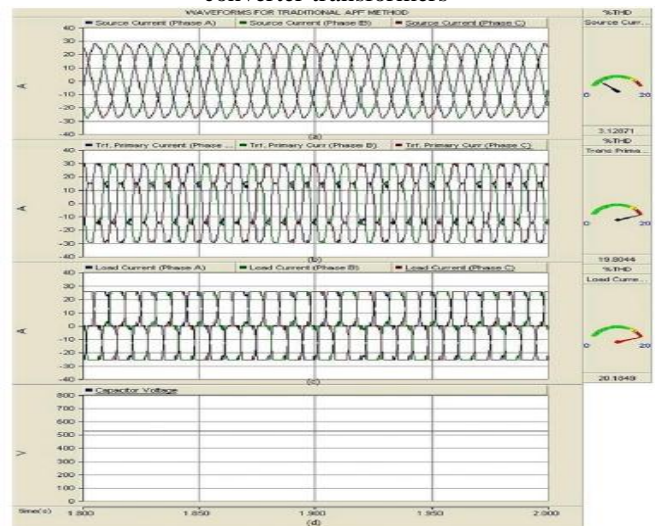Figure 7: Comparison between traditional and novel converter transformers

Figure 8: Shows results of traditional active filter: current details at load side (a), current details at the grid winding (b) and current at the ac side (c)
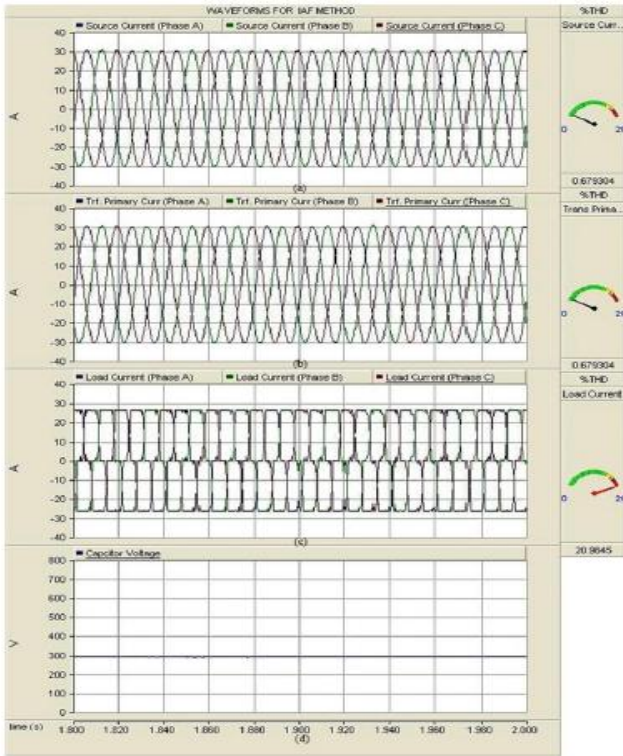
Figure 9: Results of the proposed active filtering technique: current at the load side (a), current values at grid side (b) and current at the ac side
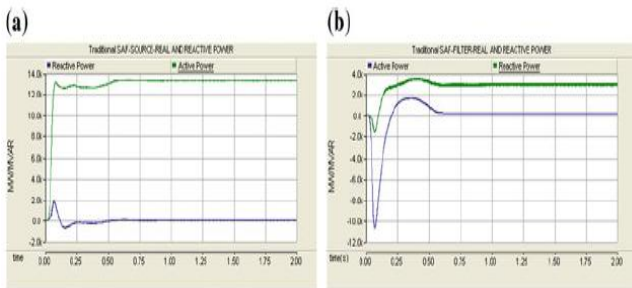

Figure 10: Shows real and reactive power flow with traditional and new converter transformers, source side (a) and filter side (b)
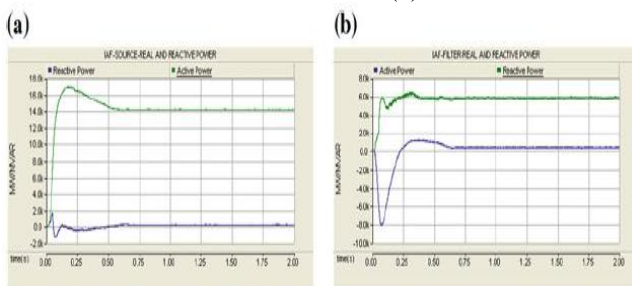

Figure 11: Real and reactive power flow using the new converter transformer, source side (a) and filter side (b)

As presented in Figure 8 and Figure 9, the results of traditional filter and proposed active filter are provided. Load current with harmonic components are witnessed in Figure 8(a) and Figure 9(b) due to non-linear load present. With the results presented in Figure 8(c) and Figure 9(c), it is evident that the traditional filter and proposed active filter are able to

avoid harmonic currents entering at source side. This will help improve quality of power in distribution systems. On the contrary, it is found as shown in Figure 8(b), harmonic current can flow through the converted transformer.

With the proposed active filter technology, it is evident that the harmonic current flows are prevented from entering into the transformer. In other words, the harmonic current is suppressed at the secondary winding. From figure 10 and Figure 11, it is observed that there is zero consumption of reactive power from the source. Figure 10(b) and Figure 11(b) show that active filter generates reactive power required for the load.

Table 2: Harmonic distortion level of traditional and proposed filters

Filtering Technique	% of observed harmonic distortion at the transformer's primary winding
Traditional filtering	19.70
Proposed active filter technology	0.66

As shown in Table 2, it is understood that the total harmonic distortion exhibited by the traditional filter is very high while the proposed active filter technology showed least harmonic distortion.
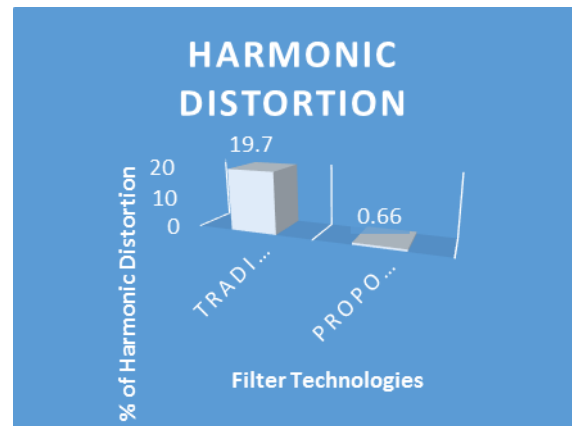
Figure 12: Shows performance of the proposed active filter technology

As presented in Figure 12, it is evident that filter technologies such as traditional filter and the proposed active filter technology are presented in horizontal axis while the vertical axis shows the % of harmonic distortion at the primary winding of the transformer. The results revealed that the proposed active filter technology has shown negligible harmonic distortion value that is 0.66 while the traditional filter showed very high distortion which causes deterioration of power quality in distribution systems. The power quality in distribution systems will be increased when distortion is nominal.

VI. CONCULSION AND FUTURE WORK

This paper defines the problem with traditional converter transformers in the process of power distribution systems. A new converter transformer is proposed and designed in order to overcome the problems with the traditional converter transformer which makes use of filter technology. However, the proposed converter transformer is equipped with new active filter technology. Thus the proposed converter transformer effectively protects distribution systems from harmonic components. The results of simulation study revealed that the power distribution network is devoid of harmonic effects.

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