Twelve pulse converter with differential delta connected transformer arrangement with reduced KVA capacities for line side harmonic reduction

Mital Patel

Electrical Department, Faculty of PG Studies & Research In Engineering & Technology
Marwadi Education Foundation's Group of Institutions
Rajkot, India
patel.mital474@yahoo.com

Abstract—now a day Harmonics is one of the most severe problems in variable frequency drives and in electrical network. Harmonics are generated due to switching action of the power electronics converters, which are known as non-linear loads. It's required to reduce this harmonics up to certain level. In this work differential delta connected transformer with different winding connection to get 30° phase shift with reduced kVA capacities are presented for harmonic current reduction. A twelve-pulse AC to DC rectifier is proposed employing only $0.18P_0$ (pu) transformer kVA. The 5th and 7th harmonics are absent in the utility line current. For high current application parallel operation of two rectifier bridges with inter-phase transformer is analyzed.

Key words—Delta-connected auto transformer, kilovolt-ampere rating, multi-pulse rectifier, inter-phase transformer

I. INTRODUCTION

Higher harmonics, poor power factor and high total harmonic distortion in the line side are common problems when nonlinear loads such as AC or DC power supplies, induction heating systems, UPS systems and aircraft converter systems are connected to the electrical system. Mostly power electronics converter are non linear loads, due to the nonlinear nature of the load, the input line current have significant harmonics which causes many problems to the other users and supply system also.

By increasing the number of Pulse at DC side, can get the better performance at the supply side. There are various methods develop on this bases. These methods use two or more converters, either in parallel or in series connection, where the harmonics generated by one converter are cancelled by another converter, by proper phase shift. One approach is to use a standard twelve-pulse converter which requires two six-pulse converters connected through Y-Δ and Y-Y isolation transformer. In this topology the cost and size of the transformer is very high. The operation of the conventional twelve pulse diode rectifier results in the cancellation of the 5th and 7th harmonics in the input utility line currents and the kVA rating of the transformer is $1.03P_o$(pu).[4] To increase the number of pulses further to 18 or 24, additional diode bridge rectifiers along with complicated multiphase transformer connection becomes necessary, which increases size and cost of the product.

In this paper new differential delta connected transformer with reduced kVA capacities are proposed to improve the quality of the utility line currents. The proposed approach is based on autotransformer arrangements between the utility and the diode bridge rectifiers so that the size of the transformer is reduced in comparison to the isolation transformer of the conventional twelve –pulse converter. In the differential delta connection, the winding are interconnected such that the kVA to be transmitted by the actual magnetic coupling is only a portion of the total kVA. The reduced rating of transformer parts required in this connection makes it physically smaller, less costly, and higher efficiency than conventional transformers. The reduced kVA rating of the connection of 12 pulse rectifier is $0.18V_oI_o$ (pu).

II. REDUCED kVA DIFFERENTIAL DELTA ARRANGEMENT FOR 12-PULSE RECTIFIERS

Fig. 1(a) shows the twelve-pulse configuration of the proposed approach to reduced kVA rating of the transformer. Here all the windings are on the same core. kVA rating of the differential delta connected transformer are reduced because of the current passing from primary winding is just only the current difference between secondary windings. So conductor size in primary winding will reduce according that used conductor material will reduced so cost automatically reduced and definitely size will reduced. But the problem with this type of connection is there is no isolation between windings. With differential delta connection in transformer, rectifier will not operate alone in parallel connection. There will be interference of one rectifier bridge to another rectifier bridge. Due to this problem there will be a flow of zero sequence current in the rectifier input side. Which will increase harmonic level. So its essential to reduce zero-sequence and to make a converter to operate alone to make the 12 pulse operation and to get reduced THD at line side current. If we provide isolation at the positive and negative side of the differential delta connected transformer then there will be elimination of zero sequence current and independent rectifier bridge operation can be possible. Isolation can be provided by means of Inter-phase transformer.
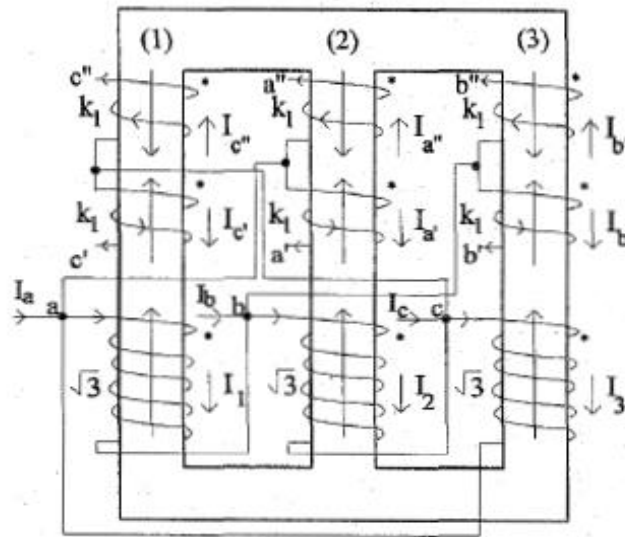
Fig 1(a) winding configuration of differential delta connection on same core
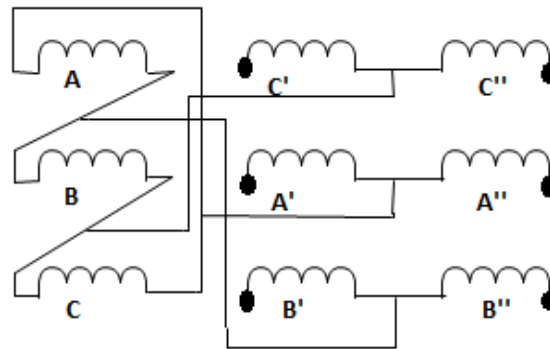

Fig 1(b) Illustrates the implementation of differential delta connected transformer

By introducing connection in figure 1(b) it is very easy to understand the winding implementation for 30° phase shift. By solving the vector diagram of transformer connection it will help to calculate turns ration between primary and secondary winding, winding currents, voltage ratings , transformer kVA rating. This connection gives boost up voltage by a factor of $\frac{1}{\cos \phi}$. Here ϕ is a angle between two secondary.
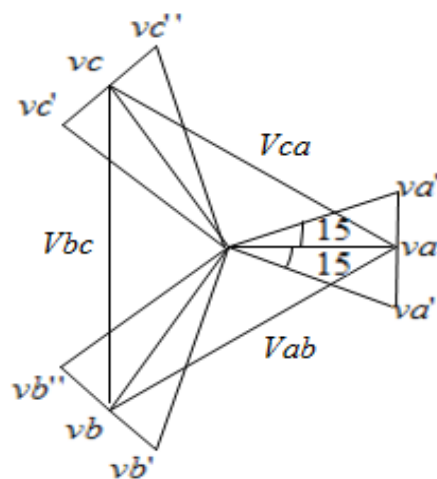
Fig 1(c) vector diagram of differential delta connection
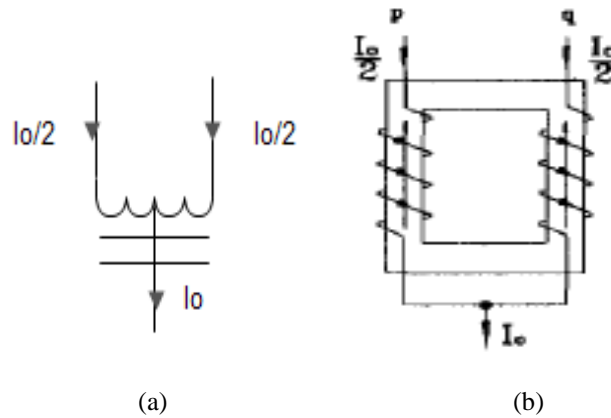
(a)   (b)

Fig 2(a) winding configuration of inter-phase reactor
Fig 2(b) Physical arrangement of inter-phase reactor

The transformer bank between the utility and the rectifier acts like a passive filter, which eliminate the fifth and seventh harmonics in the line current of the utility inter-phase by introducing a 30 degree phase shift.

The vector diagram of the differential delta-type connection and the winding configuration on a three limb core are shown in fig 1(c) respectively. The phase shift angle between a'b'c' and a''b''c'' is 30 degrees. Therefore, the length K_1 becomes, $K_1 = 0.2679$ (pu)
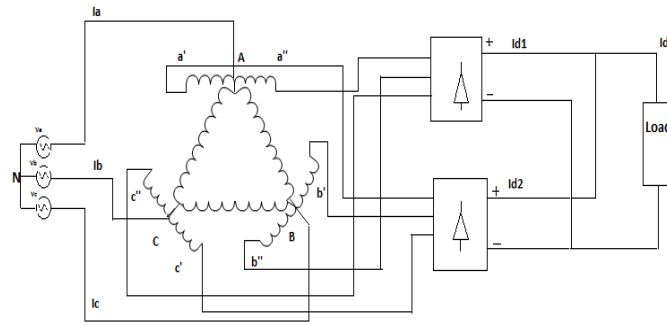
Fig 3(a) proposed reduced kVA twelve-pulse approach with differential delta arrangement

Input current analysis

From fig 1(a) one limb of three limb core assuming $\sqrt{3}$ turns (pu) between terminals a and b, the MMF equation becomes,

$$\sqrt{3}I_1 = K_1(I_c'' - I_c')$$

Similarly, for core limbs two (2) and three (3), the MMF equation becomes,

$$\sqrt{3}I_2 = K_1(I_a'' - I_a') \tag{2}$$

$$\sqrt{3}I_3 = K_1(I_b'' - I_b') \tag{3}$$

Input utility line current I_a can be expressed as ,

$$I_a = I_1 + I_a' + I_a'' - I_3 \tag{4}$$

From above equation I_a becomes

$$I_a = I_a' + I_a'' + K_1 \frac{1}{\sqrt{3}}(I_c'' - I_b'' + I_b' - I_c') \tag{5}$$

Similarly input line current I_b and I_c can be expressed as

$$I_b = I_b' + I_b'' + K_1 \frac{1}{\sqrt{3}}(I_a'' - I_c'' + I_c' - I_a') \tag{6}$$

$$I_c = I_c' + I_c'' + K_1 \frac{1}{\sqrt{3}}(I_b'' - I_a'' + I_a' - I_b') \tag{7}$$

Now, output voltages are higher than input voltage by the factor of $\frac{1}{\cos 15}$.[2] 15º is the angle between the two output vectors. For analysis the voltage vector diagram is solved to determine turns ration N between the long winding and short winding. For 15º phase shift the required phase shift is

$$N = \frac{\sqrt{3}}{\tan(\frac{\varphi}{2})} \tag{8}$$

The proposed twelve pulse approach is simulated on PSIM.

Output voltage analysis

In this section output voltage V_o and voltage across the inter-phase rector are calculated in order to facilitate the design of delta connected transformer and the inter-phase reactor. for the sake of simplicity two rectifier bridges are connected through coupled reactor .

Accordingly Fourier series calculation the dc output voltage of converter 1 becomes,

$$V_{01} = 0.8270 \ V_m' \tag{9}$$

Similarly, output voltage of the converter 2 , V_{02},becomes,

$$V_{02} = -0.8270 \ V_m' \tag{10}$$

Therefore, the dc output voltage of the twelve-pulse converter,
is,

$$V_o = V_{01} - V_{02} \tag{11}$$

$$= 1.6540 \ V_m'$$

Due to differential delta connection there will be flow of zero sequence current which will is a third harmonic component is blocked by inter-phase reactor.

The voltage across the IPT (between two rectifiers) is

$$V = N \ A \ \frac{dB}{dt} \tag{12}$$

Where: N – number of turns, in our case 2
A – is the core cross-section area
B – Flux density

$$\int V dt = 2 \ N \ A \ B_m \tag{13}$$

Where B_m – amplitude of flux density.

Since volts-second Vs is Vs $= \int V dt$
we obtain

$$A = \frac{V_s}{2NB_m} \tag{14}$$

The frequency of the IPT voltage is $300 H_z$, according to this equations size of the IPT is decided.[6]

To define the rating of IPT it is mandatory to define an inductance value of transformer which will support to avoid current unbalance at rectifier output and current rating of load Current.

Simulation results

In this paper the simulation and experimental work is done for the 45 kW drive load with 50 Hz frequency ,415 supply voltage.
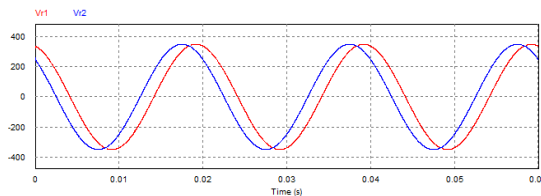

Fig 4(a) Output voltage of auto transformer secondary with ± 15 ° phase shift
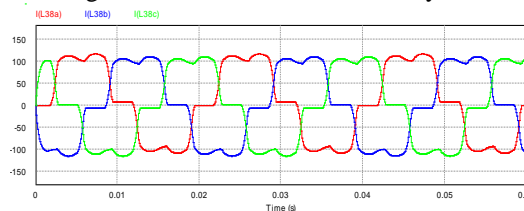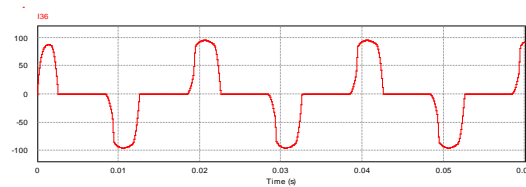

Fig 4(b) Line current without IPT

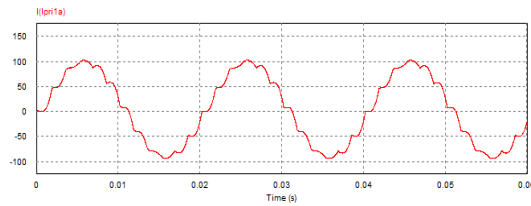Fig 4(c) Rectifier input current without IPT
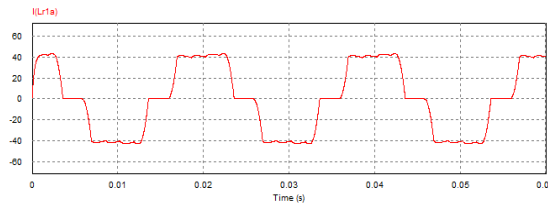

Fig 4(d) Line current with IPT

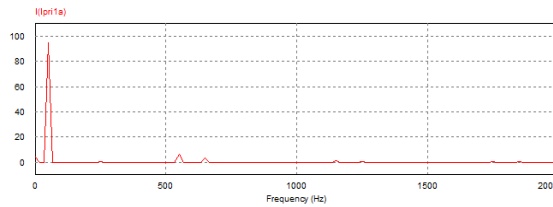Fig 4(e) Rectifier input current with IPT

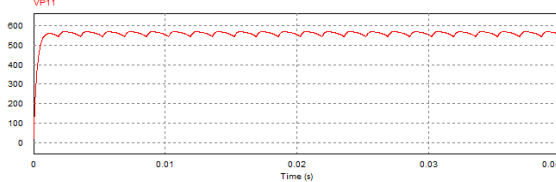Fig 4(f) Frequency spectrum of line current

Fig 4(f) output voltage across load with IPT

kVA Rating of the Differential Delta Connected transformer [4]

The transformer utilized in the proposed twelve-pulse system (fig 3(a)) is designed such that the size of the transformer is minimized. The rms value of the small winding current is,

$$|I'_a| = 0.4082 \ I_o \qquad (15)$$

From (2) the rms value of the large winding current is,

$$|I_1| = 0.0446 \ I_0 \qquad (16)$$

The rms value of the small winding voltages is,

$$|V'_{aa}| = K_1 \frac{V_m}{\sqrt{2}} \qquad (17)$$
$$= 0.1895 \ V_m$$
$$|V_{ab}| = \sqrt{3} \ \frac{V_m}{\sqrt{2}} \qquad (18)$$
$$= 1.2247 \ V_m$$

Then the total kVA of the transformer becomes,

$$kVA_{tot} = \frac{(6 \ |I_a'| |V'_{aa}| + 3 \ |I_1| |V_{ab})|}{2} \qquad (19)$$
$$= 0.1834 \ I_o V_o$$

Thus the 12 pulse arrangement requires a transformer kVA of only 18% of the output kVA. This amounts to 82% reduction in transformer kVA employed in the conventional 12-pulse scheme.

This scheme gives results as good as compare to conventional transformer with reduced size

III. EXPERIMENTAL RESULTS WITHOUT IPT

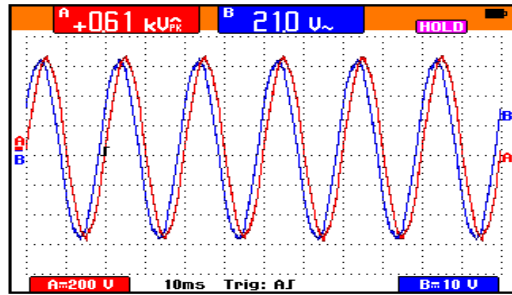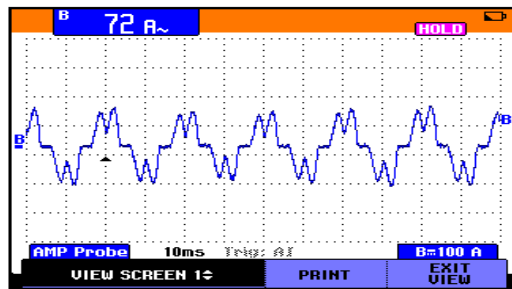Fig 5(a) Phase shifting between transformer secondary
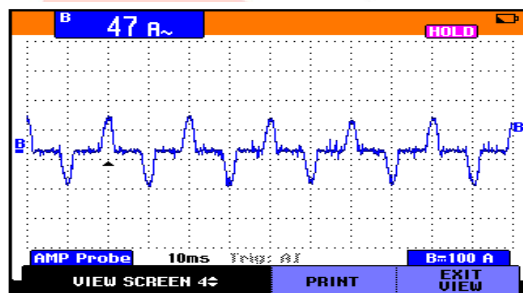
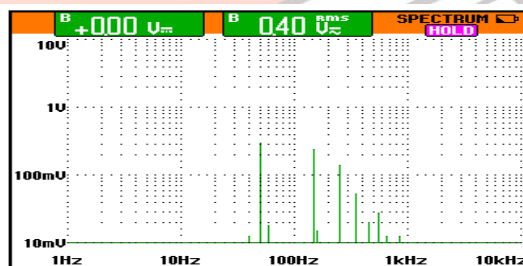

Fig 5(b) Line current

Fig 5(c) Rectifier input current

Fig 5(d) Harmonic spectrum of rectifier input current
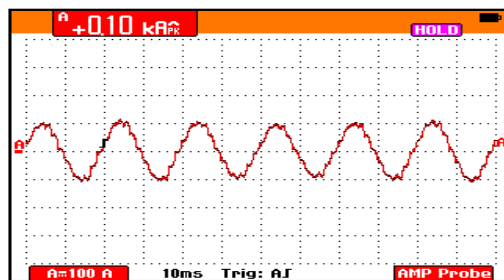
IV. EXPERIMENTAL RESULTS WITH IPT
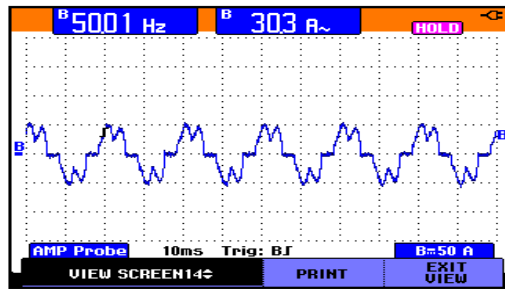

Fig 6(a) Line current

Fig 6 (b) Rectifier input current

Table 2 % THD of supply current and rectifier input current

12 Pulse rectifier system	% THD of supply current	% THD of rectifier side input current
Without IPT	37.4 %	81 %
With IPT	8 to 10 %	34 %

V. CONCLUSION

In this paper 12-pulse converter with differential delta connection arrangement to enhance the utility power quality of high current DC power supplies have been introduced. The size of the twelve-pulse rectifier with this arrangement is reduced to 18% of the conventional 12-pulse rectifier and reducing ripple content at the output side. Further improvement can be obtained by injecting current in the inter-phase rector for line current to be near about the sinusoidal current.

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[5]   Sewanchoi,PrasadN,Enjeti.Iraj.Pital“Autotransfoemer configurationsto enhance utility power quality of high power ac/dc rectifier systems” power electronics leboratry department of Electrical Engineering .
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