# ANALYSIS AND SIMULATION OF 12 PULSE RECTIFIER CIRCUITS

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***Abstract*-In this paper the autotransformer connection with reduced kVA capacities are presented for harmonic current reduction in power diode rectifier-type utility interface systems and also reducing in kVA rating compared to the convectional 12 pulse converter. Based on the concept of an autotransformer, a 12-pulse rectifier system is realized with resultant transformer kVA rating of $0.18P_o$ (pu). In this arrangement the 5, 7, 17, 19, etc. harmonics are absent from the utility input line current. Analytical design equations are presented to facilitate the design of the system components. Simulation results verify the proposed concept.**

## I. INTRODUCTION

Non-linear loads such as UPS system, adjustable speed drives, power supplies and aircraft converter systems, when connected to the electrical supply, tend to draw distorted line currents, producing the large harmonics, power factor, and high total harmonic distortion (THD). Non-linear loads de-rate the power system and may create interference in other equipment. These draw line currents that are rich in harmonics. The problems associated with harmonic currents are well known. These include overheating of distribution transformers and transmission lines, line voltage distortion, power system instability etc.

Several methods have been developed over the years to reduce the presented problems [1]-[2]. One popular approach is to use a conventional 12-pulse converter, which requires two six-pulse converters connected via Y-Δ and Y-Y isolation transformers as shown in Fig.1. The operation of the conventional 12-pulse diode rectifier results in the cancellation of the fifth and seventh harmonics in the input utility line currents, and the kVA rating of the transformer is 1.03(pu) [3].

In this project, new polyphase transformer arrangements with reduced kVA capacities are proposed to improve the quality of the utility line currents. The new proposed approach is based on autotransformer arrangements between the utility and the diode bridge rectifiers so that the size (in kVA) of the transformer is reduced in comparison of the isolation transformer of the conventional 12-pulse converter. In the autotransformer, the windings are interconnected such that the kVA to be transmitted by the actual magnetic coupling is only a portion of the total kVA. The reduced kVA rating of transformer parts required in an autotransformer to make it physically smaller, less costly, and higher efficiency than conventional transformers.

Further, the autotransformer arrangement also yields equal leakage reactance's in series with each line of the rectifier bridges, which contributes to equal current sharing.

## II. CIRCUIT ANALYSIS OF PROPOSED AUTOTRANSFORMER ARRANGEMENTS FOR 12-PULSE DIODE RECTIFIER SYSTEM

Fig.2 (a) shows the 12-pulse configuration of the proposed approach to reduce the kVA rating of the transformer. The winding configuration of an interphase reactor is shown in Fig.2 (b). In this 12-pulse configuration autotransformer; the 30 degrees phase shift was introduce to eliminate the fifth and seventh harmonics. The vector diagram of the proposed autotransformer connection and the winding representation on a three limb core are shown in Fig.3 (a) and (b) respectively.

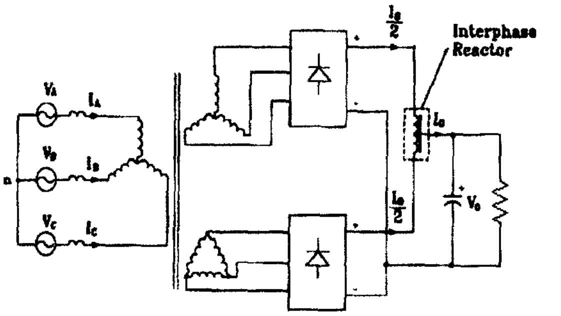
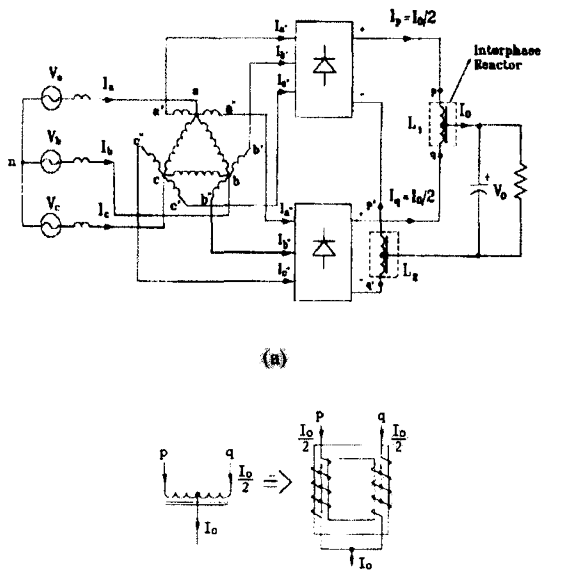


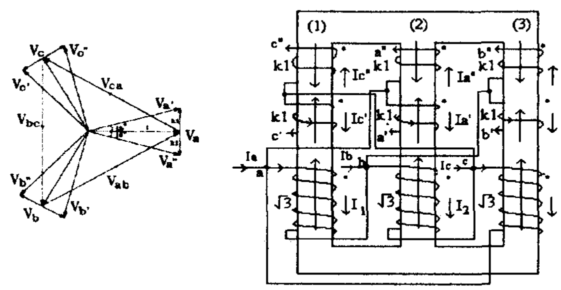

Fig.1. Conventional 12-pulse converter



(a)

(b)

Fig.2. (a) Proposed approach of 12-pulse autotransformer configuration to reduce the kVA rating (b) winding configuration of an interphase reactor



(a) (b)

Fig.3. (a) vector diagram of the proposed delta-type autotransformer connection (b) the winding representation on a three limb core

From Fig.3 (a), the length $k_1$ becomes

$$k1 = 0.2679\,(pu) \tag{1}$$

From limb one (1) of the three-limb core shown in Fig.3 (b), the magneto-motive force (MMF) equation becomes

$$\sqrt{3} * I_1 = k_1(I_{c''} - I_{c'}) \tag{2}$$

Similarly, for core limbs two (2) and three (3), the magneto-motive (MMF) equations becomes

$$\sqrt{3} * I_2 = k_1(I_{a''} - I_{a'}) \tag{3}$$

$$\sqrt{3} * I_3 = k_1(I_{b''} - I_{b'}) \tag{4}$$

By applying KCL at point 'a' (refer to Fig.3 (a) above), Input utility line current $I_a$ can be expressed as

$$I_a = I_1 + I_{a'} + I_{a''} - I_3 \tag{5}$$

Then from (2), (4), and (5), input current $I_a$ becomes

$$I_a = I_{a'} + I_{a''} + \frac{k_1}{\sqrt{3}}\,(I_{c''} - I_{b''} + I_{b'} - I_{c'}) \tag{6}$$

Similarly, input currents $I_b$ and $I_c$ can be expressed as

$$I_b = I_{b'} + I_{b''} + \frac{k_1}{\sqrt{3}}\,(I_{a''} - I_{c''} + I_{c'} - I_{a'}) \tag{7}$$

$$I_c = I_{c'} + I_{c''} + \frac{k_1}{\sqrt{3}}\,(I_{b''} - I_{a''} + I_{a'} - I_{b'}) \tag{8}$$

### A. *Input Current Analysis*

Input current analysis are analyzed and represented as a Fourier series. This facilitates evaluation of input current harmonics.

The three-phase utility input voltages used in this project are

$$V_a = \hat{V}_m \sin(\omega t) \tag{9}$$

$$V_b = \hat{V}_m \sin(\omega t - \tfrac{2}{3}\pi) \tag{10}$$

$$V_c = \hat{V}_m \sin(\omega t + \tfrac{2}{3}\pi) \tag{11}$$

By ignoring the source inductances, two sets of the rectifier input voltages becomes

$$V_{a'} = \hat{V}_{m'} \sin(\omega t + \tfrac{\pi}{12}) \tag{12}$$

$$V_{b'} = \hat{V}_{m'} \sin(\omega t + \tfrac{\pi}{12} - \tfrac{2}{3}\pi) \tag{13}$$

$$V_{c'} = \hat{V}_{m'} \sin(\omega t + \tfrac{\pi}{12} + \tfrac{2}{3}\pi) \tag{14}$$

And

$$V_{a''} = \hat{V}_{m'} \sin(\omega t - \tfrac{\pi}{12}) \tag{15}$$

$$V_{b''} = \hat{V}_{m'} \sin(\omega t - \tfrac{\pi}{12} - \tfrac{2}{3}\pi) \tag{16}$$

$$V_{c''} = \hat{V}_{m'} \sin(\omega t - \tfrac{\pi}{12} + \tfrac{2}{3}\pi) \tag{17}$$

where

$$\hat{V}_{m'} = \sqrt{1+\left(tan\frac{\pi}{12}\right)^2}\, V_m = 1.035V_m \qquad (18)$$

Considering a highly inductive load current at the rectifier outputs, the rectifier input currents can be represented as [4]

$$I_{a'} = \sum_{n=1,3,5...}^{\infty}\left[\frac{4I_p}{n\pi}\cos\left(n\frac{\pi}{6}\right)\right]\sin n\left(\omega t+\frac{\pi}{12}\right) \qquad (19)$$

$$I_{b'} = \sum_{n=1,3,5...}^{\infty}\left[\frac{4I_p}{n\pi}\cos\left(n\frac{\pi}{6}\right)\right]\sin n\left(\omega t+\frac{\pi}{12}-\frac{2}{3}\pi\right) \qquad (20)$$

$$I_{c'} = \sum_{n=1,3,5...}^{\infty}\left[\frac{4I_p}{n\pi}\cos\left(n\frac{\pi}{6}\right)\right]\sin n\left(\omega t+\frac{\pi}{12}+\frac{2}{3}\pi\right) \qquad (21)$$

$$I_{a''} = \sum_{n=1,3,5...}^{\infty}\left[\frac{4I_q}{n\pi}\cos\left(n\frac{\pi}{6}\right)\right]\sin n\left(\omega t-\frac{\pi}{12}\right) \qquad (22)$$

$$I_{b''} = \sum_{n=1,3,5...}^{\infty}\left[\frac{4I_q}{n\pi}\cos\left(n\frac{\pi}{6}\right)\right]\sin n\left(\omega t-\frac{\pi}{12}-\frac{2}{3}\pi\right) \qquad (23)$$

$$I_{c''} = \sum_{n=1,3,5...}^{\infty}\left[\frac{4I_q}{n\pi}\cos\left(n\frac{\pi}{6}\right)\right]\sin n\left(\omega t+\frac{\pi}{12}-\frac{2}{3}\pi\right) \qquad (24)$$

Where $I_p$ and $I_q$ are the output current magnitudes of the two rectifiers, respectively. From (6) and (9) to (24), input line current $I_a$ for the proposed 12-pulse system is shown to be

$$I_a = \sum_{n=1,3,5...}^{\infty}\left[\frac{4}{n\pi}cos\left(n\frac{\pi}{6}\right)\right]A_n \sin n(\omega t-\emptyset_n) \qquad (25)$$

Where

$$A_n = \sqrt{\left(I_p+I_q\right)^2[d_n]^2+\left(I_q-I_p\right)^2[n_n]^2}$$

$$\emptyset_n = tan^{-1}\left\{\frac{(I_p-I_q)n_n}{(I_p+I_q)d_n}\right\}$$

$$n_n = sin\left(\frac{n\pi}{12}\right)-\frac{2}{\sqrt{3}}k_1 sin\left(\frac{2\pi n}{3}\right)\cos\left(\frac{n\pi}{12}\right)$$

$$d_n = cos\left(\frac{n\pi}{12}\right)+\frac{2}{\sqrt{3}}k_1 sin\left(\frac{2\pi n}{3}\right)sin\left(\frac{n\pi}{12}\right) \qquad (26)$$

Since $I_p = I_q = I_o/2$, substituting this into (26) yields $A_5 = 0, A_7 = 0, A_{17} = 0$ and $A_{19} = 0$. Therefore, the utility input current harmonics consist only of the 12-pulse characteristic harmonics ($h = 12k \pm 1, k = 1,2,3\ldots$) and the fifth, seventh, seventeenth and nineteenth, etc harmonics are absent in utility input line currents. From (26), it is also noted that the fundamental power factor is unity.

### B. *Output Voltage Analysis*

The information of the output voltage across IPR is important because it tells which significant harmonic voltage that causes the current to circulate. To calculate the output voltage, $V_o$ let's consider the upper part of the two bridges connected to interphase reactor $L_1$ as midpoint converter as shown in Fig.4 .The output voltage at point p and q is in the form of

$$V_{pn} = \frac{3}{\pi}V_m{}'\sin\frac{\pi}{3}\left[\frac{-\cos n\pi/3}{n^2-1}\right].e^{+j\frac{n\pi}{12}}\Big|_{n=0,3,6,9...} \qquad (27)$$

$$V_{qn} = \frac{3}{\pi}V_m{}'\sin\frac{\pi}{3}\left[\frac{-\cos n\pi/3}{n^2-1}\right].e^{-j\frac{n\pi}{12}}\Big|_{n=0,3,6,9...} \qquad (28)$$

Where

$$V_{m'} = {V_m}/{\cos 15^0} = 1.035V_m \qquad (29)$$

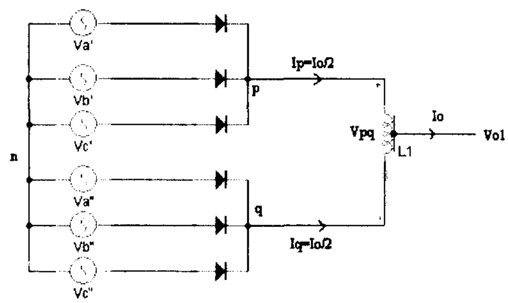



Fig.4. Midpoint converter representation for the upper parts of the bridge rectifiers connected to interphase reactor

$V_m$ is the amplitude of the supply voltage. Let's consider the dc voltage first. Therefore, the dc output voltage of the midpoint converter becomes

$$V_{o1} = \frac{1}{2}\left(V_{pn,dc}+V_{qn,dc}\right)$$

$$= \frac{3}{\pi}V_m{}'\sin\frac{\pi}{3} = 0.8270V_m{}' \qquad (30)$$

Similarly, the output voltage of the midpoint converter regarding the lower part of the two rectifiers $V_{o2}$, becomes

$$V_{o2} = -0.8270V_m{}' \qquad (31)$$

Therefore, the dc output voltage of the 12-pulse autotransformer rectifier is

$$V_o = V_{o1}-V_{o2} = 1.6540V_{m'} = 1.7123V_m \qquad (32)$$

The voltage across interphase reactor $L_1, V_{pq}$ becomes

$$V_{pq} = V_{pn} - V_{qn}$$

$$= \frac{12}{\pi}sin\frac{\pi}{3}\sum_{3,6,9..}^{\infty}\frac{1}{n^2-1}\cos\frac{n\pi}{3}sin\frac{n\pi}{12}\sin n\omega t$$

### C. *kVA Rating of the 12 Pulse Autotransformer*

The autotransformer utilized in the 12 pulse rectifier circuit above is designed such that the size (in kVA) of the transformer is minimized. Assuming the dc output current $I_o$ is highly inductive, the rms value of the input rectifier currents is

$$|I_{a'RMS}| = \sqrt{\frac{240}{360}\frac{I_o}{2}} = 0.4082I_o \tag{34}$$

Therefore, the rms value of the large winding currents is

$$|I_{1'RMS}| = \sqrt{\frac{120}{360}}\left(\frac{k_1}{\sqrt{3}}\frac{I_o}{2}\right) = 0.0446I_o \tag{35}$$

The rms value of the small winding voltages is

$$|V_{a'aRMS}| = k_1\frac{V_m}{\sqrt{2}} = 0.1895\left(\frac{V_o}{1.7123}\right) = 0.1107V_o \tag{36}$$

Also, the rms value of the large winding voltage is

$$|V_{abRMS}| = \frac{\sqrt{3}V_m}{\sqrt{2}} = 1.2247\left(\frac{V_o}{1.7123}\right) = 0.7152V_o \tag{37}$$

Then, the sum total volt-amp product of the autotransformer winding is

$$kVA_{tot} = 6|I_{a'RMS}||V_{a'aRMS}| + 3|I_{1'RMS}||V_{abRMS}|$$

$$= 0.36641I_oV_o \tag{38}$$

Hence, the equivalent kVA rating of the autotransformer is

$$kVA_{eq} = \frac{1}{2}kVA_{tot}$$

$$= 0.18341I_oV_o \tag{39}$$

Thus, the 12 pulse arrangement requires a transformer kVA of only 18% of the output kVA.

## III. SIMULATION RESULTS

In this project, the current and voltage waveforms will be analyzed using Fourier analysis. By doing this, the harmonics component for 12 pulse autotransformer could be observed. The result also will be used to compare with the simulation result. Before deriving the input current for the 12 pulse, it is crucial to obtain the Fourier series of the quasi square waveform shown in Fig.5. This is the basic current waveform which drawn by the rectifier bridges. The peak value is $I_o$, however, in parallel bridges, this value may be changed. For 12 pulse, there are two bridges in parallel, therefore, the peak is $I_o/2$.

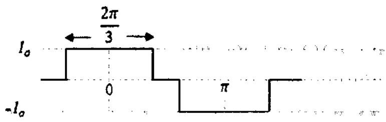



Fig.5. Quasi square waveform

Based on the derivation in (26), Fourier series of the quasi square waveform can also be determine using two single pulses. The first or positive pulse has width of $2\pi/3$ and centered at $\alpha = 0$.

Therefore,

$$A_{np} = \frac{I_o}{n\pi}sin\frac{n\pi}{3} \tag{40}$$

The second or negative pulse has equal width but centered at $\alpha = \pi$. Therefore

$$A_{nn} = -\frac{I_o}{n\pi}sin\frac{n\pi}{3}e^{-jn\pi} \tag{41}$$

The quasi square waveform is the result of positive and negative pulse, which is

$$A_n = A_{np} + A_{nn} = \frac{2I_o}{n\pi}sin\frac{n\pi}{3}\Big|_{n=odd} \tag{42}$$

Where Magnitude $A_n = 2 \times |A_n| = \frac{4I_o}{n\pi}\sin\frac{n\pi}{3}$

### A. *Conventional 12 pulse star/star-delta transformer*

The input line current consists of three currents, which is

$$I_a = I_1 + \frac{I_4}{\sqrt{3}} - \frac{I_6}{\sqrt{3}} \tag{43}$$

Fig.6 (a) shows the rectifier input currents and the resultant input line current waveform. Current $I_1$ is in phase with the input current, current $I_4$ has phase shift of +30° and current $I_6$ is -240° away of $I_1$. Let's see the Fourier series of the individual current. Applying (42)

$$I_4 = \frac{2I_p}{n\pi}sin\frac{n\pi}{3}e^{+jn\pi/6} \quad ,I_6 = -\frac{2I_p}{n\pi}sin\frac{n\pi}{3}e^{-jn\pi/6}$$

$$I_1 = \frac{2I_q}{n\pi}sin\frac{n\pi}{3} \tag{44}$$

But

$$I_a = I_1 + \frac{I_4}{\sqrt{3}} - \frac{I_6}{\sqrt{3}} = \frac{2}{n\pi}sin\frac{n\pi}{3}\left[I_q + \frac{I_p}{\sqrt{3}}\left(2jcos\frac{n\pi}{6}\right)\right] \tag{45}$$

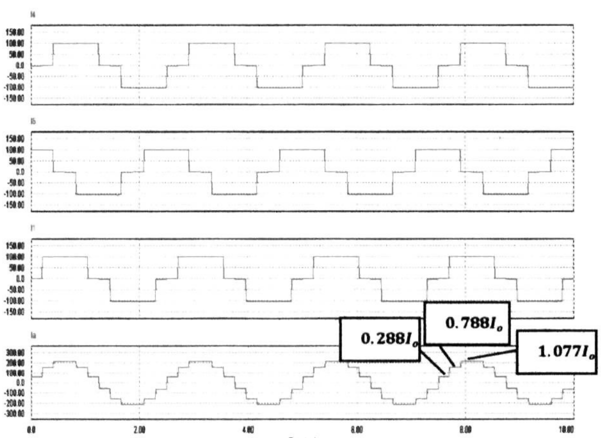
Under equal sharing condition, the bridge output current $I_p = I_q = I_o/2$, hence

$$I_a = \frac{I_o}{n\pi} sin\frac{n\pi}{3}\left[1 + \frac{2}{\sqrt{3}}\left(cos\frac{n\pi}{6}\right)\right]\Big|_{n\neq3,5,7...} \quad (46)$$

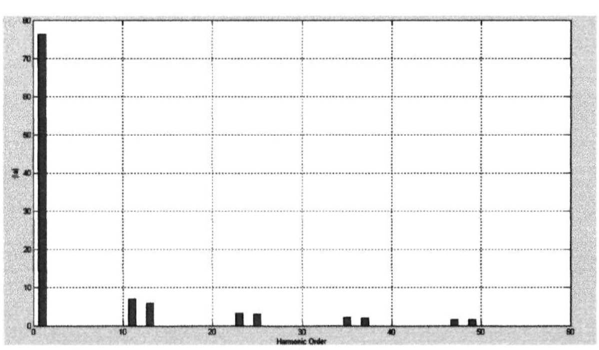
Fig.6 (b) shows the harmonic spectra using (46) with $I_p = I_q = I_o/2$. The harmonic characteristics are in the form of $12k \pm 1$ harmonics. Table I below shows the magnitude for each harmonic. The THD is calculated to be $14.1732\%$.

TABLE I
HARMONICS CURRENT IN CONVENTIONAL 12 PULSE TRANSFORMER

| Harmonics | Ia (peak) |
|---|---|
| 1 | 76.4473 |
| 11 | 6.9498 |
| 13 | 5.8806 |
| 23 | 3.3233 |
| 25 | 3.0579 |




(a)



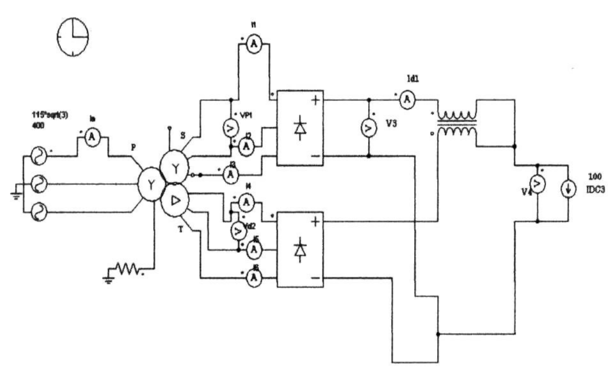
(b)

Fig.6. (a) Rectifier input currents and the input line current waveform (b) Harmonic spectra of 12 pulse star/star-delta isolated transformer.

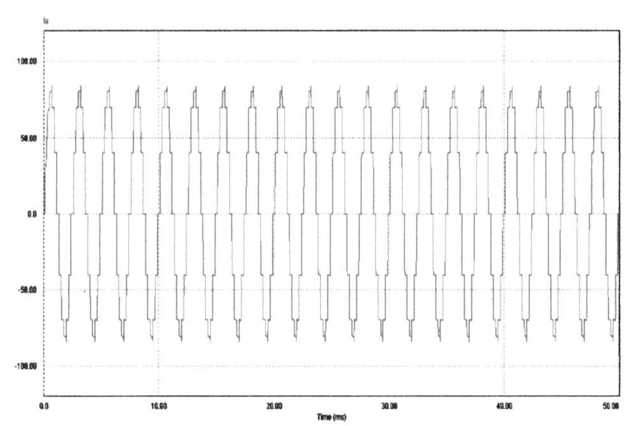
Fig.7 (a) shows the PSIM model of conventional 12 pulse star/star-delta. From the simulation, the harmonic spectra can be observed. Fig.7 (b) shows the simulated conventional 12 pulse input line current waveform. Fig.8 shows the harmonic spectra of the input line current. Table II below shows the magnitude for each harmonic. Notice that the $5^{th}, 7^{th}, 17^{th}$and $19^{th}$ harmonics are absent. The THD is calculated to be 14.6697%.

TABLE II
HARMONICS CURRENT IN CONVENTIONAL 12 PULSE TRANSFORMER

| Harmonics | Ia (peak) |
|---|---|
| 1 | 79.6782 |
| 11 | 6.9282 |
| 13 | 6.2326 |
| 23 | 3.2779 |
| 25 | 3.0511 |



(a)



(b)

Fig.7. (a) PSIM model of the conventional 12 pulse star/star-delta (b) Input line current of 12 pulse star/star-delta isolated transformer.

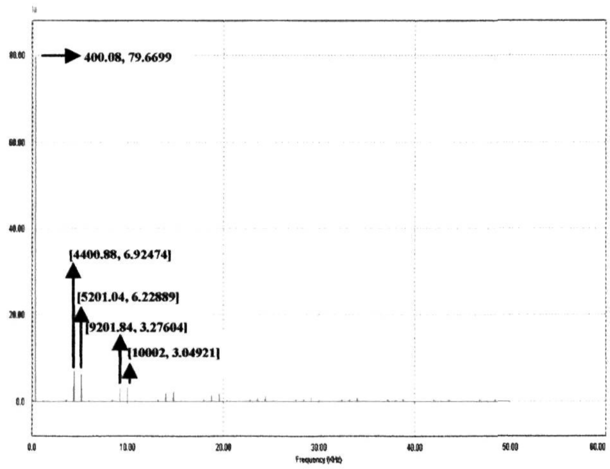



Fig.8. Harmonic spectra of the input line current.

### A. *12 Pulse autotransformer*

It is already mentioned that the currents which are drawn by the diode bridges are in the form of quasi square wave with 30 degree phase shift between the bridges. Therefore applying (42) to each of the line current yield,

$$I_{a'} = \frac{2I_p}{n\pi}\sin\frac{n\pi}{3}e^{\frac{jn\pi}{12}} \qquad I_{a''} = \frac{2I_q}{n\pi}\sin\frac{n\pi}{3}e^{-\frac{jn\pi}{12}}$$

$$I_{b'} = \frac{2I_p}{n\pi}\sin\frac{n\pi}{3}e^{-\frac{jn2\pi}{3}}.e^{\frac{jn\pi}{12}} \qquad I_{b''} = \frac{2I_q}{n\pi}\sin\frac{n\pi}{3}e^{-\frac{jn2\pi}{3}}.e^{-\frac{jn\pi}{12}}$$

$$I_{c'} = \frac{2I_p}{n\pi}\sin\frac{n\pi}{3}e^{\frac{jn2\pi}{3}}.e^{\frac{jn\pi}{12}} \qquad I_{c''} = \frac{2I_q}{n\pi}\sin\frac{n\pi}{3}e^{\frac{jn2\pi}{3}}.e^{-\frac{jn\pi}{12}} \tag{47}$$

From (6) the input current is

$$I_a = I_{a'} + I_{a''} + \frac{k_1}{\sqrt{3}}\left(I_{c''} - I_{b''} + I_{b'} - I_{c'}\right)$$

substituting the Fourier series of the rectifier current into (47), yield

$$I_a = \frac{2}{n\pi}\sin\frac{n\pi}{3}$$

$$\left[\cos\frac{n\pi}{12}\left(I_p + I_q + j\frac{2}{\sqrt{3}}k_1\sin n\frac{2\pi}{3}(I_p - I_q)\right) + jsin\frac{n\pi}{12}\left(I_p - I_q + j\frac{2}{\sqrt{3}}k_1\sin\frac{n2\pi}{3}(I_p + I_q)\right)\right]\Bigg|_{n=odd} \tag{48}$$

where Magnitude of current $I_a = 2 \times |I_a|$

Therefore, by having this equation, the harmonic spectra can be observed. Fig.9 shows the harmonic spectra of the 12 pulse autotransformer. The harmonic spectra are calculated under balance condition with each bridge output gives equal current, which is half of load current.

The load current, $I_o$ can be calculated using (32) as follows

$$I_o = \frac{V_o}{R_L} = \frac{1.7123V_m}{4} = 69.33A$$

Notice that the $5^{th}, 7^{th}, 17^{th}$and $19^{th}$ harmonics are absent. Table III below shows the magnitude for each harmonic. The THD is calculated to be 14.1732%.

$$h = 12k \pm 1\,; k = \text{any integer}$$

TABLE III
HARMONICS CURRENT IN 12 PULSE AUTOTRANSFORMER

| Harmonics | Ia (peak) |
|---|---|
| 1 | 79.144 |
| 11 | 7.1949 |
| 13 | 6.088 |
| 23 | 3.441 |
| 25 | 3.1658 |

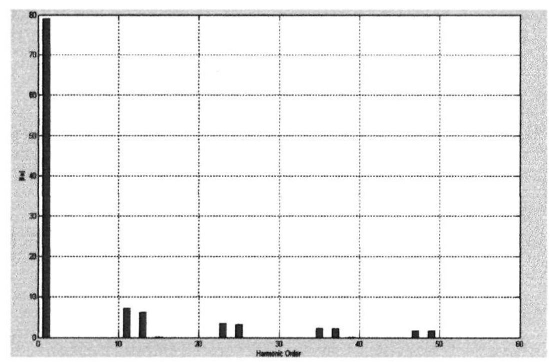


Fig.9. Harmonic spectra of the 12 pulse autotransformer

Fig.10 shows the MICROCAP model of 12 pulse autotransformer.

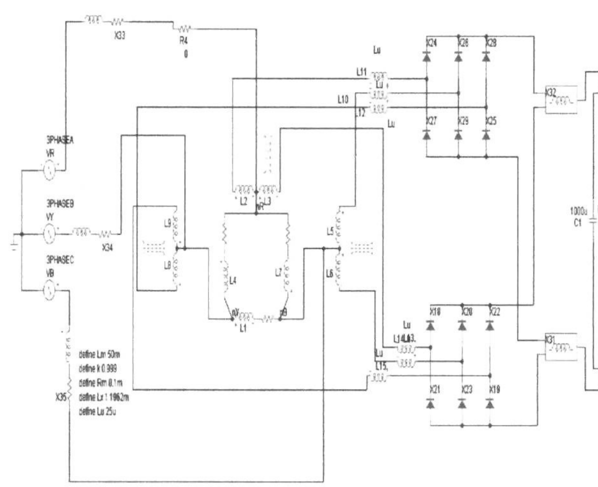
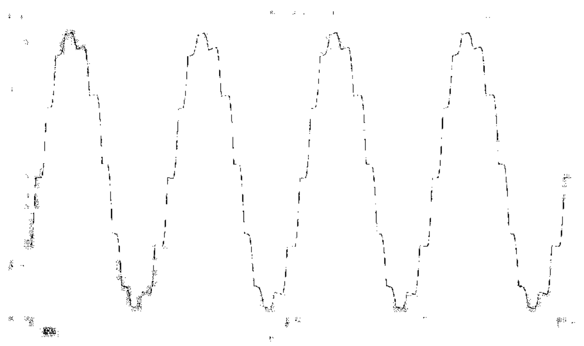
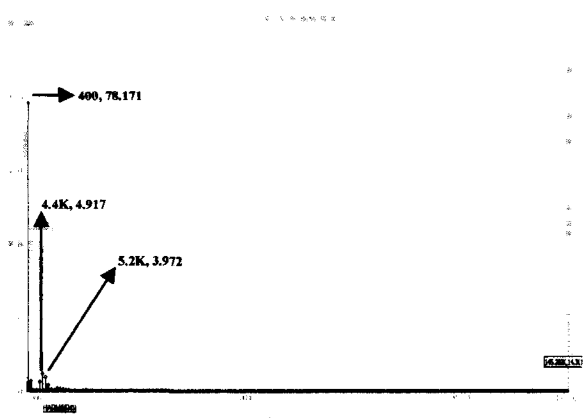


Fig.10. MICROCAP model of the 12 pulse autotransformer.

From the simulation, the harmonic spectra can be observed. Fig.11 (a) shows the simulated 12 pulse autotransformer input line current waveform. Fig.11 (b) shows the harmonic spectra of the input line current. Notice that the $5^{th}, 7^{th}, 17^{th}$ and $19^{th}$ harmonics are absent. The THD is calculated to be 13.9%.



(a)



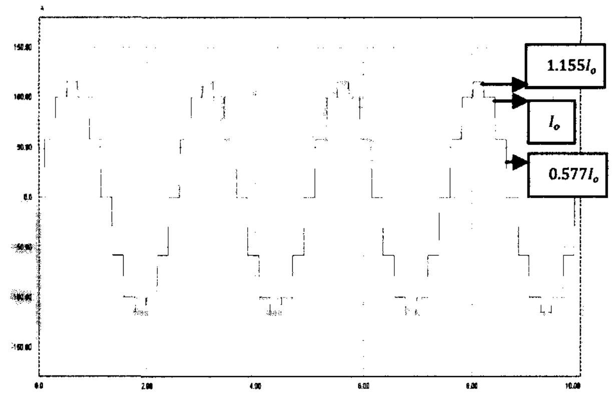

(b)

Fig.11. (a) Simulated 12 pulse autotransformer input line current waveform (b) Harmonic spectra of the input line current.

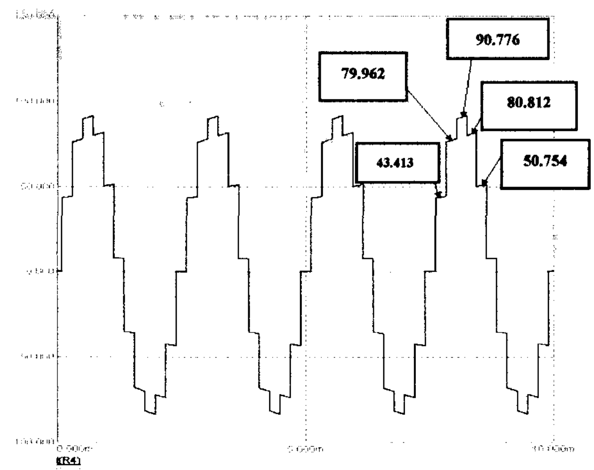
## B. *Ideal circuit*

In order to simulate the ideal circuit, the leakage reactance should not be present. However a very small supply leakage inductance is needed. This is to sort out the initial condition problem, which occurs in the absence of supply inductance. The theoretical input line current should be as in Fig.12 (a) below.

Fig.12 (b) shows the simulated input line current, $I_a$ waveform. Here, it could be observed that the current steps are not what in theory. This is because, the current waveform in Fig.12 (a) is not symmetrical, which the positive value is bigger than the negative value. It is identified to be the problem caused by the small series resistance in the autotransformer large winding. Fig.13 shows the harmonic spectra of the input line.




(a)




(b)

Fig.12. (a)Theoretical input line current, $I_a$ waveform.(b)Simulated input line current, $I_a$ waveform .

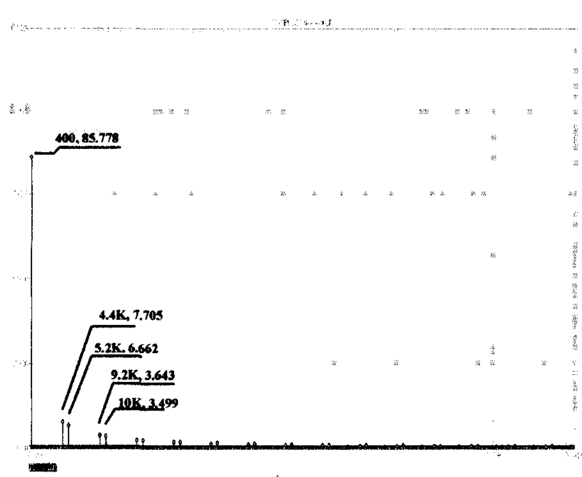



Fig.13. Harmonic spectra of input current.

TABLE IV

HARMONICS CURRENT IN 12 PULSE AUTOTRANSFORMER

| Harmonics | Ia (peak)-Theory | Ia (peak)-Simulation |
|---|---|---|
| 1 | 79.144 | 85.778 |
| 11 | 7.1949 | 7.705 |
| 13 | 6.088 | 6.662 |
| 23 | 3.441 | 3.643 |
| 25 | 3.1658 | 3.499 |

Table IV above shows the comparison between both simulation and theoretical results. The THD for simulation is 15.0025% whilst in theory the THD is 14.1732%.

### *B. Current Sharing*

The circuits used in this project have been simulated under ideal condition, which all components in each phase have symmetrical value (e.g. the ac line leakage inductance). It is observed that under this condition, it give the nearly equal current sharing. However under unbalance condition, which usually occurs in practical, the circuit does not gives equal current sharing result. Fig.12 shows the harmonic spectra of the input line under the unbalance condition. Table V below shows the magnitude for each harmonic. The THD is calculated to be 16.7375%.

TABLE V

HARMONICS CURRENT IN 12 PULSE AUTOTRANSFORMER

| Harmonics | Ia (peak) |
|---|---|
| 1 | 84.619 |
| 5 | 6.36 |
| 7 | 6.385 |
| 17 | 3.959 |
| 19 | 3.451 |

Under the unbalance condition, the 5, 7, 17, 19, etc. harmonics are present in the utility input line current. To create the unbalance condition, one inductor has been added at one phase in the circuit. This shows that if the current sharing in the circuit is unequal, the 5, 7, 17, 19, etc. harmonics are present in the utility input line current.

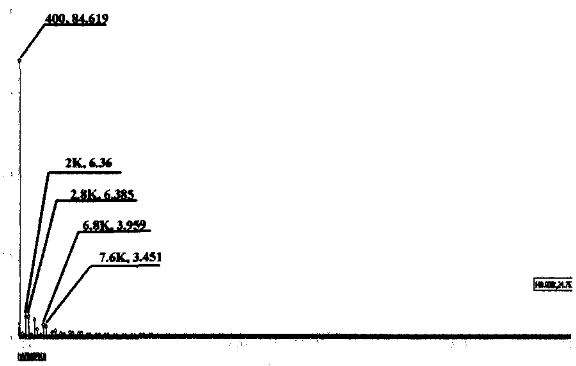
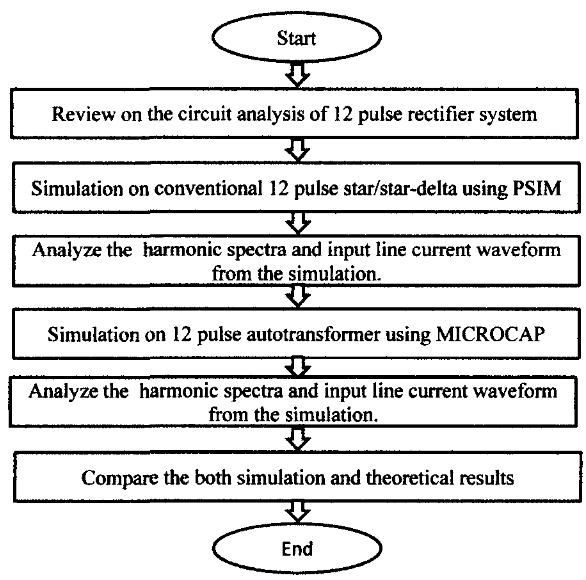



Fig.12. Harmonic spectra of the input line

## IV. FLOW CHART

The flow of methodology used in this project is shown as below:




## V. FUTURE WORK

There are a few problems in getting the simulation done initially. It starts with the initial condition problems, which was sorted out by getting zero initial condition for the leakage inductance. Next problem deals with the coupling inductor which is used to model the autotransformer. In doing this, the voltage vector diagram is crucial, because it tells which inductors are in the same limb, hence the same phase. In this project, an unbalance current might be obtained due to the unsymmetrical phase shifted. Further work on this multipulse system could include the method to overcome this problem.

## VI. CONCLUSION

This project has successfully simulated and analyzed 12 pulse diode rectifier systems. The advantage of using the autotransformer over the conventional isolated transformer is its physicals size. It has been shown that 12-pulse operations can be realized with transformer kVA of 0.18 (pu) of load kVA compared to the conventional isolated transformer. This amounts to an 82% reduction in transformer kVA or physical size compared to the conventional isolated transformer.

Besides the simulation, the Fourier analysis has been carried out to give a theoretical reference of harmonic spectra for the input line current. The harmonic characteristic of the line current for the 12-pulse had been confirmed and the comparison between the simulation and theoretical results had been shown.

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