The Effect of 12 Pulse Converter Input Transformer Configuration on Harmonics of Input Current

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Abstract. This paper discusses the effect of the 12-pulse converter input transformer configuration on the input harmonic currents. This is done because there are many transformer connection configurations, which according to the standard there are 5 transformer connection groups. The research method begins with a literature study on the 12-pulse converter. Next, determine the specifications of the 12-pulse converter and build the 12-pulse converter. Then, a theoretical analysis was carried out on the waveform of the 12-pulse converter current with the Dy11/d0 and Yd1/y0 input transformer configurations. From the analysis and simulation results, it was found that the THDi of the two 6 pulse converters obtained 29% THDi, while the 12-pulse converter inputs side obtained 11.59%-13.6% THDi. The input transformer configuration does not affect the THDi results, except for the power sent by the 12-pulse converter with the input transformer configuration Yd1_y0 to 1/3 compared to the Dy11_d0 connection.

1. Introduction

The use of semiconductor power in electric power system technology continues to grow, which affects electrical loads, from domestic electrical loads to industrial electrical loads. These electrical loads are non-linear loads that produce harmonic current distortion. It causes additional losses, so that the system temperature increases, the system power factor decreases. To reduce this harmonic distortion in high power industrial loads such as high-power drive systems a 12-pulse converter is used. As stated in [1,2] this converter can be constructed by connecting in series two 6 pulse converters, each of which has a 30o phase difference. This phase shift can be obtained by configuring the input transformer connection of the converter.

This input transformer configuration will affect the harmonic content of the input current, so that it also affects the input voltage. As expressed in [1], where the harmonic input current of 6 pulses of order 5 drops to 0.03% and the voltage drops to 8%, so that the total harmonic value. The distortion also decreased, [2] where the THD of the current fell from 4.16 to 0.52%, while the THD of the voltage fell from 11.29% to 1.29%. Likewise, [3,4] stated that the 12-pulse converter using the input transformer autotransformer harmonic input currents of the order 5, 7, and 11 could be suppressed. This research was conducted to analyze the behavior of the harmonic distortion in a 12-pulse converter with a certain transformer connection. This is done because of the many types of 3 Phase Transformer connections, some three-phase transformer connections include Yy0, Dd0, Yd1, Dy1, Yd5, Dy5, Yy6, Dd6, Yd11, and Dy11.

The methodology used in this research is a quantitative method which is carried out by building a theory related to the 12-pulse converter, analyzing the behavior of harmonic currents, performing simulations with PSIM software, and measuring. It is started with determining the 12-pulse converter specifications to be researched, namely:

- Input voltage: 400 Volts
- Output Voltage: 150 Volt
- Output Current: 10 Ampere
- Input transformer configuration: Dy11/d0 and Yd1/y0
From this design, each 6-pulse converter must produce an output voltage of 75 V so that the 6-pulse converter input voltage can be derived as follows:

DC output voltage 6 pulses converter: \( V_{\text{DCout}} = \frac{3V_{\text{m}}\sqrt{3}}{\pi} \), so that with a DC output voltage of 75 V, the secondary effective voltage of the star connected transformer is = 32 volts and the secondary winding of the transformer connected to the delta is = 55.5 volts.

The converter below shows a 6 pulse converter with a Dy11 input transformer connection and has a waveform of output voltage, output current, and input current as shown in Figure 1.

![Figure 1. 6 Pulse converter, output waveform, and input current with Dy11 input transformer](image1.png)

This current flow in the y phase winding. Using the approximation that the waveform is a square wave. The current is in the phase D winding. In phase with the current in the y phase winding and the source current to the D winding has a form that is the result of subtracting phase 1 and phase 3 (see the current loop in circuit schematic). The results of which are shown in Figure 2.

![Figure 2. Waveform of the input current for the Dy11 transformer connection](image2.png)
The following is a 6 pulse converter with input transformer connection Yd1, where the primary winding has a Y connection, while the secondary winding has a Delta connection. With a delta connection, line currents and phase currents have a phase difference of 30°. The 6 pulse converter that is supplied by a transformer with a Yd1 connection will have a voltage wave and an output-input current as shown in Figure 3.

![6 Pulse Converter Diagram](image1)

**Figure 3.** 6 Pulse converter, output waveform and input current with Yd1 input transformer

This current flow in the Line input converter, where the line current is the result of the reduction of the phase 1 current with the 3 phase current in the Delta winding so that the line current value is shifted 30° from the phase current. Using the approximation that the waveform is a square wave. It appears that the input current waveform in the phase D winding, the result is shown in Figure 4. The input current in the phase D winding is in phase with the current in the phase w winding, yang. So that the input current waveform on the converter is the same, both on the Dy11 and Yd1 connections. The effect of the input transformer connection only affects the phase position of the relevant input current.

![Input Current Waveform](image2)

**Figure 4.** Waveform of Yd1 transformer connection input current
As expressed in [1], where the harmonic input current of the converter 6 pulses of order 5 drops to 0.03% and the voltage drops to 8%, so that the total harmonic distortion value also decreases, [2] where the current THD drops from 4.16 to 0.52% while the THD Voltage decreased from 11.29% to 1.29%.

2. Methodology

12 PULSE CONVERTERS

A 12-pulse converter is a converter that converts AC voltage into DC voltage, wherein one cycle the AC voltage will be converted into a 12-pulse DC voltage. In [3], [4] states that the 12 pulse converter using the autotransformer input transformer harmonic input current order 5, 7, and 11 can be suppressed. In addition to using a passive filter to reduce the input current harmonics to the converter, the transformer configuration used can also reduce the input current harmonics [5,6,7]. In addition, to have an impact on the harmonic content of the use of an input transformer, it also affects the capacity of the transformer used [3] and [5], [6] which states that the required transformer capacity is only about 40% of the DC load power. Also, in [7] shows that the input transformer connection can also be used to increase the power factor naturally. 12-pulse converter with autotransformer input transformer as stated in [8] with a zigzag connection can improve the quality of electrical power.

The 12-pulse converter circuit with input transformer configuration Dy11 / d0 is shown in Figure 5. Assuming the load has an induction of 0.1 H and R = 15 Ohm, then the waveform of the input current in each part of the converter is a square wave as shown in Figure 6.

![Figure 5. 12-pulse converter with input transformer Dy11 / d0 connection](image)

![Figure 6. The Waveform of the input current on a 12-pulse converter with a Dy11 / d0 connection input transformer](image)
the same transformer, the input voltage for each phase will be 0.58 from the previous configuration so that the output voltage becomes 87 volts, and the output current becomes 5.8 Ampere.

\[ \text{Figure 7. 12-pulse converter with input transformer configuration } \text{Yy0 / d1} \]

From this waveform, it appears that the input current of the 12-pulse converter with the Dy11/d0 and Yd1/y0 input transformer configuration has the same shape, except that in the Yd1/y0 configuration the input current becomes smaller.

3. Results and Discussion
HARMONIC CURRENT INPUT ON 12 PULSE CONVERTER

a. Dy11 / d0 input transformer configuration

As shown in Figure 8, the input current in each converter is I, thus, in the phase winding connected to Y. The phase current is also equal to I. Meanwhile, in winding d the current in the phase winding will be \( I/\sqrt{3} \). On the primary side, namely in winding D, the current in the secondary y will produce a current \( I/ ay \) where \( ay = 400/32 = 12.5 \), while the current in the secondary d will produce a current \( I/ad \) where \( ad = 400/55 = 7,27 \). Thus, the phase current of the primary winding D will be equal to \( \left( I/12.5 + I/\sqrt{3}/7,27 \right) \). The current on the input
side of winding D will be equal to \(\left(\frac{l_{12.5}}{\sqrt{3}} + \frac{l_{7.2}}{\sqrt{3}}\right)\) as shown in figure 8 (axis 4). By referring to the figure, the input current in winding D can be stated (Tables 1 and 2).

\[
i_s(\omega t) = \sum_{n=1}^{\infty} a_n \sin n\omega t + b_n \cos n\omega t \quad (17)
\]

And with I = 10 Ampere.

### Table 1. \(i_s(\omega t) = \sum_{n=1}^{\infty} a_n \sin n\omega t + b_n \cos n\omega t\)

| Harmonic Order | 1  | 3  | 5  | 7  | 9  | 11 | 13 | 15 | 17 | 19 |
|----------------|----|----|----|----|----|----|----|----|----|----|
|                | a  | 2.88 | 0.00 | -0.04 | -0.03 | 0.00 | 0.26 | 0.22 | 0.00 | -0.01 | -0.01 |
|                | b  | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|                | theta | -90 | -90 | -90 | -89 | -89 | -89 | -89 | -89 | -89 | -89 |

Thus, the converter input current equation at the Dy11 / d0 transformer connection can be stated, 

\[
i_{in_d}(\omega t) = \sum_{n=1,3,5} c_n \sin (n\omega t + \theta). \]

Harmonic values of the order 3, 5, 7, and 9 are below 2% so that they can be ignored, then the 12 pulse converter input current can be stated:

\[
i_{in_d}(\omega t) = 2.9 \sin (\omega t - 90) + 0.3 \sin (3\omega t - 90) + 0.2 \sin (7\omega t - 90) + 0 + 0 + \ldots \text{etc.}
\]

With the effective current rating \(I_{eff} = (2.9^2 + 0.3^2 + 0.2^2)^{1/2} = 2.9\) Ampere, and Total Harmonic Distortion \(THD_I = \frac{(0.3^2 + 0.21^2)^{1/2}}{2.9} = 0.119 = 11.9\%\)

The current harmonic spectrum is shown in Figure 9.

**Figure 9.** Harmonic spectrum for a 12-pulse converter input current with a Dy11/d0 connection input transformer

Simulation Results

Converter Output Voltage (Figure 10)
**Figure 10.** The simulation results of the output voltage waveform converter 12-pulses with the input transformer Dy11/d0 connection.

Input current converter (Figure 11)

**Figure 11.** The simulation results of the current 12-pulse converter input waveform with the input transformer Dy11/d0 connection

Input Current Harmonic Spectrum (Figure 12 and Table 3)

**Figure 12.** Harmonic spectrum of the 12-pulse converter input current with the input transformer Dy11/d0 connection

| Koneksi Dy11_d0 | Gel_Arru | Fund | h-3   | h-5   | h-7   | h-9   | h-11  | h-13  | h-15  | h-17  | h-19  | Irms  | THD (%) |
|----------------|----------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------|
| In_y           | 10.96    | 0    | 2.19  | 1.56  | 0     | 0.81  | 0.79  | 0     | 0.64  | 0.52  | 11.38 | 27.92% |
| In_d           | 10.96    | 0    | 2.19  | 1.56  | 0     | 0.81  | 0.79  | 0     | 0.64  | 0.52  | 11.38 | 27.92% |
| sumber_D       | 3.02     | 0    | 0.00  | 0.00  | 0     | 0.27  | 0.21  | 0     | 0     | 0     | 3.04  | 11.33% |
b. Yd1/y0 input transformer configuration

As shown in Figure 10, the input current in each converter is \( I / \sqrt{3} \). Thus, in the phase winding connected Y, the phase current is also the same as \( I / \sqrt{3} \). Meanwhile in winding d, the current in the phase winding will be equal to \( I / 3 \). On the primary side, i.e. in winding Y, it will be equal to \( (\frac{I}{\sqrt{3}} 1, 5, \frac{I}{3} 7,27) \) as shown in figure 10 (axis 4). Referring to this figure, the input current in winding Y can be stated

\[
i_{in,Y}(\omega t) = \sum_{n=1}^{\infty} a_n \sin n \omega t + b_n \cos n \omega t \quad \text{.............................. (18)}
\]

And with \( I = 10 \) amperes (Table 4).

| Sampai dengan \( \omega t \) = (rad) | 0,524 | 1,048 | 2,095 | 2,619 | 3,143 | 3,667 | 4,190 | 5,238 | 5,762 | 6,286 |
|-----------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Arus sumber (30)                  | 0,3   | 0,7   | 0,96  | 0,7   | 0,3   | -0,3  | -0,7  | -0,96 | -0,7  | -0,3  |

The solution of equation (18) is stated in the following table 5

| Harmonic Orde | 1   | 3   | 5   | 7   | 9   | 11  | 13  | 15  | 17  | 19  |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| c             | 0,99| 0,02| 0,02| 0,02| 0,01| 0,10| 0,09| 0,00| 0,01| 0,02|
| a             | 0,99| 0,02| 0,02| 0,02| 0,01| 0,09| 0,08| 0,00| 0,01| 0,01|
| b             | -0,02| -0,02| 0,00| 0,00| 0,00| -0,04| -0,05| 0,00| -0,01| -0,02|
| Theta         | -89,04| -46,98| -84,29| -78,95| -72,13| -64,29| -56,09| -48,17| -41,02| -19,09|

Thus, the converter input current equation at the Yd1 transformer connection can be stated,

\[
i_{in,Y}(\omega t) = \sum_{n=1,3,5}^{\infty} c_n \sin(n \omega t + \Theta)
\]

The values of harmonic currents of the order 3, 5, 7, and 9 are below 2% so that they can be ignored. Then, the 12 pulse converter input current can be stated:

\[
i_{in,Y}(\omega t) = 0,99 \sin(\omega t - 90) + 0,1 \sin 11(\omega t - 64) + 0,09 \sin 13(\omega t - 56) + 0 + 0 + .......... \text{ etc.}
\]

With effective value

\[I_{eff} = (0,99^2 + 0,1^2 + 0,09^2)^{1/2} = 1,00 \text{ Amp.}\]

With Total Harmonic Distortion, \( THD_I = \frac{(0,1^2+0,09^2)}{0,99} = 0,136 = 13,6\% \)

The current harmonic spectrum is shown in Figure 13

**Figure 13.** Harmonic spectrum of the 12 pulse converter input current with the input transformer Yd1/y0 connection
Simulation Results

Converter Output Voltage (Figures 14-16 and Table 6)

Figure 14. Simulation results of the output voltage wave converter 12-pulses with the input transformer Yd1/y0 connection

Figure 15. Simulation results of the 12-pulse converter input current waveform with the input transformer Yd1/y0 connection.

Figure 16. Harmonic spectrum for the 12-pulse converter input current with the input transformer Yd1_y0 connection.

Table 6. Harmonic Spectrum

| Harmonic Order | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | Irms | THD |
|----------------|---|---|---|---|---|----|----|----|----|------|-----|
| c              | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 1.00 |
| a              | 0.99 | 0.02 | 0.02 | 0.02 | 0.01 | 0.09 | 0.08 | 0.00 | 0.01 | 0.01 | 1.00 |
| b              | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| theta          | -90 | -90 | -89 | -89 | -89 | -89 | -89 | -89 | -89 | -89 | -89 |
4. Conclusion

From the results of the analysis and simulation, it is found that the input side of the two 6 pulse converters obtained thdi of 27.9%, while the 12-pulse converter with Dy11_d0 configuration output current is in accordance with the plan. Besides, on the Yd1_y0 connection the output current becomes 5.8 amperes or 1 / √ 3. Meanwhile, the 12 pulse converter harmonics, in the two input transformer configurations discussed, harmonics of order 3, 5, 7 and 11 as well as harmonics 15, 17, 19 and 21 can be eliminated, so that only fundamental waves and harmonics of order 11 and 13 alone with the THD value in the two converters relatively the same, ranging from 11.9% to 13.6%. This shows that the second input transformer configuration does not affect the thdi results, except the power sent by the converter with 12 pulses configuration input transformer Yd1_y0 becomes 1/3 compared to the Dy11/d0 connection.

References

[1] M. &. H. (M. Reza Fauzan, “Analisa Harmonisa akibat pengruh penggunan Converter pada Kereta Rel istrik 1 x 25 KV Jogjakarta – Solo,” ELECTRICIAN-Jurnal Rekayasa dan Teknologi Elektro, pp. 192 -202.
[2] Ali, M. M., Mochamad, A., and Purnomo, M. H. analysis of Fully Controlled 12 Pulse Converter System and Single Tuned Passive Filter., Digilab ITS
[3] Liang, T.-J., Chen, J.-F., Chu, C.-L., and Chen, K.-J. 1999. Analysis of 12 pulse phase control AC/DC converter,” in IEEE 1999 International Conference on Power Electronics and Drive Systems. PEDS'99 (Cat. No.99TH8475), Hongkong.
[4] Bhim Singh, G. B. V. G. 2006. Harmonic Mitigation Using 12-Pulse AC–DC Converter in Vector-Controlled Induction Motor Drives,” IEEE TRANSACTIONS ON POWER DELIVERY, Vols. 21(3), pp. 1483 – 1492.
[5] Paice, D. a. 2000. Transformers formultipulseAC/DC converter, US. Patent, Rosewood, Palm Harbor,
[6] H. H. S. 2017. Reduction of Harmonics using 12-pulse AC-DC Converter in Vector controlled Induction Motor Drives, in International Journal of Innovative Research in Computer and Communication Engineering, 1.
[7] Samosir, A. S. 2015. Studi Penggunaan Penyearah 18 Pulsa dengan Transformator 3 Fasa menjadi 9 fasa Hubungan segi Enam,” Telokomnika, 13, pp. 21 – 32.
[8] Bhim Singh, S. G. 2007. Pulse Multiplication in Autotransformer Based AC-DC Converters,” Journal of Power Electronics, Vols. 7(3), pp. 199 – 202.
[9] Singh, B., Vipin Garg and Bhuvaneswari, d G. 2008. An Input Current Waveshaping AC-DC Converter for Rectifier Loads, Journal of Power Electronics, Vols. 8(1), pp. 1 – 9.
[10] S. C. A. R. v. J. P. N. E. I. Pitel. 1995. Polyphase transformer arrangements with reduced kVA capacities for harmonics current reduction in rectifier type utility interface,” in Proceedings of PESC ’95 - Power Electronics Specialist Conference, Atlanta USA