HARMONICS PRODUCED IN A THREE-PHASE UNCONTROLLED-CONVERTER TRANSFORMER UNDER UNBALANCED VOLTAGE CONDITIONS

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ABSTRACT
For three–phase converters, the knowledge of the orders and relative amplitudes of lower harmonic components is essential for a filter design.
Under unbalanced conditions of the supply voltage, harmonics that are not produced under balanced conditions are generated.
The effect of unbalanced- supply conditions on the harmonics generated in the primary of a transformer feeding a three- phase six- pulse uncontrolled converter is investigated theorticaly .The validity of theortical results is demonstrated practically.

الخلاصة
للمبدلات الثلاثية الأطوار التي ترتبط للحصول على فولتية تيار مستمر من مصدر تيار متناوب ثلاثي الأطوار تكون معرفة الترتيب والقيمة النسبية لذروة التوافقيات الواطئة أساسية لتصميم المرشح.
تحت تأثير الحالة غير المتوازنة للفولتية ثلاثية الأطوار تتولد توافقيات لم تكن تتولد في حال التوازن للفولتية ثلاثية الأطوار.
تم دراسة تأثير حالة عدم توازن فولتية المصدر على التوافقيات المتولدة في ابتدائي المحولة التي تغذي مبدل دايودي ثلاثي الأطوار سداسي النبضات.

KEY WORDS
Three-phase converters, Harmonics evaluation, Noncharacteristic Harmonics

INTRODUCTION

It is known that harmonics generated into the supply is a major problem associated with three-phase a.c to d.c converters. Rashid and Masood (1988) have shown only theorticaly that noncharaterstic harmonics are generated under unbalanced conditions of a three-phase six-pulse converter. Due to harmonic components of the primary current of the transformer, additional losses can be expected due to increased current density of the main winding and a small increase in core loss due to asymmetrical magnetic cycle.
The paper describes how non characteristic harmonics are produced in a six-pulse uncontrolled rectifier under unbalanced supply conditions by practical investigation. Harmonics generated are recorded and the results are compared with the results of analysis.

NONCHARACTERSTIC HARMONICS DUE TO UNBALANCED SUPPLY VOLTAGE

For a three-phase converter under unbalanced supply conditions, the supply line to neutral voltages are expressed as

$$V_a=E_1 \sin \omega t \tag{1}$$

$$V_b=E_2 \sin (\omega t- (2\pi /3)) \tag{2}$$

$$V_c=E_3 \sin (\omega t+ (2\pi /3)) \tag{3}$$

Fig.(1a) shows the circuit diagram of a three-phase six-pulse uncontrolled converter, the waveforms of line voltages are shown in **Fig.(1b)** under unbalanced conditions and the waveforms of input currents are shown in **Fig.(1c)**. The transfer function with respect to the input port of the converter can be expressed as

$$S_a(\omega t)=S_1(\omega t)- S_4(\omega t) \tag{4}$$

$$S_b(\omega t)=S_3(\omega t)- S_6(\omega t) \tag{5}$$

$$S_c(\omega t)=S_5(\omega t)- S_2(\omega t) \tag{6}$$

The output voltage can be expressed as

$$V_0=V_a\, S_a+V_b\, S_b+V_c\, S_c \tag{7}$$

If the transfer functions is expressed as:

$$S_a(\omega t)= \sum_{n=1}^{\infty} H_{na} \sin (n\omega t- n\alpha) \tag{8}$$

$$S_b(\omega t)= \sum_{n=1}^{\infty} H_{nb} \sin (n\omega t- n\alpha-2n\pi /3) \tag{9}$$

$$S_c(\omega t)= \sum_{n=1}^{\infty} H_{nc} \sin (n\omega t- n\alpha+2n\pi /3) \tag{10}$$

It is observed that the average values S_a ,S_b and S_c are zero when the phase voltages are balanced. However, a mean value for S_a , S_b and S_c will appear when the phase voltages are unbalanced. Substituting eqs(8-10) into eq.(7) yields

$$V_0=\sum_{n=1}^{\infty} H_{na}\, E_1 \sin (n\omega t- n\alpha) \sin n\omega t + H_{nb}\, E_2 \sin (n\omega t- n\alpha -2n\pi /3) \sin (n\omega t -2n\pi /3) +$$

$$H_{nc}\, E_3 \sin (n\omega t- n\alpha +2n\pi /3) \sin (n\omega t+2n\pi /3) \tag{11}$$

Considering the converter to be lossless, the instantaneous input power to the converter equals instantaneous output power of the converter. Thus

$$v_i(\omega t)\, i_i(\omega t)= v_o(\omega t)\, i_o(\omega t)=v_i(\omega t)\, S(\omega t)\, i_o(\omega t)$$

Which gives

$$i_i(\omega t)= S(\omega t)\, i_o(\omega t) \qquad (12)$$

From eq. (12), the output current can be expressed as:

$$i_o(\omega t) =I_{dc}+\sum_{n=1}^{\infty} I_n \sin(n\omega t+B_n)$$

Substituting into eq. (12) yields

$$i_i(\omega t) = \sum_{k=1}^{\infty} H_k \sin(k\omega t+\psi_k)\ ][I_{dc} +\sum_{n=1}^{\infty} I_n \sin(n\omega t+B_n)\ ] \qquad (13)$$

$$= I_{dc} \sum_{k=1}^{\infty} [H_k \sin(k\omega t+\psi_k) +\sum_{k=1}^{\infty}\sum_{n=1}^{\infty} (H_k I_n /2)\ [\cos((n-k)\,\omega t+B_n- \psi_k)-\cos((n+k)\omega t+B_n+ \psi_k)\ ] \qquad (14)$$

From eq. (14) it is observed that the first term gives the m-th harmonic component for k=m, the second and third terms give the m-th harmonic components when

n-k =m i.e n= m+k

n+k =m i.e n= m-k

n-k =-m i.e k= m+n

Taking into account the conditions above, the expression for the m-th harmonic component of the input line current can be written as

$$i_{im}(\omega t)=I_{dc}H_k\sin(k\omega t+\psi_k)+\sum_{k=1}^{\infty} ((H_k I_{m+k})/2)\cos(m\omega t+B_{m+k}- \psi_k)- \sum_{k=1}^{m-1} ((H_k I_{m-k})/2)\cos(m\omega t+B_{m-k}+\psi_k)$$

$$+ \sum_{n=1}^{\infty} ((H_{n+m}\, I_n\ ) /2)\cos[-m\omega t + B_n- \psi_{n+m}]$$

PRACTICAL IMPLEMENTATION

The effect of voltage unbalanced on the harmonics produced in the input current of a transformer feeding an uncontrolled three-phase bridge rectifier is cheked practically. A system consist of a three phase transformer an uncontrolled bridge rectifier and a load is built. The system is tested under balanced and unbalanced voltage conditions. The frequency components of the input currents for the three-phases are measured using a wave analyzer type.

The results of test shows that under unbalanced conditions noncharacteristic harmonics appear due to unbalanced voltage conditions. This demonstrates the validity of analysis results predicted theoretically. The results of analysis are compared with test results.

Fig. (2) shows the practical and theoretical results of the frequency spectrum of input currents of the three phases for balanced conditions.

Fig. (3) shows the frequency spectrum of input currents of the three phases under unbalanced voltage conditions.

CONCLUSION

The effect of three-phase voltage unbalance up on the harmonics produced in the input current of a three-phase uncontrolled bridge converter supplying a d.c load is investigated analytically and practically.

The results show that noncharaterstic harmonics are produced due to voltage unbalance. These harmonics are to be taken into account in the design of the filter at the input terminals of the system.

REFRENCES:

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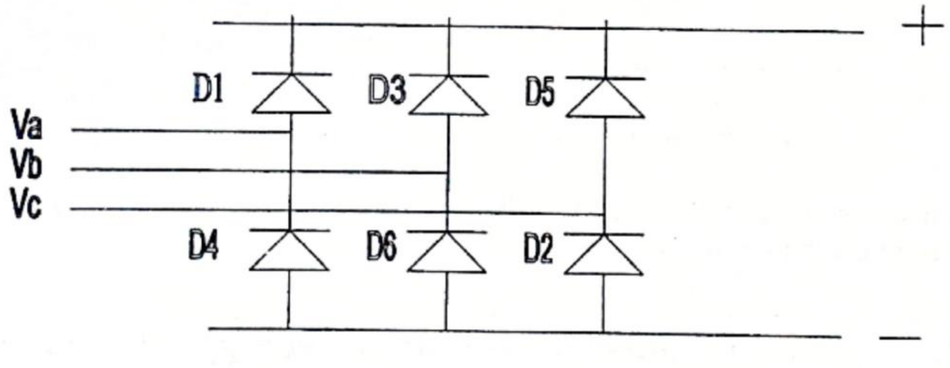
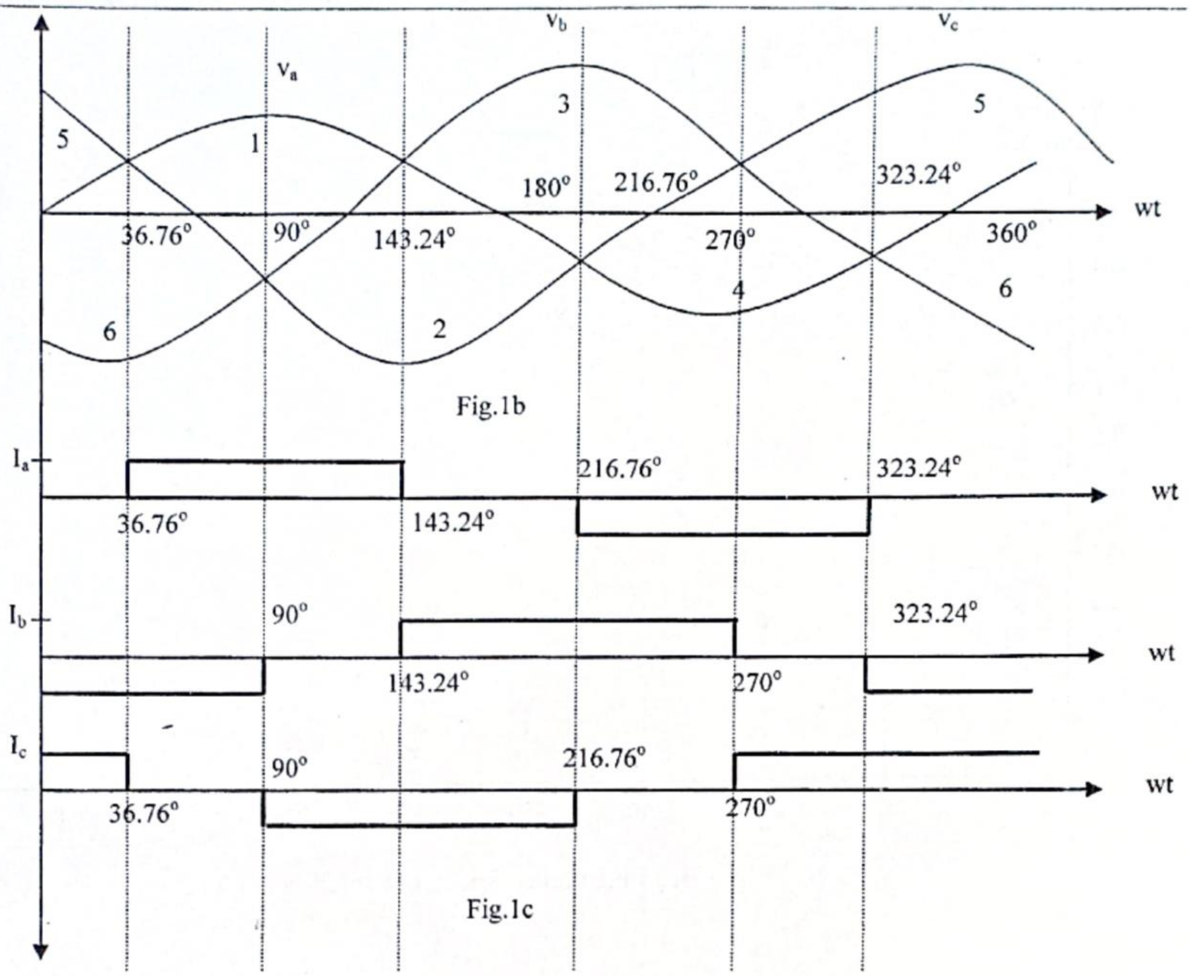


Fig. (1a) Circuit Diagram of 3-ϕ Bridge Rectifier



Input Current of a 3-ϕ Bridge Rectifier Under Unbalanced Condition

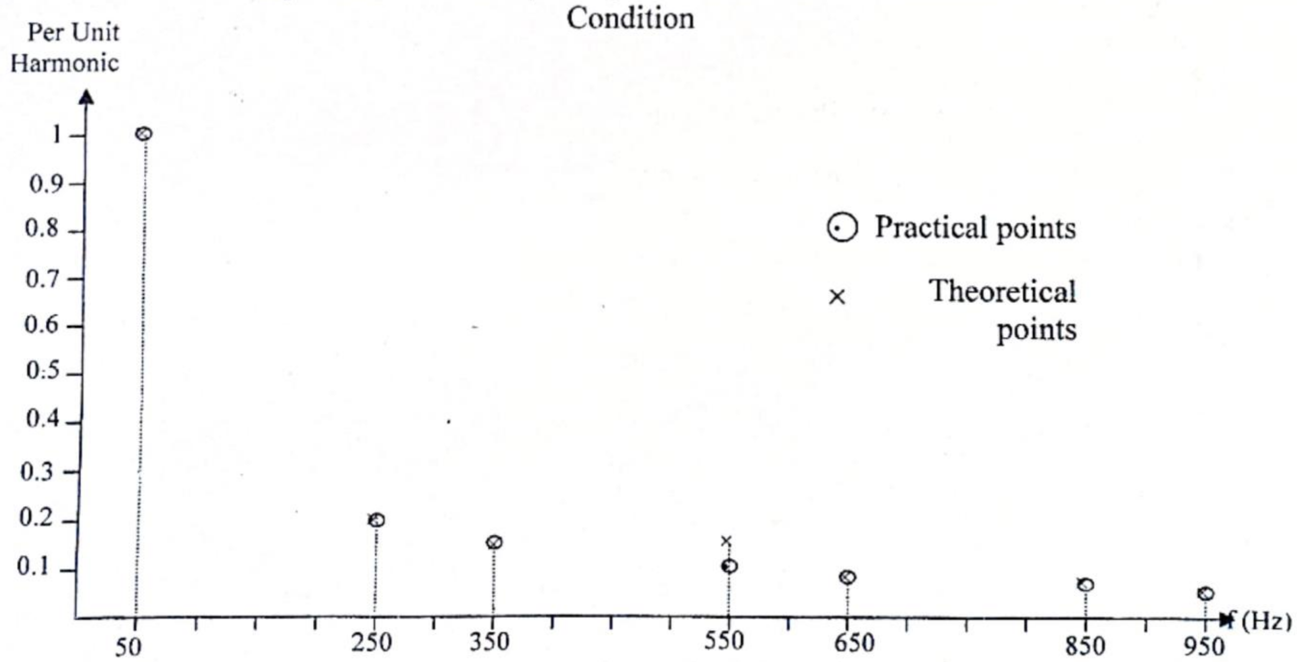


Fig. (2) Frequency Spectrum of Input Current of 3-Phase Bridge Rectifier at the Balanced Condition.

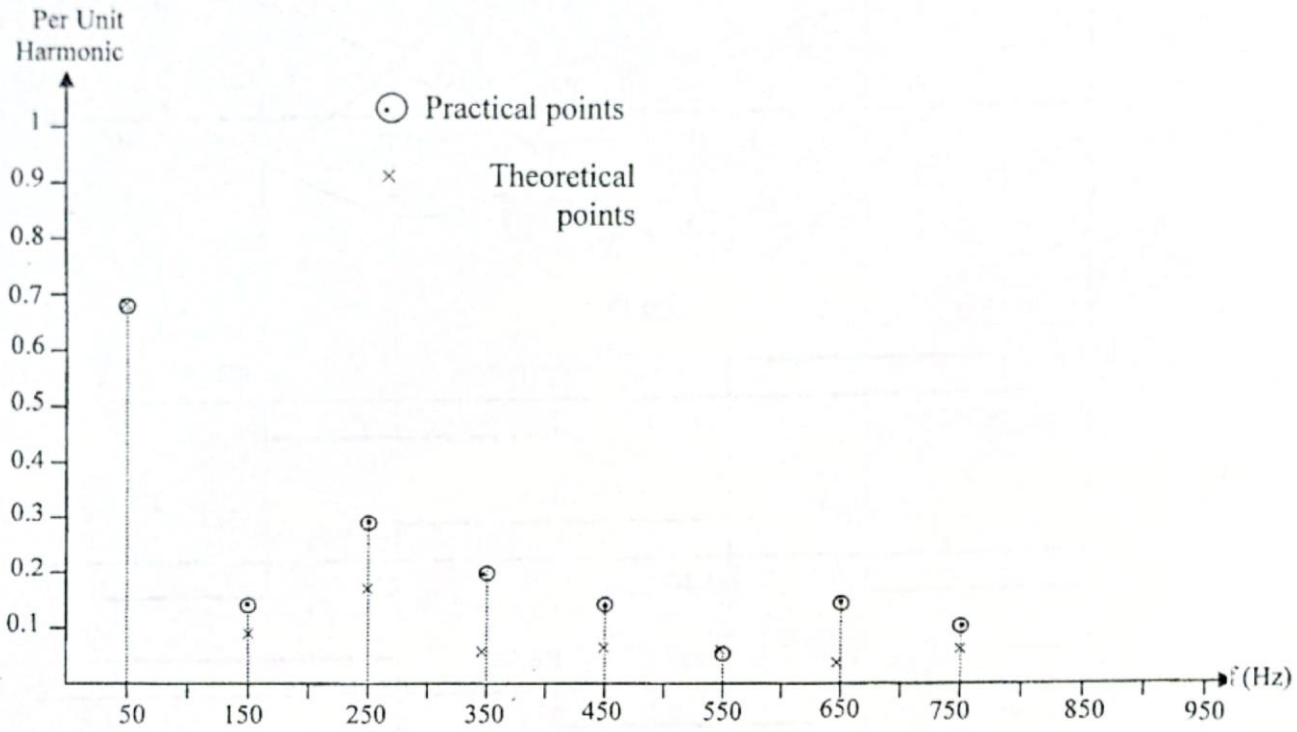


Fig. (3a) Frequency Spectrum for Phase (A) .

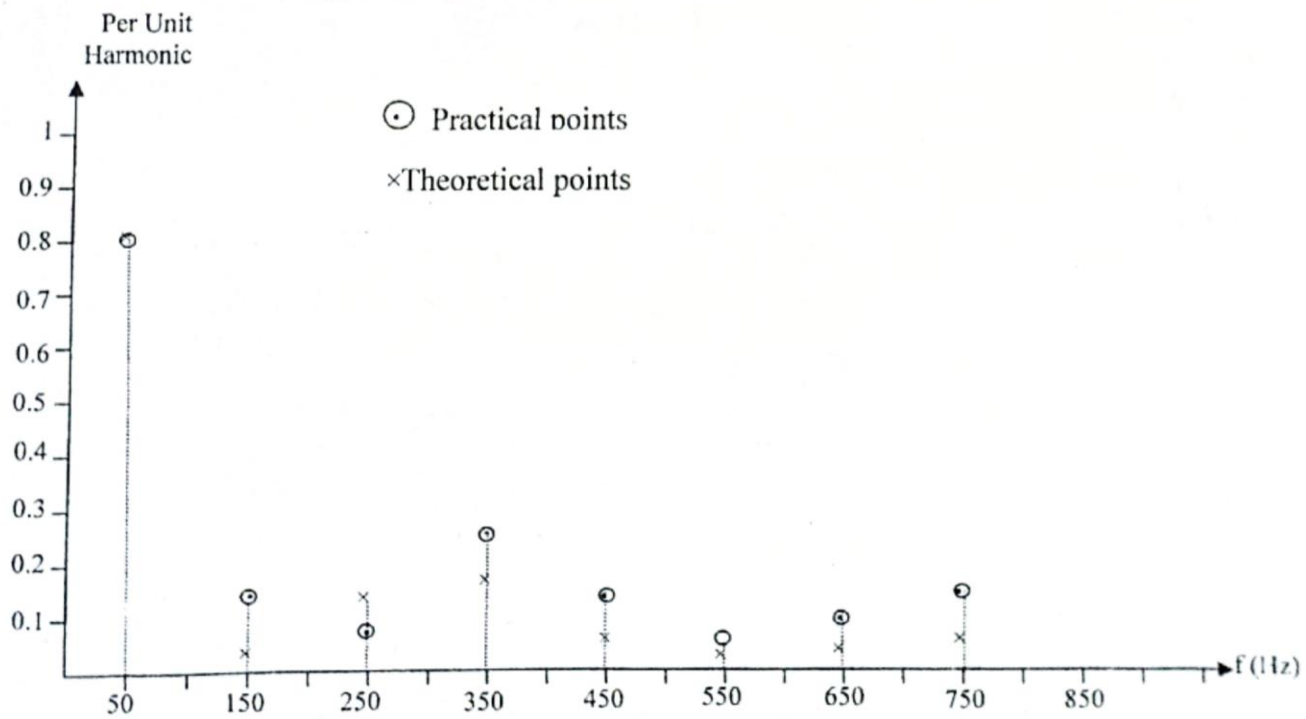


Fig. (3b) Frequency Spectrum for Phase (B) .

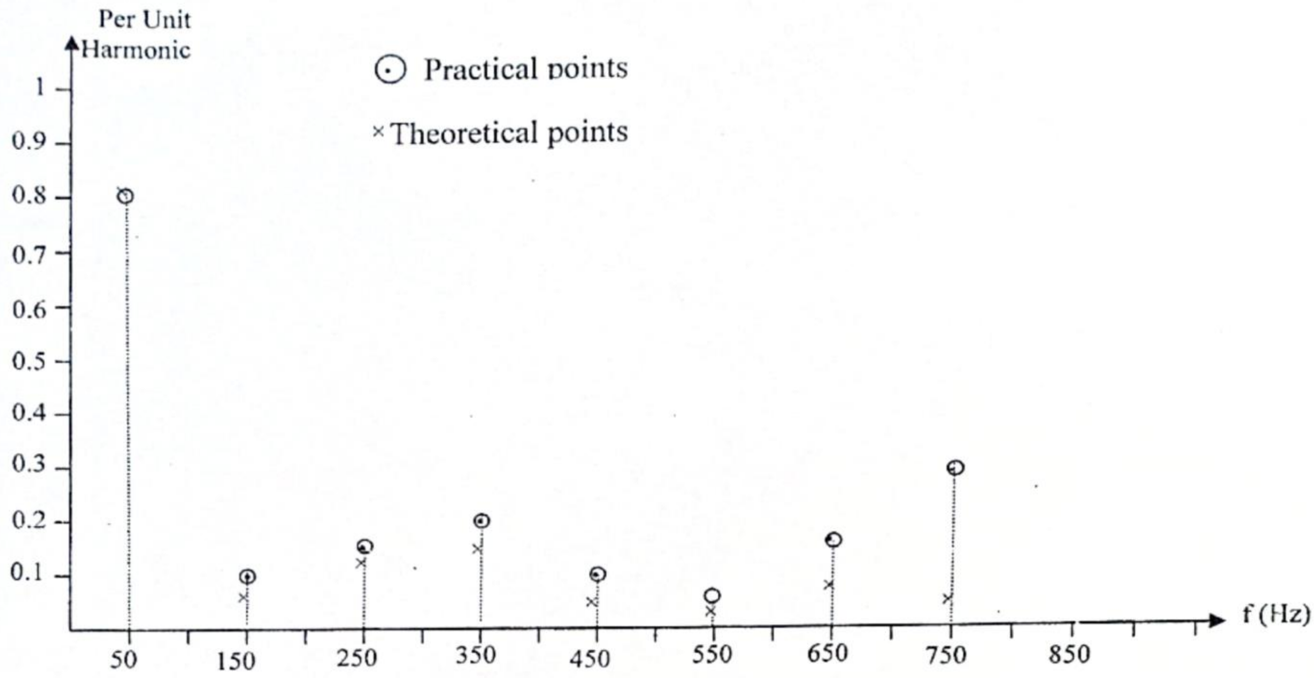


Fig. (3c) Frequency Spectrum for Phase (C) .

Fig. (3) Frequency Spectrum of Input Current at Unbalanced Condition