Mitigation of Total Harmonic Distortion using Delta – Wye Transformer as a Triplen Harmonic Filter in Three Phase Rectifier

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Abstract-

Index Terms- **The 3-phase diode bridge rectifier has the least line current distortion among 6-pulse rectifiers; however, its total harmonic distortion (THD) of 31.08% violates power quality standards. This paper reports distortion reduction by lowering magnitudes of harmonics in the line currents using a delta-wye transformer between the 3-phase utility and the diode bridge rectifier. The leakage inductances of the transformer windings provide a filtering effect on the line current harmonics thus providing THD mitigation of utility line currents. The efficacy of the technique is proved by Power System Computer Aided Design (PSCAD) simulations considering the bridge rectifier with and without the delta-wye transformer of vector group Dy1. Experimental results without and with the Dy1 transformer feeding the diode bridge rectifier are presented.**

I. Introduction

The three phase diode bridge is, perhaps, the most popular of the six-pulse rectifiers and is extensively used, however, with the stringent contemporary power quality standards [1],[2] stipulating specific permissible levels of total harmonic distortion (THD) at the ac utility interface, it is subject to investigation to confirm and verify its compliance with the latest expectation. With the advent of improved power quality ac-dc converters [3] it has becomes imperative to explore techniques to improve the power quality at the ac interface of the three-phase diode bridge rectifier. The topology has been subject to investigation for harmonic reduction [4]-[6] at the ac interface for almost two decades and several new methods [5]-[9] have been suggested including hysteresis current control [7] and current injection [8]. Modification [10] of prevalent techniques too has been advocated. It is well established [11] that the six-pulse diode bridge topology, shown in fig. 1, has a total harmonic distortion (THD) OF 31.08% at the ac interface that is well above the 5% norm as stipulated by IEEE 519-1992. This paper investigates the effect of connecting the six-pulse diode bridge topology to the three-phase ac utility via a delta-wye (Δ-Y) transformer in terms of reducing the magnitudes of the characteristics current harmonics using leakage inductances of the transformer windings as filters, thus mitigating ac utility line current harmonics and improving the THD at the utility.

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II. HARMONICS IN A RECTIFIER

For an ideal p-pulse rectifier, drawing level load current, with no losses, and no overlap, only harmonics of the order

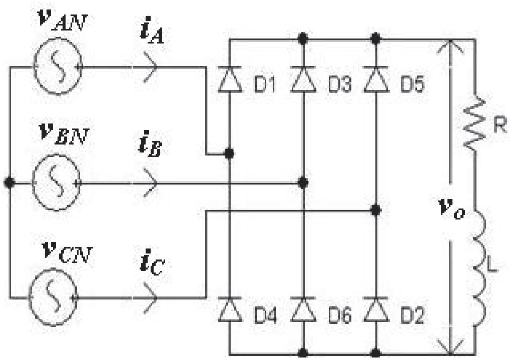


Fig. 1. An ac utility directly connected to a three-phase diode bridge rectifier feeding an inductive load.

$$r = mp \pm 1$$

(Where m =1, 2, 3,etc.) are present in the input current, and they are of magnitude 1/r times the fundamental. The equation shows that the higher the pulse number p, the more harmonics present in the voltage waveform and r the order of the input current harmonic.

The assumption of level load current is often unjustified for the above statements to be true, and it practice, at large firing delays, the harmonic components differ from the simple relationship of 1/r to the fundamental.

A. Triplen Harmonics

In respect to balanced three-phase systems, some general observations can be made. The triplen harmonics, that is, those of order 3m, where m=1, 2, 3, etc., are all in phase with each other at all instants as illustrated by:

$i_{a(3m)} = I \sin 3\omega mt.$

$i_{b(3m)} = I \sin (3\omega mt-2\pi/3)$

$i_{c(3m)} = I \sin (3\omega mt+2\pi/3).$

Hence, $i_{a(3m)} = i_{b(3m)} = i_{c(3m)}$.

This clearly implies that the triplen harmonics are in phase.

In symmetrical component theory the flow of triple-frequency components is similar to a zero-sequence component, with the neutral current being three times that in each line.

B. Positive sequence harmonics

Harmonics of order (3m+1) can be expressed as:

$1_{a(3m+1)} = I\sin[(3m+1)\omega t]$

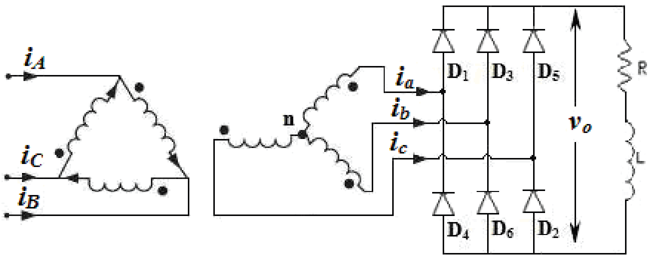


Fig. 2. An ac utility source connected via delta-wye (Dy1) transformer to a three-phase diode bridge rectifier feeding an inductive load.

A harmonics of order (3m + 1) such as seventh (m=2) are of the same sequence as the fundamental.

C. Negative sequence harmonics

A harmonics of order (3m – 1) is at a reversed (negative) Sequence to that of the fundamental. For example, a fifth (m = 2) harmonics will set up a reverse torque component in an induction motor if its input contains such a harmonic.

III. Δ - Y TRANSFORMER AS A HARMONIC FILTER

The delta-wye (Δ-Y) transformation is available with several vector groups including once without and with its neutral terminal on the wye side being accessible. The vector groups Dy1 is considered for investigation and the corresponding topology with the six-pulse diode bridge rectifier is shown in Fid. 2. The neutral on the Wye side is not accessible for this vector group connection. If the wye neutral is not connected to the load, then the absence of the neutral means that there can be no triplen harmonic components in the line currents.

IV. SIMULATION OF SIX PULSE DIODE BRIDGE TOPOLOGIES

The two topologies of the three-phase diode bridge rectifier
Including one wherein the rectifier bridge is directly coupled to the ac utility, as shown in Fig. 1, are simulated for resistive and inductive loading and an estimate of the hatmonic distortion in the line current at the input of the rectifier and at the ac utility is obtained for each configuration.

A. Assumptions

The three-phase ac utility is presumed to be ideal i.e. it has zero impedance and, therefore, lossless apart from being balanced and possessing time invariant frequency of 50 Hz. The phase sequence is assumed to be ABC for all the simulations. The power diodes in the rectifier are also assumed to be ideal from the commutation perspective in that the turn-on and turn-off times are considered to be negligible. The effect of the source and load inductances on the output voltage, V_0 are ignored i.e. the commutation or overlap angle, μ, is presumed to be zero. The effect of reverse recovery time of the diodes on V_0 is also ignored. The simulations pertaining to the topology that employs the delta-wye transformer configuration assumes that the operation of the rectifier is well within the magnetic core saturation limit.

V. SIMULATION RESULTS AND DISCUSSIONS

A)Power Quality for AC Utility Directly Connected to 3-phase Rectifier

1) Rectifier Feeding Resistive Load: In this section the results pertaining to six-pulse diode bridge topology directly connected to the 3-phase ac utility are depicted and discussed. Fig. 3 shows the three line currents at the ac interface that are also the input currents of the rectifier. The dc link voltage and the corresponding load current for a resistive load are shown in Fig. 4. The dc link current and voltage waveforms are in phase, as expected, with a ripple frequency of 300Hz i.e. six times that of the 50Hz ac utility frequency. Between two half pulses, each of width 1.666ms at either end of the 20ms time period corresponding to the 50Hz fundamental frequency of the ac utility, there are five pulses each of 3.333ms thus accounting for the six-pulse dc voltage

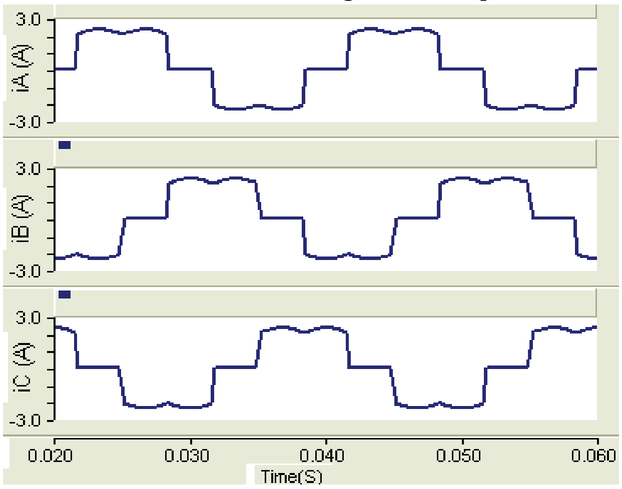


Fig. 3. Line current of ac utility direction connected to a three-phase diode bridge rectifier feeding a resistive load.

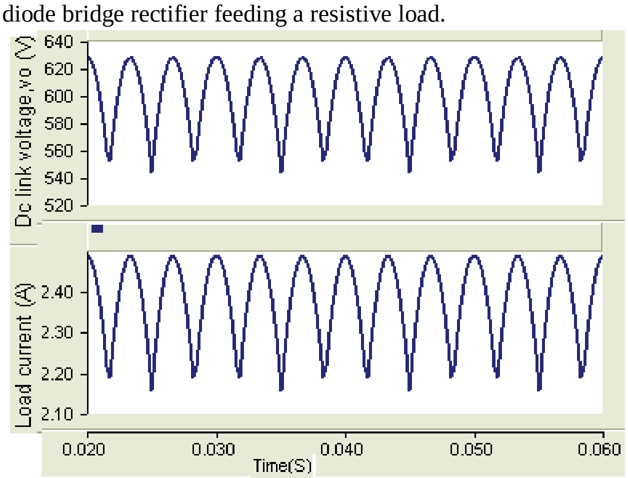


Fig. 4. DC side voltage and current of the 3-phase diode bridge rectifier feeding a resistive load directly connected to ac utility

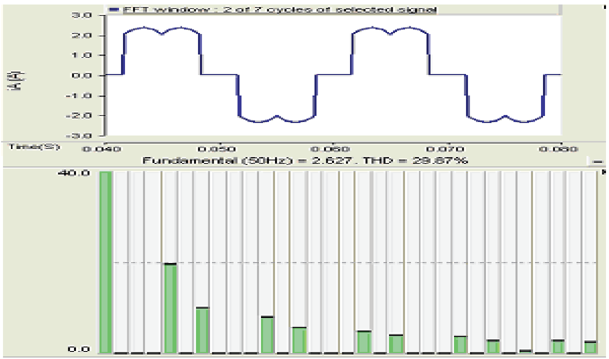
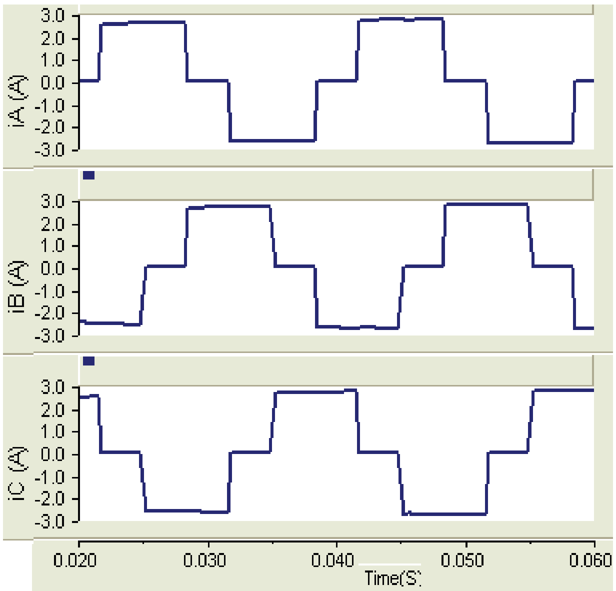


Fig. 5. FFT analysis of the line current, I_a at the ac utility for resistive load.

Voltage output. Fig. 5 depicts the fast fourier transform (FFT)

Of the ac utility line current. Harmonics up to the 20^{th} have been considered. The THD of input current of the rectifier, also the ac utility line current, is 29.87%.

2) *Rectifier Feeding inductive Load:* The waveforms of the line currents of the ac utility directly connected to the six-pulse rectifier feeding an inductive load are shown in Fig. 6.coparision of these waveforms with those pertaining to resistive load in Fig. 3 clearly shows that the currents are flat topped in the former. This is because of the predominance of inductance in the load for waveforms in Fig. 6. The dc link voltage and the associated load current are shown in Fig. 7. The dc link voltage is identical with that for the resistive load shown in Fig. 4. And from the waveforms it is clear that the peak line voltage is root2 times the r.m.s. value of 440V i.e. 622.25V. The load current, however, expectedly differs from that pertaining to the resistive load in that the ripple content is substantially reduced. The THD of the ac utility line current is obtained to be 30.40% and the relevant FFT is shown in Fig. 8. The marginal increase of 0.53% in THD of the line current for this case vis-à-vis the previous case can be attributed to the change in the wave shape of the line currents because of the inductance in the load



Fig, 6. Line current of ac utility directly connected to a three-phase diode bridge rectifier feeding an inductive load.

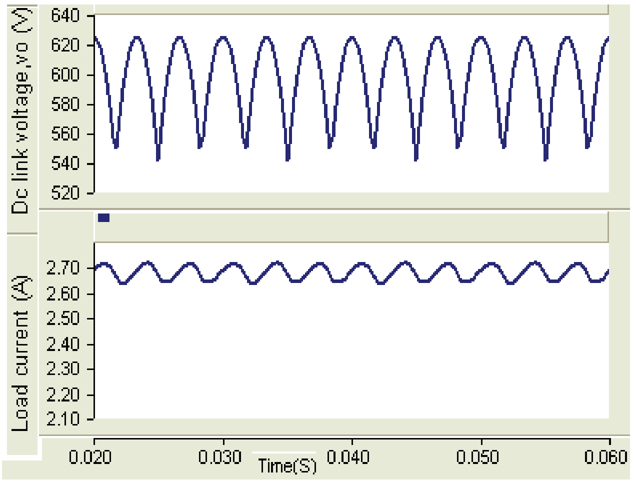


Fig. 7. DC side voltage and current with the ac utility directly connected to a three-phase diode bridge rectifier feeding an inductive load.

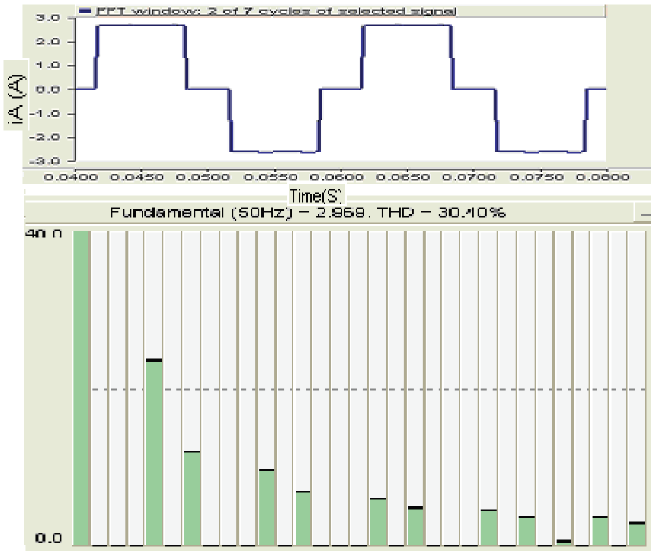


Fig. 8. FFT of the line current, I_a at the ac utility for inductive load.

B. Power Quality for AC Utility Connected via Dy1 Transformer to 3-phase Rectifier

1) *Rectifier Feeding Resistive Load:* Figs. 9 and 10 show the current drawn from the ac utility that are also the primary delta winding line currents and the phase currents in the delta winding respectively. The peak value of the line currents in Fig. 9 is 3.03A while that of the phase currents in Fig. 10 is 1.54A. The secondary wye currents that are also the rectifier input currents shown in Fig. 11, are in phase wih the currents in Fig. 10, and have a peak value of 2.525A that is almost root3 times that of the latter. The line currents on the delta side must theoretically have the same peak value of 2.525A as the wye side since the voltage ratio (of the line voltage) is 1:1, however, the discrepancy of 0.505A (3.03A – 2.525A) is because of the magnetizing current of the transformer. The dc link voltage shown in Fig. 12 comprises six complete pulses for the 20ms time period corresponding to the 50Hz fundamental frequency rather than those obtained without the Dy1 transformer shown in Figs. 4 and 7. The FFT of the ac utility line current is shown in Fig. 13, wherein, it is clear that

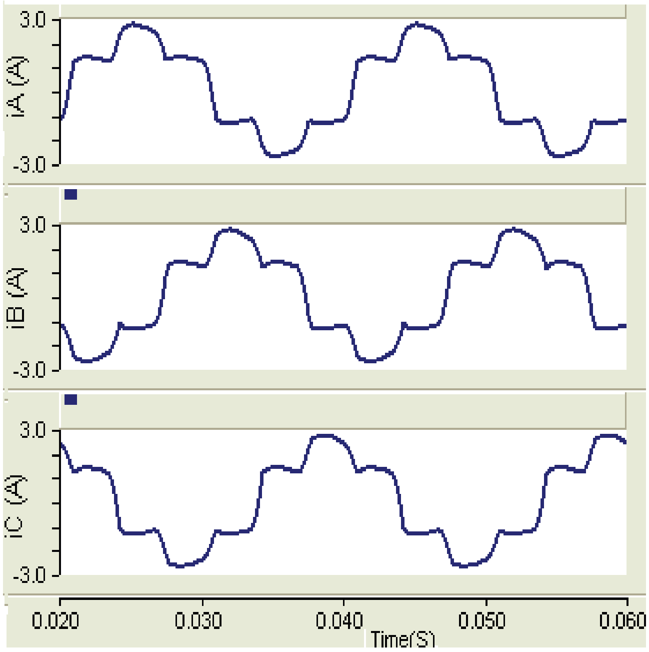


Fig. 9. Line current of an utility connected via delta-wye (Dy1) Transformer to a 3-phase diode bridge rectifier feeding a resistive load.

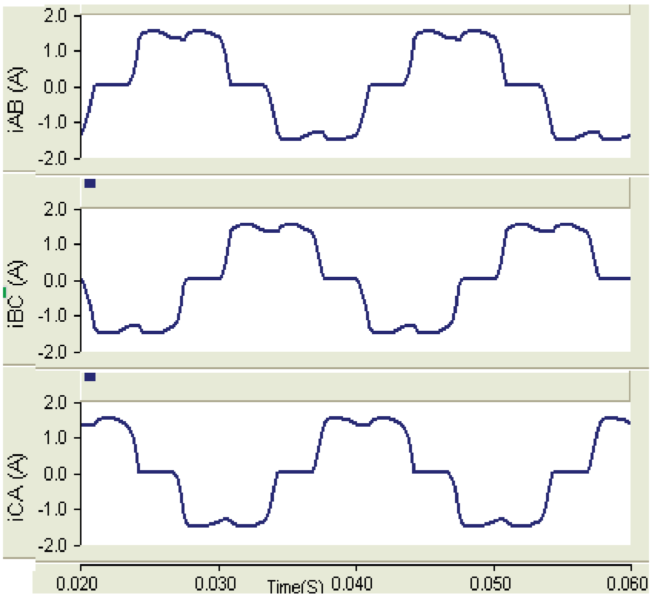


Fig. 10. Phase current of the delta winding of delta-wye (Dy1) transformer coupled to a 3-phase diode bridge rectifier feeding a resistive load.

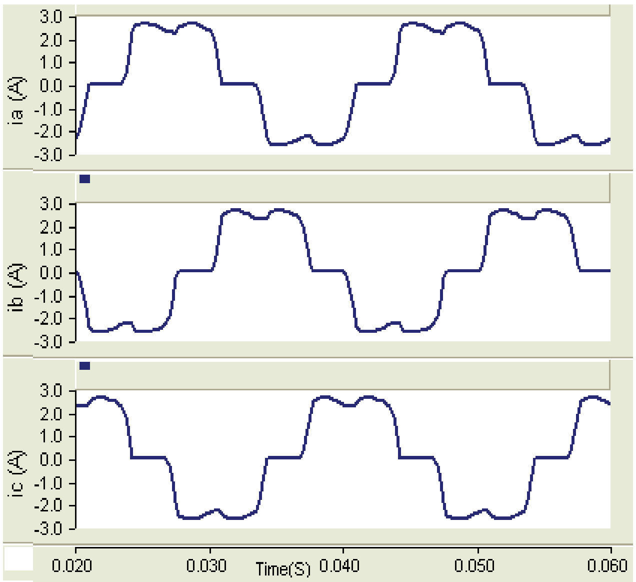


Fig. 11 Input current of a 3-phase diode bridge rectifier, feeding a resistive load, coupled to an ac utility via delta-wye (Dy1) transformer.

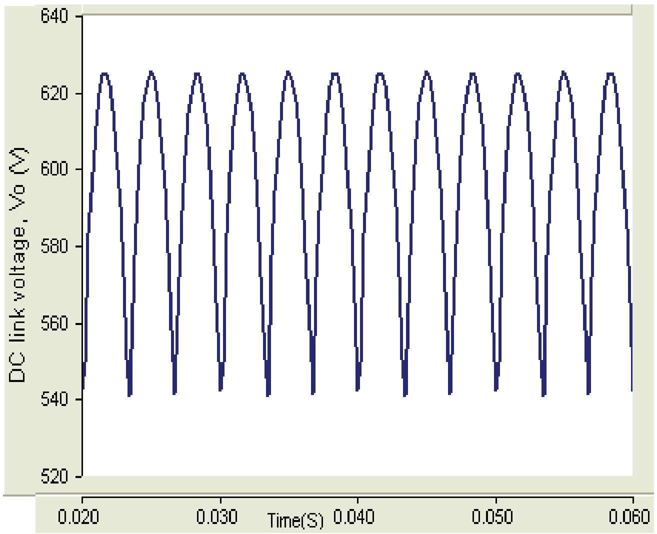


Fig. 12. DC link voltage of a three-phase diode bridge rectifier, feeding a resistive load, coupled to an ac utility via delta-wye (Dy1) transformer.

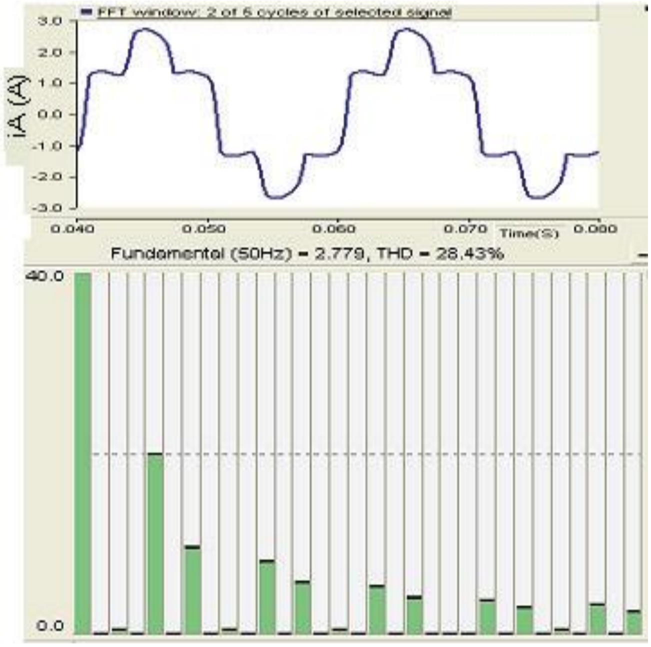


Fig. 13. FFT analysis of the line current, I_a, at the ac utility connected via Dy1 transformer to a 3-phase diode bridge rectifier feeding a resistive load.

a THD value of 28.43% is obtained that is an improvement of 1.44% over the 29.87% value for resistive load without the Dy1 transformer .

2)*Rectifier Feeding Inductive Load:* The waveforms of the line and phase currents on the Δ-connected primary winding, line currents on the Y-connected winding and dc link voltage for the topology shown in Fig. 2 are similar to those shown for the same topology feeding a resistive load except that the currents are flat topped. The line currents on the Δ-side and the corresponding FFT indicating a THD of 28.69% are shown in Figs. 14 and 15 respectively.

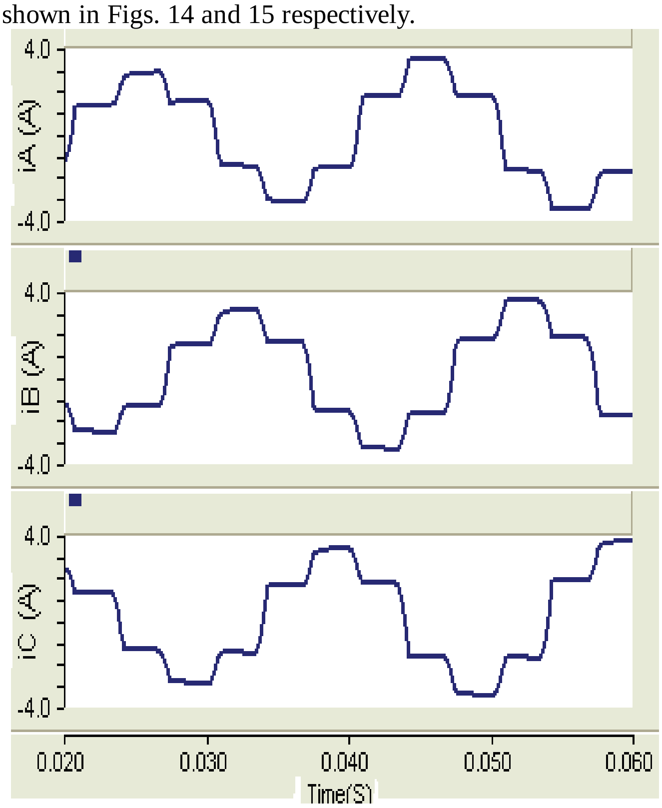


Fig. 14. Line currents of ac utility connected via delta-wye (Dy1) transformer to a three-phase diode bridge rectifier feeding an inductive load.

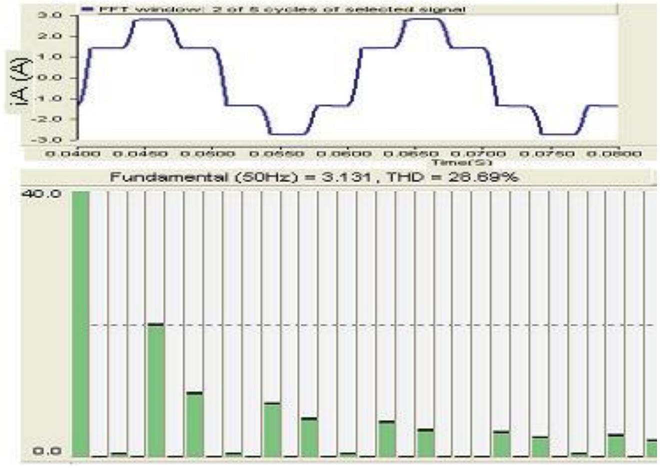


Fig. 15. FFT of the line current, i_a, at the ac utility connected via Dy1 transformer to a 3-phase diode bridge rectifier feeding an inductive load.

The efficacy of the delta-wye transformer as a harmonic filter for line current mitigation of a 6-pulse diode bridge rectifier, based on MATLAB simulations, has already Been reported [12]. This paper has successfully validated the current harmonic filtering effect of the leakage inductances of delta-wye transformer windings for the same rectifier topology using the PSCAD software based simulations. Modern power systems are required to be smart. Smartness need not necessarily mean use of sophisticated control and hardware including sensors etc. Conventional equipment used judiciously also can effectively aid in maintaining contemporary power quality requirements.

VI. Conclusion

The harmonics content in the line current of the generic six-pulse diode bridge topology are much higher than modern power quality stipulations, however, its connection to the ac utility via a delta-wye transformer results in an improved current profile at the harmonic filtering provided by the leakage inductances of the transformer windings.

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