HARMONIC MITIGATION OF 12-PULSE DRIVES WITH UNBALANCED INPUT LINE VOLTAGES

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ABSTRACT

Twelve-pulse drives are frequently specified by consulting engineers for heating, ventilating and air conditioning applications because of their theoretical ability to reduce harmonic current distortion, but very little information has been published showing how twelve-pulse drives perform under actual operating conditions with unbalanced input line voltages. This paper presents test data which demonstrate that twelve-pulse drives do not achieve the level of harmonic mitigation most engineers expect and that these drives may not meet the requirements of IEEE-519 under practical operating conditions. The actual performance of twelve-pulse and six-pulse drives is compared to the performance of a six-pulse drive fed by a Matrix Harmonic Filter. The Matrix Harmonic Filter provides superior harmonic mitigation at lower cost.

In the mid 1960s when power semiconductors were only available in limited ratings, twelve-pulse drives provided a simpler and more cost effective approach to achieving higher current ratings than direct paralleling of power semiconductors. This technique is still employed today in very large drive applications. A typical diagram of a large twelve-pulse drive appears in figure 1. The drive’s input circuit consists of two six-pulse rectifiers, displaced by 30 electrical degrees, operating in parallel. The 30-degree phase shift is obtained by using a phase shifting transformer. The circuit in figure 1 simply uses an isolation transformer with a delta primary, a delta connected secondary, and a second wye connected secondary to obtain the necessary phase shift. Because the instantaneous outputs of each rectifier are not equal, an interphase reactor is used to support the difference in instantaneous rectifier output voltages and permit each rectifier to operate independently. The primary current in the transformer is the sum of each six-pulse rectifier or a twelve-pulse wave form.

Theoretical input current harmonics for rectifier circuits are a function of pulse number and can be expressed as:

$h = (np \pm 1)$ where $n = 1, 2, 3, \ldots$ and p = pulse number

For a six-pulse rectifier, the input current will have harmonic components at the following multiples of the fundamental frequency.

5, 7, 11, 13, 17, 19, 23, 25, 29, 31, etc.

For the twelve-pulse system shown in figure 1, the input current will have theoretical harmonic components at the following multiples of the fundamental frequency:

11, 13, 23, 25, 35, 37, etc.

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Note that the 5th and 7th harmonics are absent in the twelve-pulse system. Since the magnitude of each harmonic is proportional to the reciprocal of the harmonic number, the twelve-pulse system has a lower theoretical harmonic current distortion.

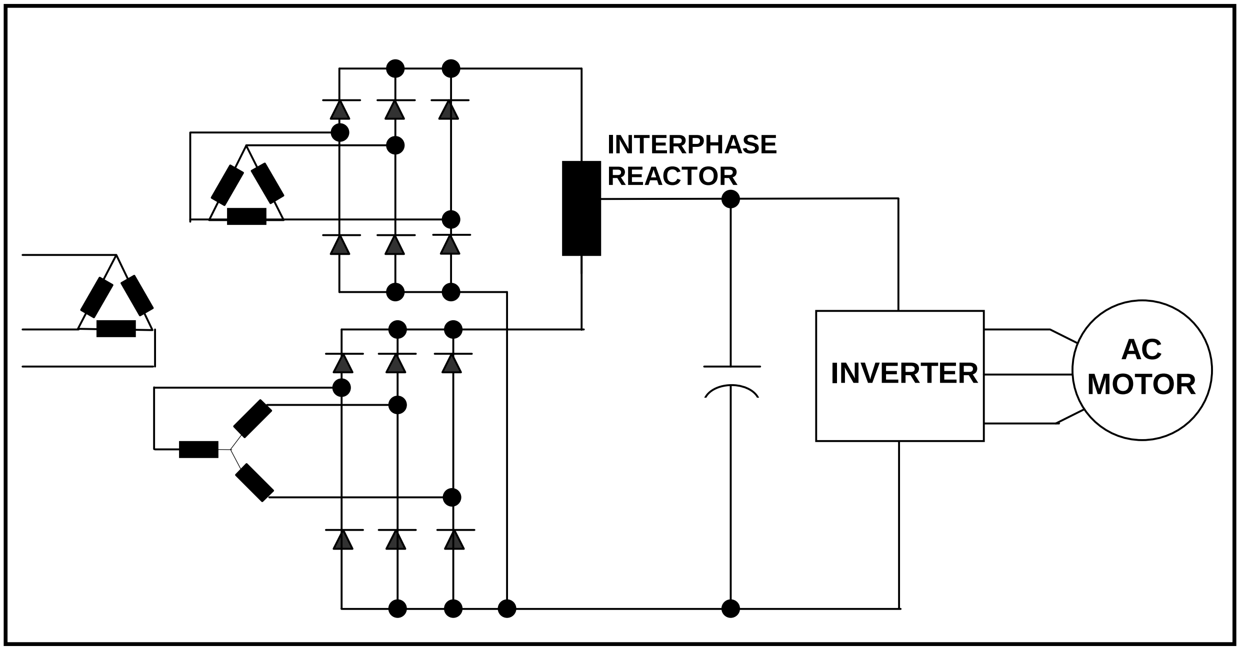

Figure 1

The problem with the circuit shown in figure 1 is that the two rectifiers must share current exactly to achieve the theoretical reduction in harmonics. This requires that the output voltage of both transformer secondary windings match exactly. Because of differences in the transformer secondary impedances and open circuit output voltages, this can be practically accomplished for a given load (typically rated load) but not over a range in loads. This is a very significant problem of the parallel twelve-pulse configuration.

A twelve-pulse system can also be constructed from two six-pulse rectifiers connected in series. In this configuration, two six-pulse rectifiers, each generating one half of the DC link voltage, are series connected. Refer to figure 2. In this connection, problems associated with current sharing are avoided and an interphase reactor is not required. For applications where harmonics rather than high current ratings are the issue, this solution is much simpler to implement than the parallel connection.

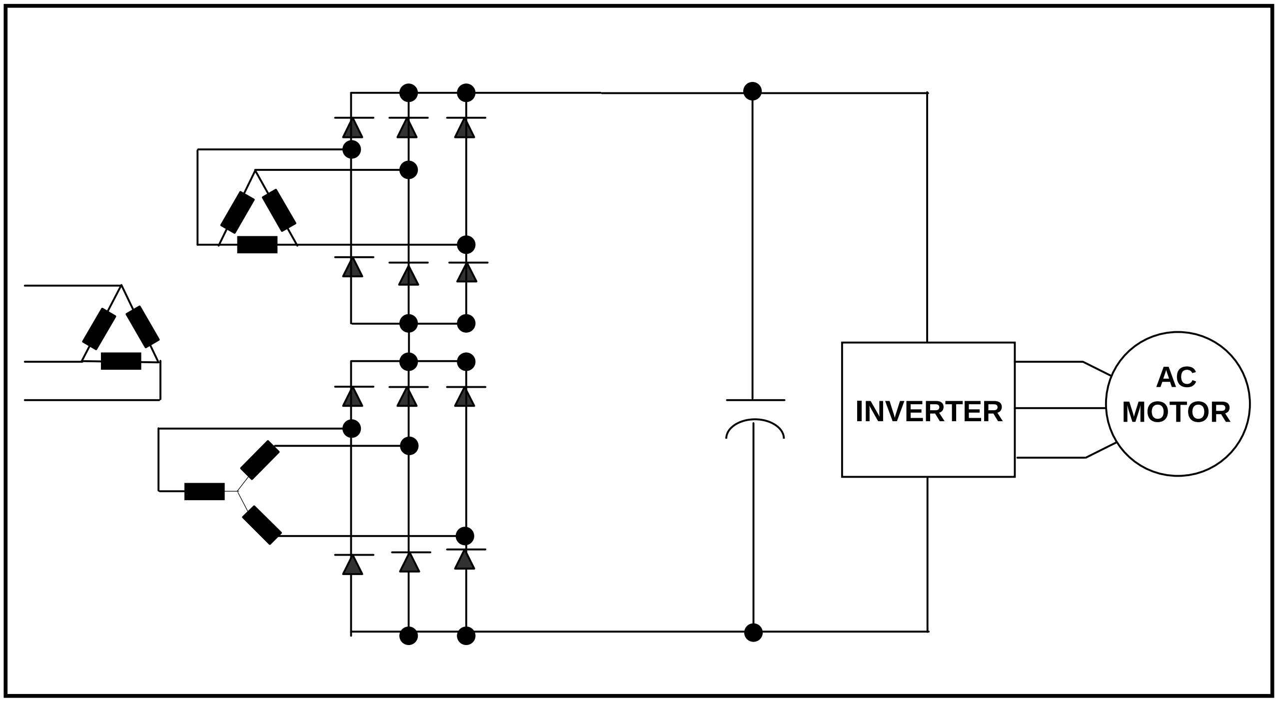

Figure 2

Using the series rectifier connection, it is very easy to construct a twelve-pulse drive from a standard six-pulse drive if the six-pulse drive has its DC bus terminals available or permits access to one side of the DC bus. Many standard AC drives provide terminals in the DC bus to accommodate an external DC link choke. These same terminals can be used to add an external rectifier converting the drive to twelve-pulse operation. Refer to figure 3. In this case there is no need for extra circuitry to control inrush current for the second rectifier. The net result is a system solution well within the means of many system integrators.

There are many fine textbooks and articles in which rectifier circuits are examined and analyzed in detail. However, most of the analysis is performed under the assumption of balanced three-phase line voltages. Our practical experience suggests that this assumption is not valid for many industrial and commercial power systems, particularly systems with nonlinear loads. As we traveled around the United States working primarily with drive applications, our impression was that most power systems were operating with 1% to 3% unbalance at the point of utilization.

ANSI C84.1 – 1995 defines percent voltage unbalance as:

$$\frac{100 \text{ X (max. deviation from average voltage)}}{\text{(Average Voltage)}}$$

This same standard also reports that based on field surveys, 98% of power systems are within 0 - 3.0% voltage unbalance range and 66% are within 0 - 1.0% unbalance at the point of common coupling. The standard recommends that electric supply systems be designed and operated to the limit of a maximum voltage unbalance to 3% when measured at the electric utility revenue meter under no-load conditions. Load unbalance within the building power distribution system adds to the utility unbalance at the point of utilization.

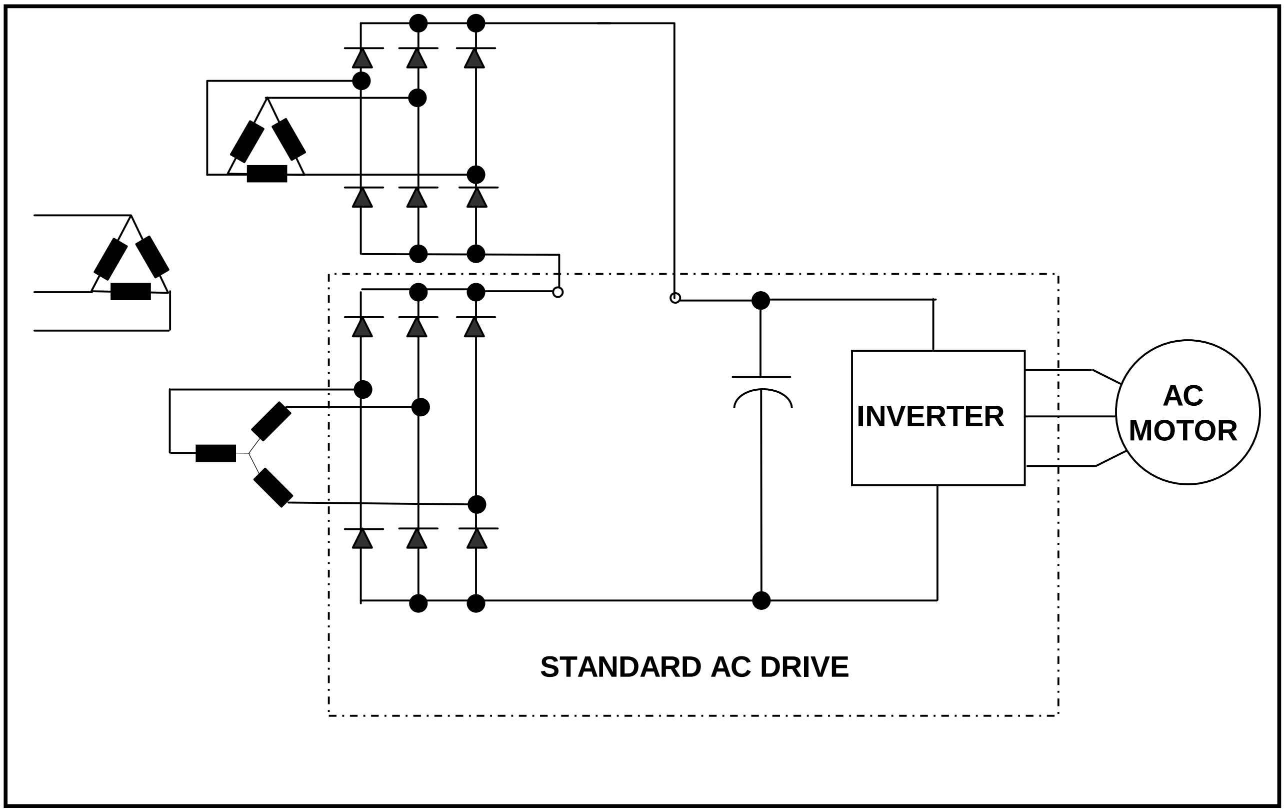

Figure 3

To determine how a twelve-pulse drive system operates under unbalanced line voltage conditions, we constructed a 30 HP twelve-pulse drive from a standard delta delta-wye isolation transformer and standard six-pulse drive using the series bridge connection shown in figure 3. An auto transformer could have been used in place of the isolation transformer. The auto transformer costs less and requires less mounting space, but the isolation transformer was selected because it provides better performance and is readily available from stock. The system was tested with line voltage unbalance ranging from 0% to 3% and with loads ranging from 5% to 110%. The input total harmonic current distortion, THID, is shown in figure 4. THID varied from 12% at full load with balanced line voltages to 65% at 17% load with a 3% unbalance. The data show that the harmonic performance of twelve-pulse drives degrades rapidly with increasing line voltage unbalance. Many users expect that THID should not exceed specified limits from no load to full load. The graph reveals that THID in twelve-pulse drives is very much a function of load. Good performance also requires balanced line voltages.

To determine how a six-pulse drive system operates under unbalanced line voltage conditions, we tested a 30 HP drive with a 5% line reactor operating from a power source with a 1% impedance. This system was tested with line voltage unbalance ranging from 0% to 3% and with loads ranging from 5% to 110%. The total harmonic current distortion, THID, is shown in figure 5. THID varied from 29% at full load with balanced line voltage to 95% at 5% load with a 3% line voltage unbalance. The harmonic performance of the twelve-pulse drive is significantly superior to a six-pulse drive under all conditions of line unbalance.

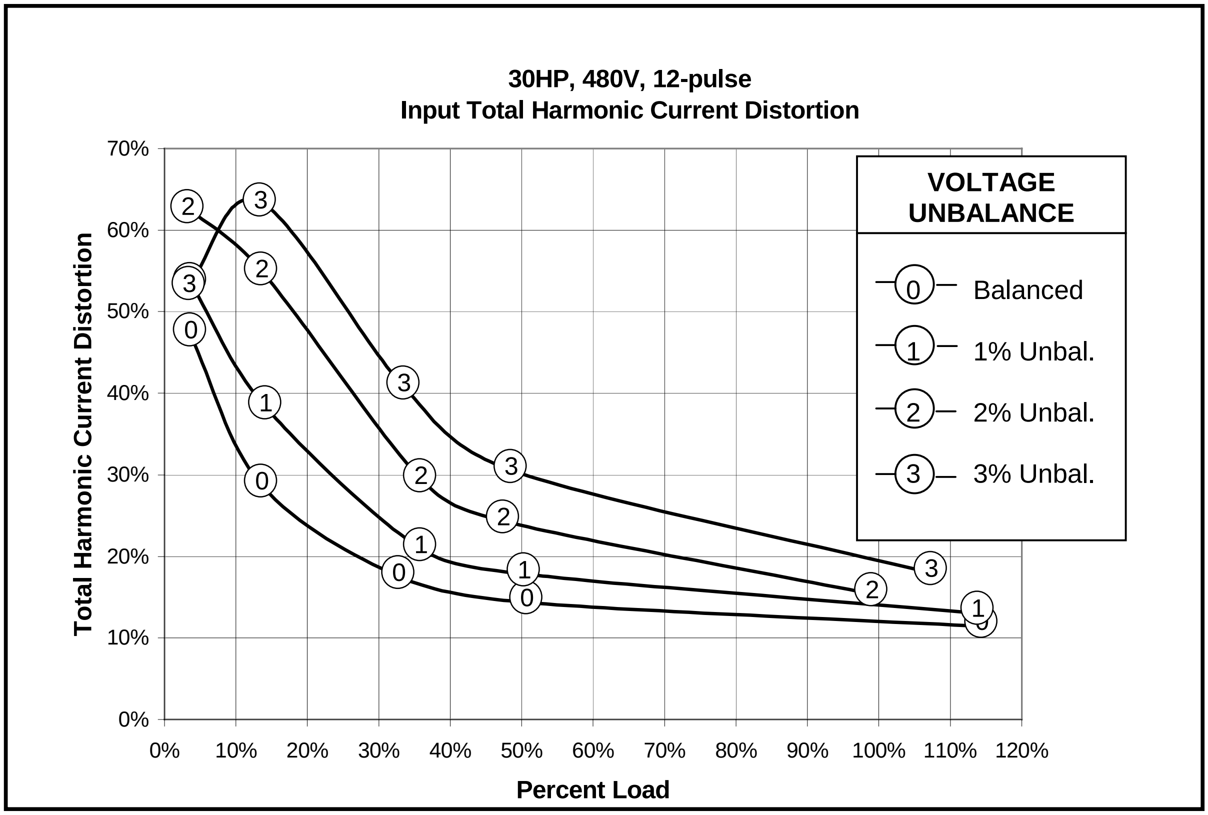

Figure 4

It is interesting to compare the performance of the twelve-pulse drive with a standard six-pulse drive fitted with an MTE Matrix Harmonic Filter under similar conditions of unbalanced line voltages. The Matrix Harmonic Filter is a type of low pass harmonic filter designed to work with standard six-pulse drives. A Matrix Harmonic Filter was tested feeding a 30 HP six-pulse drive. This system was tested with line voltage unbalance ranging from 0% to 3% and with loads ranging from 5% to 110%. The input total harmonic current distortion, THID, is shown in figure 6. THID varied from 4.7% at full load with balanced line voltage to 9% at 25% load with a 3% line voltage unbalance. The low pass filter provides better harmonic performance than the twelve-pulse system throughout the load range and is significantly less sensitive to voltage unbalance. At 25% load with a 1% line voltage unbalance, the twelve-pulse drive has an input total harmonic current distortion of 29% while the six-pulse drive fed from a low pass Matrix Harmonic Filter has a THID of 7% under the same operating conditions.

Conclusion

Drives are applied in heating, ventilating, and air conditioning applications because loads are variable and users demand energy efficiency and comfort. Varying loads result in load unbalances within building power distribution systems which add to the utility line voltage unbalance at the point of common coupling. Harmonic mitigation techniques which are not effective with line voltage unbalances of 1% to 3% at the point of utilization will not as a practical matter achieve useful results. The data in this report show that a standard six-pulse drive fed from a low pass Matrix Filter provides superior harmonic performance to a twelve-pulse drive in applications with variable loads and line voltage unbalances ranging from 0% to 3%.

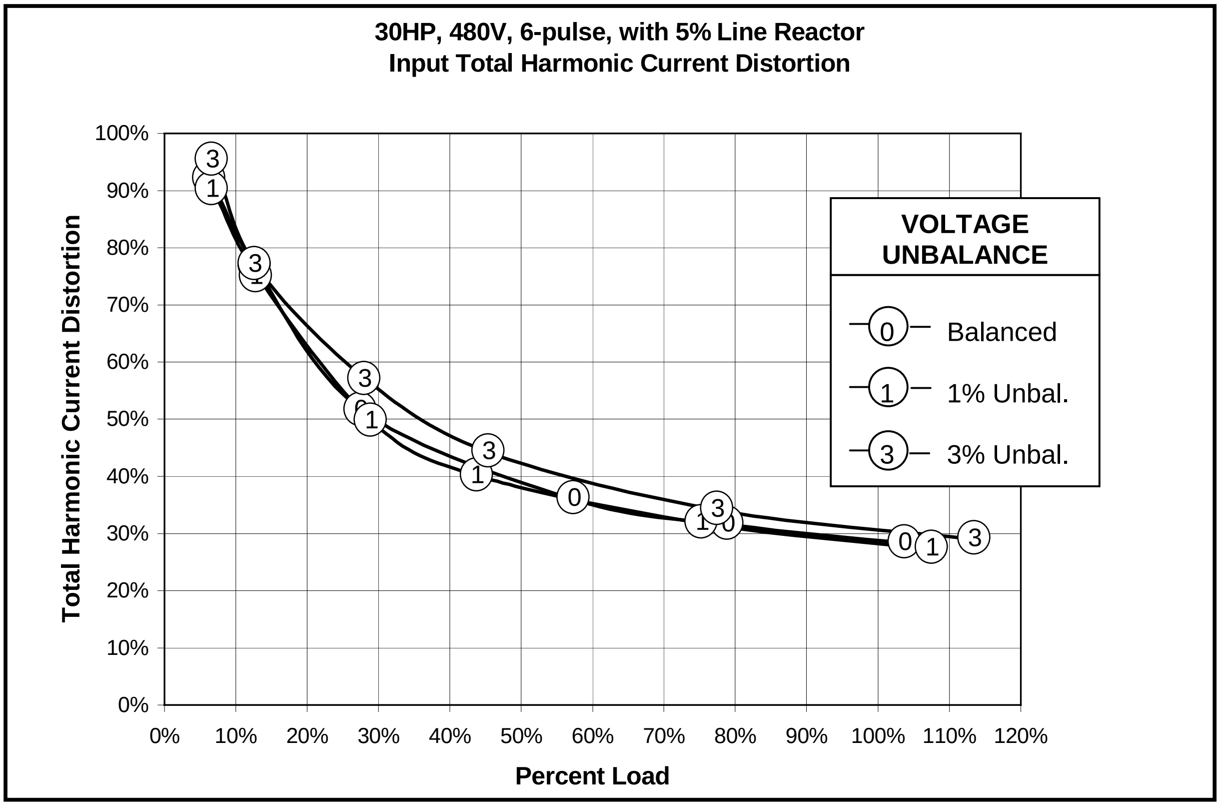

Figure 5

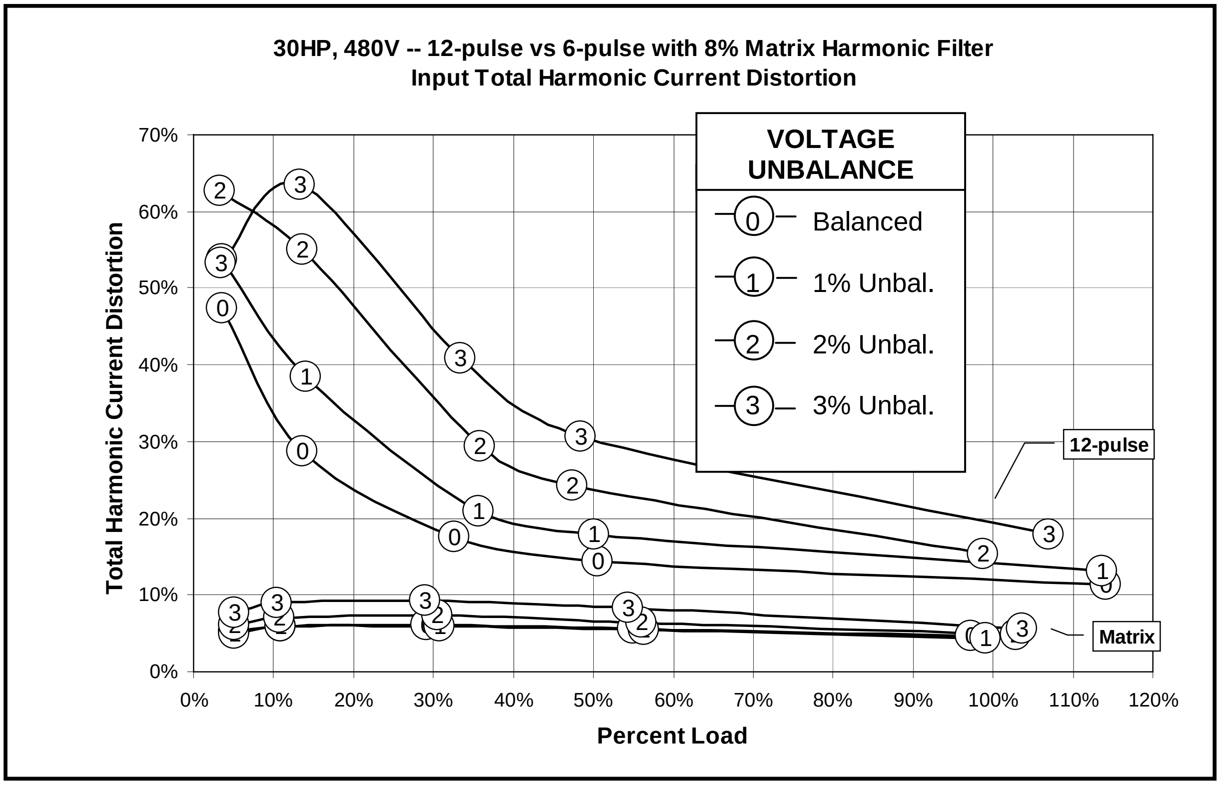

Figure 6