Managing Harmonic Distortion with Quasi 12-pulse

■ Conventional Reduction Techniques

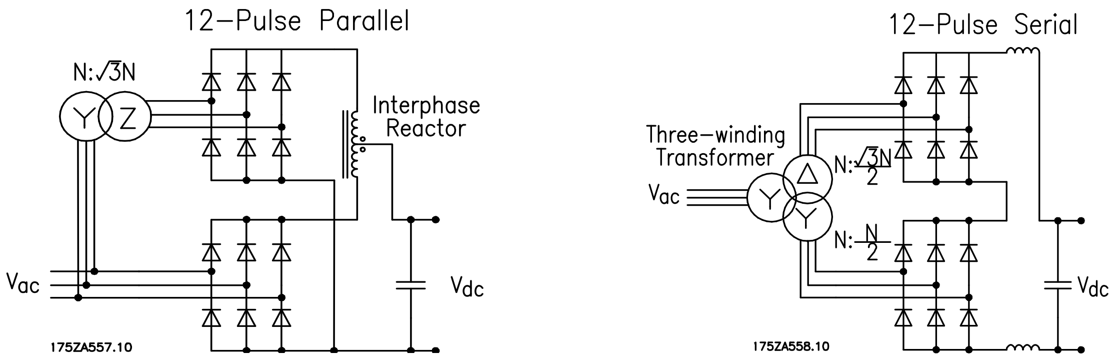
For many years, the most commonly used method for reducing harmonic distortion caused by Variable Frequency Drives in electrical systems has been to add AC line reactors at the drives' input terminals. This reduces the harmonic distortion to a level which will be sufficient in most installations. There is however a practical limit to the size of the reactors which can be installed and therefore also to the possible reduction in harmonics which can be obtained by using this technique.

The reason is that the drives' ability to supply full output torque is reduced as a result of voltage drop across the reactors. The only way to compensate for this is to increase the current supplied to the motor. This means that the motors must be able to manage higher currents at the same torque requirement. Larger drives may also be required. However, this causes a waste of resources as a result of increased generation of heat. This must be considered when dimensioning the system in order to avoid overheating.

Another well-known technique is to implement DC reactors in the intermediate circuit. This is however not very practical if large reactors are needed, since these reactors would produce a lot of heat in the drives and reduce the drives' efficiency.

In order to avoid the unfortunate side effects of AC or DC reactors in installations where high requirements to the reduction of harmonic distortion exist, it has become the norm in certain markets to utilise 12 pulse drives. These drives consist of two 6 pulse rectifiers and either a phase shifting transformer in front of one of the rectifiers or a three winding transformer in front of the combined rectifier. See Figure 1 for schematic.

Figure 1: 12 Pulse Drives with Rectifiers in Parallel and in Series



This design provides excellent harmonic performance. The 5th and 7th harmonic currents are cancelled almost completely. The two rectifiers and either a phase shifting transformer and an interface reactor (left solution in Figure 1) or a three winding transformer (right solution in Figure 1) makes this solution at least 50% more expensive than a standard drive with built-in DC reactors. Therefore a more wide spread use of it would mean a drastic increase in the cost per drive installed.

■ The alternative solution

An alternative solution would be to use phase shifting transformers in front of 50% of the drive load and then leave the other drives connected to the normal mains.

The cost of this solution is only about 16% higher than the cost of a standard Danfoss VLT frequency converter. Since a transformer is only required on every second drive, the total impact on the frequency converter cost is reduced to 8%. This is, however, compared to a standard solution without any additional harmonic filtering.

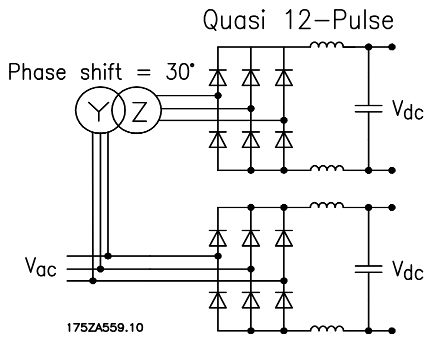
When considering this type of harmonic filtering, a comparison with a solution where a 5% AC line reactor is used would be more realistic. This will not nearly give the performance of the quasi 12 pulse, but it is the largest AC line reactor which can be recommended installed in front of a Danfoss VLT Frequency Converter. A 5% AC line reactor will increase the drive cost by approx. 2%. This means that the actual additional cost to a project would come to approx. 6%.

The argument against this solution compared to a "true" 12-pulse solution is that the balance of the load is important to the performance, because the improved performance is a result of the cancellation of the 5th and 7th harmonic current due to the 30° phase shift.

When the load is not balanced, the harmonics on the drives with high load are not cancelled. This is because the whole basis for the cancellation is that the current vectors are of equal amplitude and that the angle between them is 180°. The angle is maintained by the phase shifting transformer, but the amplitude varies as the load decreases. When the load only decreases on one of the drives, the length of the vectors becomes unequal and full cancellation is not achieved.

Figure 2 shows the system configuration for an installation using quasi 12-pulse. Please notice that standard 6 pulse frequency converters are used and that the estimated load on each drive group should be as close to equal as possible to achieve the best effect. See the following sections to get a general impression of the performance of quasi 12 pulse on the 2 drive groups.

Figure 2: System Configuration for Quasi 12 Pulse



■ Simulation of the Effects of Varying Load

The research at Danfoss Drives into the significance of load variations has revealed that there is a significant advantage to be obtained by using quasi 12 Pulse as long as all drives are above 20% load. Whether or not the load is the same is less important.

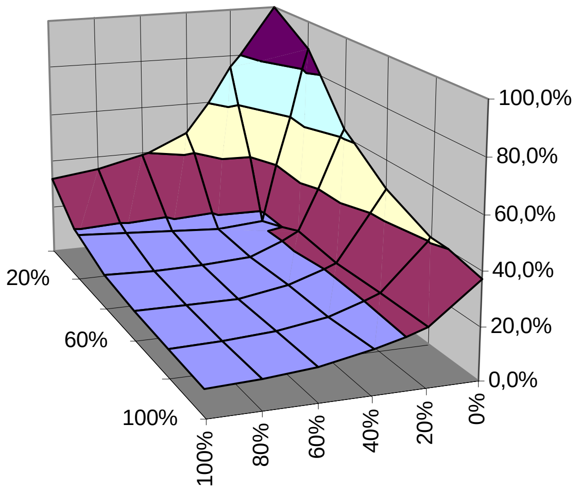
Table 1 and Figure 3 on the following page show the results of a simulation of the Total Harmonic Current Distortion (THCD) as a function of the load on two drive groups.

Table 1: Total Harmonic Current Distortion as a Function of Varying Load

Drive group 1 (columns); Drive group 2 (rows)

Load	100%	80%	60%	40%	20%	0%
100%	10.7%	11.6%	13.4%	16.7%	22.3%	37.4%
80%	10.6%	11.1%	12.4%	15.5%	21.8%	41.3%
60%	11.7%	11.5%	12.1%	14.8%	21.9%	48.6%
40%	13.9%	13.2%	13.0%	14.8%	22.8%	63.6%
20%	18.4%	17.5%	16.1%	14.7%	16.6%	88.5%
0%	32.2%	34.7%	38.9%	47.0%	74.5%	(100.0%)

Figure 3: Total Harmonic Current Distortion as a Function of Varying Load



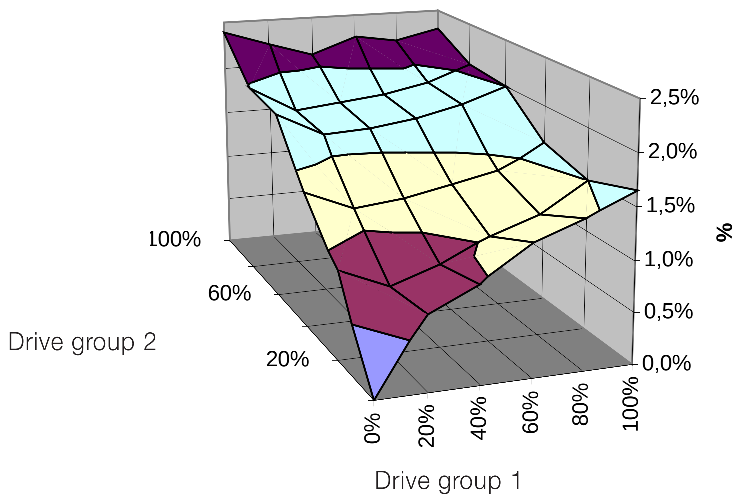
The impact on the Total Harmonic Voltage Distortion (THVD) in the system was also simulated under the same conditions and the results are shown below in Table 2 and Figure 4.

Table 2: Total Harmonic Voltage Distortion as a Function of Varying Load

Drive group 1 (columns); Drive group 2 (rows)

Load	100%	80%	60%	40%	20%	0%
100%	2.3%	2.2%	2.3%	2.1%	2.2%	2.4%
80%	2.1%	1.9%	1.8%	1.7%	1.7%	2.0%
60%	2.0%	1.8%	1.8%	1.7%	1.7%	1.9%
40%	1.6%	1.4%	1.3%	1.2%	1.1%	1.4%
20%	1.5%	1.2%	1.1%	0.8%	0.7%	0.9%
0%	1.7%	1.4%	1.3%	1.0%	0.7%	0.0%

Figure 4: Total Harmonic Voltage Distortion as a Function of Varying Load



Comments to the Simulation Results

Table 2 and Figure 4 show that the Total Harmonic Voltage Distortion level never exceeds 5% when quasi 12 pulse is used in combination with a Danfoss drive. This will be true in most systems as long as the transformer's drive load (in kVA) does not exceed 90% of transformer's nominal power.

Furthermore the Total Harmonic Current Distortion will never exceed 25% under the same conditions provided that there is a load balance between drives on the phase shifting transformer and the drives connected directly to the main transformer which is always 1:5 or better. This does not mean that the load on each individual drive cannot go below 20%, only that if 50% of the drives are at no load, the other 50% must be at least at 40% load for each of the two drive groups.

It is a precondition for this solution to be valid that the nominal drive load can be distributed equally between the phase shifting transformer and the drive group directly connected to the main transformer. Alternatively, a phase shifting transformer is connected to every second drive in the installation. More accurate information about the voltage distortion generated in a specific system where this solution is used, requires a detailed simulation including the background distortion and single-phase non-linear loads.

Knowledge about the single-phase non-linear loads is more critical in a 12-pulse installation, since there is no cancellation of the 5^{th} and 7^{th} harmonics generated by these loads. This applies to installations where the drives are equipped with 12-pulse rectifiers as well as in installations where a quasi 12-pulse installation is made.

Single phase non-linear loads could be equipment such as computers, Xerox machines, faxes, fluorescent light, radios, televisions and small air-conditioners all of which use a rectifier to generate a DC voltage supply. Some of these machines use active filters which do not produce harmonics, but this is not the norm yet. Also fluorescent light can have balanced or electronic ballasts which do not produce harmonic distortion.

In installations where standard 6-pulse rectifiers are used, the 5th and 7th harmonics generated are counterphased to those of the single-phase loads and background distortion. Information about the single-phase loads and background distortion is therefore not as critical in a 6-pulse installation.

Conclusion

In installations where it is very important to achieve low voltage distortion, quasi 12 pulse will give the optimum results at the lowest cost.