DESIGN CONSIDERATIONS WHEN APPLYING VARIOUS ASD TOPOLOGIES TO MEET HARMONIC COMPLIANCE

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***Abstract*—In order to limit the harmonic distortion produced by Adjustable Speed Drives (ASD's), manufacturers have introduced several methods of both passive and active harmonic mitigation. Users of ASD's however, who are faced with the various options often find it difficult to select the most appropriate one for their particular application. Using computer simulation and laboratory measurements, this paper analyzes the most common passive solutions which include AC line reactors or DC link chokes, phase shifting to produce multi-pulse ASD's and inline passive harmonic filters. Various design considerations, particularly related to power system parameters, are addressed.**

Index Terms – Adjustable Speed Drives, ASD, compatibility, distortion, harmonics, impedance, multipulse, passive filter, topologies, voltage imbalance

I. INTRODUCTION

With harmonic distortion becoming an ever increasing concern in Adjustable Speed Drive (ASD) applications, virtually all Drive manufacturers now consider limiting the generation of input current harmonics to be an important issue in their designs. This has led to the introduction of various drive topologies with differing degrees of harmonic mitigation effectiveness. Design topologies include:

1. ASD with AC line reactor or DC link choke
2. Multipulse ASD (12P, 18P, etc.)
3. ASD with inline passive filter
4. ASD with Active Front-end (AFE)

Each of these options has its advantages and disadvantages which must be taken into consideration when designing for a specific application where ASD's are to be used. These design considerations include:

1. Harmonic mitigation performance
2. Compatibility with power source, including generators
3. Influence of source impedance
4. Influence of voltage imbalance
5. Influence of background voltage distortion
6. Energy efficiency

This paper will describe the various ASD topologies that use passive forms of harmonic mitigation (all but the AFE) and analyze their application with respect to the above listed design considerations using computer simulation. Specific attention will be given to marine applications where weak power sources provide difficult challenges in meeting compliance with Certifying Body harmonic requirements.

II. ANALYSIS THROUGH COMPUTER SIMULATION

Computer simulation is used to calculate harmonic performance under various power system conditions. The computer program uses Nodal Analysis by formulating Nodal Matrix and solving the set of numerical ordinary differential equations using the backward Euler (second order and third order) method. At each point in time, non-linear devices are replaced by equivalent linear circuit models which may require many iterations before calculations converge to a solution. The program dynamically adjusts the time step to improve accuracy and reduce long simulation times. Transient analysis is achieved by solving the set of ordinary differential equations on each time point for the set time interval.

To analyze ASD applications, many models have been created for power system components and ASD topologies. This allows the user to simulate real world conditions by adjusting system parameters such as voltage imbalance and background voltage distortion. These conditions can have dramatic effects on certain topologies making them a less desirable option for many applications.

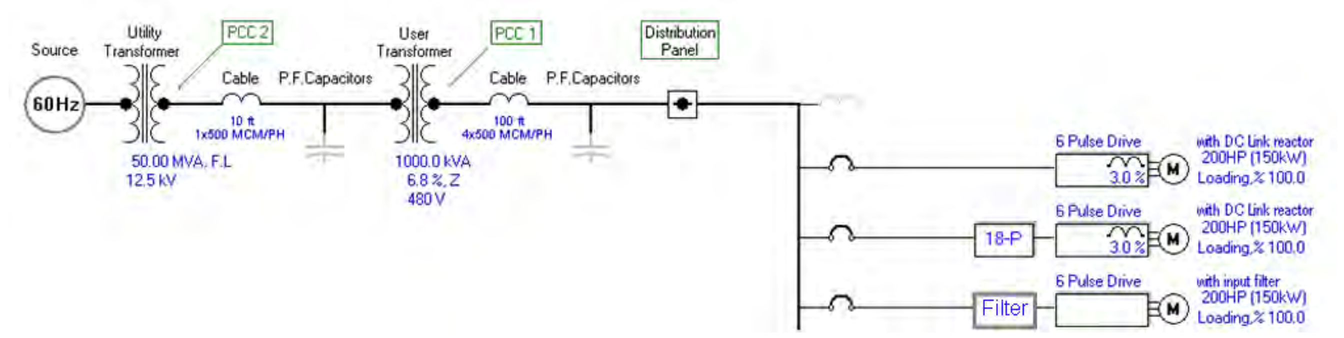


Fig. 1. 1-Line configuration for computer simulation with Utility source. 3 types of loads are shown – 6-Pulse ASD with DC Link reactor, 18-pulse ASD and 6-Pulse ASD with input filter.

For this paper, two system configurations will be considered – a Utility type distribution with transformer supply and a Generator source. For the Utility simulation, a 50 MVA fault level has been chosen to supply a 1000 kVA transformer with 6.8% impedance (Fig. 1). A 1000 kVA Generator with a PF of 0.8 and subtransient reactance of 16% is chosen for the Generator source.

III. ADJUSTABLE SPEED DRIVES AND HARMONICS

An ASD is a solid state device that converts supply voltage to a variable voltage and frequency in order to control the speed of a 3-phase induction motor (also referred to as a variable frequency drive or VFD) or to DC for DC motor applications. By controlling the motor's speed, both energy savings and better motor control can be achieved.

ASD's generate harmonic currents because their front-end or input rectifiers do not draw current in a sinusoidal manner. Instead, they draw discontinuous, pulsed currents which can be broken down into harmonic components by applying Fourier analysis. For a typical 3-phase rectifier bridge, the predominant harmonic currents that will be generated are 5th, 7th, 11th and 13th. Typical current distortion levels range from 35% to over 80% depending upon the supply impedance and whether or not an AC or DC reactor is applied to the drive.

To reduce the harmonic currents generated by ASD's, manufacturers often apply AC line reactors at the input of the rectifier, DC link reactors between the rectifier and inverter or both.

IV. PHASE SHIFTING AND MULTI-PULSE DRIVE SYSTEMS

Multi-pulse drive systems have been one of the most common topologies used for addressing harmonic mitigation. In this technique, transformers with multiple secondary windings are used to phase shift multiple ASD rectifiers against each other.

A drive system's pulse number is determined by the number of discrete converters used and the phase shift angles between these converters. The characteristic harmonics generated by the diode bridge rectifier of an ASD will follow the relationship below:

$h = np +/- 1,$

where: h = the harmonic number

n = any integer

p = the pulse number of the rectifier

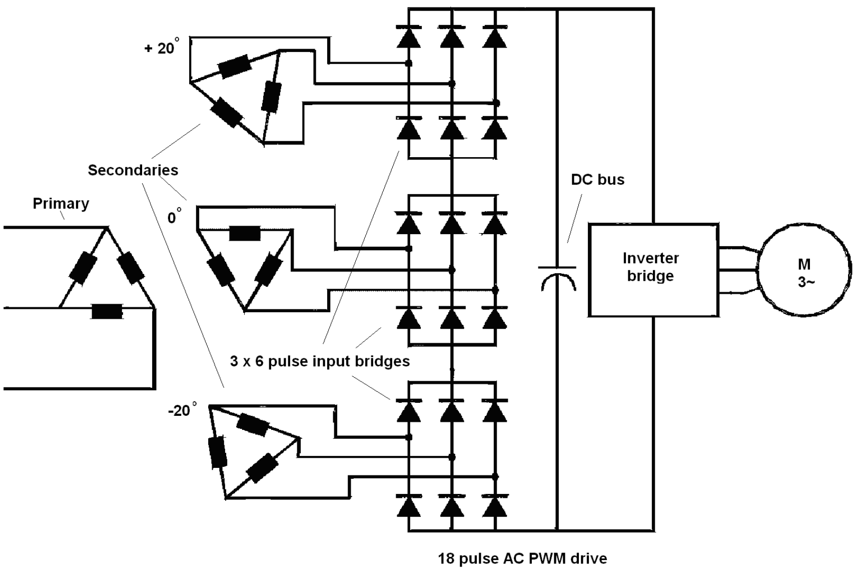


Fig. 2. Typical 18-pulse drive system. Three 6-pulse converters and three secondary windings, 20 deg displaced

Most ASD's incorporate a 3-phase, 6-pulse (p = 6) diode bridge rectifier which results in currents of harmonic number 5th, 7th, 11th, 13th, etc. being generated. When dual rectifiers are used and phase shifted by 30°, a 12-pulse scheme is created. 12-pulse ASD's will only have residual amounts of 5th and 7th harmonics as substituting p = 12 in the above equation leaves harmonics 11th, 13th, 23rd, 25th, etc. Similarly, an 18-pulse drive consists of three input rectifiers with 20° phase shifts between them (Fig. 2).

Configurations up to 48-pulse are possible for larger systems but the effectiveness of phase shifting at high pulse numbers becomes questionable because the phase angles of harmonic currents at higher frequencies are typically not similar enough to produce sufficient cancellation.

Although they are theoretically an effective means of harmonic treatment, all phase shift drive systems can perform rather poorly under real world conditions. Tolerances in manufacture of the transformer windings, applied voltage imbalances, pre-existing voltage distortion and light loading levels will have a detrimental effect on the drive's ability to cancel harmonic currents, particularly at higher frequencies.

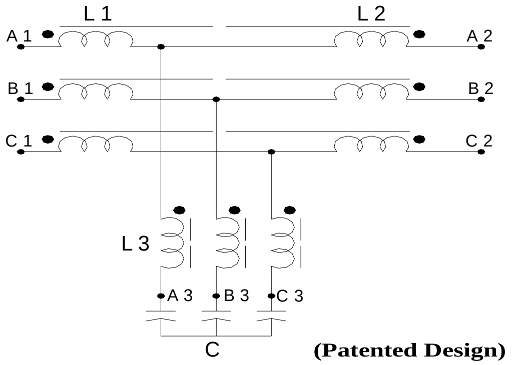
V. 6-PULSE ASD WITH INLINE PASSIVE FILTER

There are various forms of harmonic filters being employed by ASD manufacturers but most employ a combination of a blocking element and a tuned filtering element (Fig. 3). Crucial in the design of an effective filter is the prevention of harmonic importation from the line side of the filter. Without this ability, a filter could easily be overloaded when installed on a power system where other harmonic generating, non-linear loads exist on the same bus.

One configuration that produces wide spectrum filtering consists of a reactor with multiple windings on a common core and a relatively small capacitor bank. This design exploits the mutual coupling between the windings to improve performance. To prevent importation of upstream harmonics, the resonant frequency, as seen from the input terminals, is near the 4th harmonic, comfortably below the predominant harmonics of 3-phase rectifiers.

One key advantage of the unique reactor design of the wide spectrum filter is that it allows for the use of a significantly smaller capacitor bank (typically < 15% reactive power as a percent of full load rating). This will reduce voltage boost and reactive power at no load to ensure compatibility with generators.

The filter is connected in series between the main supply and the drive. Current Total Harmonic Distortion (ITHD) is typically reduced to < 6% when applied to a 6-pulse AC PWM drive regardless of whether the drive is equipped with an AC or DC reactor or not.



(Patented Design)

Fig. 3. Wide spectrum harmonic filter schematic

Wide spectrum filters can be applied to AC drives with diode or SCR pre-charge input rectifiers ranging in size from 5HP/4kW to 3500HP/2600kW at present. They can be applied to single or multiple drives but only drive loads should be connected as the filter is designed specifically for rectifier operation. The filter can usually be retrofitted to existing drives without the requirement for drive modifications, whether for single drive or for multiple drive applications.

The filter can also operate on fully controlled SCR bridges as used in DC Drives but with a slight reduction in performance.

VI. HARMONIC MITIGATION PERFORMANCE

All of these topologies will lower harmonic current content of the ASD to some extent. Table 1 shows the current and voltage distortion performance for each topology under ideal, laboratory type conditions with Utility supply. Each simulation was run with only that individual load connected. Table 2 provides the same comparisons with a Generator source. In the analysis, 12, 18 and 24-Pulse systems are included.

Although there are some minor differences, performance is very similar between an ASD equipped with an AC line reactor or one with a DC link choke when the % impedance of the reactors is similar. A slight improvement in performance is achieved with the higher 5% impedance AC reactor. Reactors with impedance > 5% are rarely used since the higher voltage drop they produce could cause ASD operational problems.

With ITHD's in the 30% or higher range, line reactors alone are rarely suitable for meeting harmonic limits required by industry standards, such as IEEE Std 519-1992 [1][2], IEC 61000-3-6 [3], IEC 61000-3-12 [4] and marine Certifying Body standards [5][6].

In generator applications, the higher source impedance of the generator has the effect of reducing the individual current harmonics and overall ITHD but also increases voltage distortion. For example, ITHD for the 3% AC line reactor has reduced to 31.1% but VTHD has increased to 5.4%.

	Current										Voltage
	ITHD	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**VTHD**
6-P with 3% AC Reactor	34.6	0	32.2	9.6	0	6.4	3.4	0	2.4	1.9	3.3
6-P with 5% AC Reactor	29.4	0	27.6	7.8	0	5.2	3.3	0	1.7	1.6	2.8
6-P with 3% DC Link Choke	34.9	0	30.6	12.3	0	8.0	4.6	0	4.1	2.8	3.9
6-P with input filter	6.3	0.2	1.4	5.2	0.1	2.6	1.2	0	1.0	0.8	0.9
12-P	12.5	0.1	0.3	0.1	0	9.9	6.0	0	0.1	0	3.1
18-P	4.8	0	0.7	0.5	0	0.2	0.4	0	3.4	2.7	1.7
24-P	2.2	0	0.2	0.1	0	0.2	0.1	0	0.1	0.1	1.1

Table 1. Harmonic current (ITHD and individual harmonic) and voltage THD for various forms of ASD passive harmonic treatments (200HP) on an Ideal Utility source of 1000 kVA as per Fig. 1

	Current										Voltage
	ITHD	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**VTHD**
6-P with 3% AC Reactor	31.1	0	29.2	8.2	0	5.7	3.3	0	1.9	1.7	5.4
6-P with 5% AC Reactor	27.4	0	25.7	7.5	0	4.6	3.2	0	1.5	1.3	4.8
6-P with 3% DC Link Choke	32.0	0	28.9	9.8	0	7.3	4.1	0	3.3	2.4	6.2
6-P with input filter	6.0	0.1	1.4	4.9	0	2.5	1.1	0	1.0	0.8	1.7
12-P	11.6	0	0.3	0.1	0	9.4	5.7	0	0	0	4.9
18-P	3.7	0	0.5	0.4	0	0.2	0.3	0	2.8	2.1	2.3
24-P	1.7	0	0.1	0.1	0	0.1	0.1	0	0.1	0.1	1.5

Table 2. Harmonic current (ITHD and individual harmonic) and voltage THD for various forms of ASD passive harmonic treatments (200HP) on an Ideal Generator source of 1000 kVA

	Current										Voltage
	ITHD	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**VTHD**
500 kVA Generator											
6-P with 3% AC Reactor	26.7	0.0	25.0	7.5	0.0	4.4	3.1	0.0	1.4	1.3	9.0
6-P with input filter	5.3	0.0	1.2	4.4	0.0	2.3	1.0	0.0	0.9	0.7	3.0
18-P	2.8	0.0	0.4	0.2	0.0	0.2	0.2	0.0	2.1	1.6	3.3
500 kVA Utility											
6-P with 3% AC Reactor	31.4	0.0	29.4	8.3	0.0	5.8	3.3	0.0	2.0	1.7	5.2
6-P with input filter	5.9	0.0	1.4	4.8	0.0	2.5	1.1	0.0	1.0	0.7	1.6
18-P	3.8	0.0	0.5	0.4	0.0	0.2	0.3	0.0	2.8	2.1	2.3

Table 3. Harmonic current (ITHD and individual harmonic) and voltage THD for various forms of ASD passive harmonic treatments (200HP) on Ideal Generator and Utility sources of 500 kVA

Improved harmonic performance can be achieved by application of multipulse drive systems. Results of simulations on the same Utility and generator power systems are shown in Table 1 and 2. Under these ideal conditions with perfectly balanced 3-phase voltages, no background voltage distortion and balanced transformer impedances and phase shifts, simulation results are quite good, especially with the higher pulse numbers (18 and 24).

It should be noted that a 3% DC Link choke has been included in the multipulse designs. This added impedance is necessary in order to achieve acceptable performance.

Good performance is also achieved with the 6-Pulse ASD with inline harmonic filter. In comparison with the 18-Pulse system, VTHD was lower even though ITHD was slightly higher. This is due to the fact that higher frequency harmonics are better suppressed by the inline filter and these higher frequencies more easily distort the voltage waveform.

With respect to voltage distortion, the inline filter also matches up very well with the 24-Pulse system. ITHD levels are a bit higher but the more important VTHD levels are essentially the same. Again this is due to better suppression at the higher harmonic numbers.

VII. COMPATIBILITY WITH POWER SOURCE, INCLUDING GENERATORS

Some items to consider when analyzing whether a particular ASD topology is compatible with a power system are (i) the level of voltage distortion created (ii) potential for resonance with the power system, (iii) the level of capacitive reactive power introduced (particularly important for generator applications) and (iv) voltage drop or boost.

Voltage distortion is listed as one of the compatibility items because if the choice of harmonic mitigation isn't capable of lowering voltage distortion to acceptable levels, all equipment connected to that power system will be subjected to these excessive levels. It is therefore important that the harmonic mitigation selected perform well under all operating conditions as described in this paper.

Since most power systems are inductive in nature, line reactors and multipulse phase shifting transformers present very little potential for introducing harmonic resonance. The exception might be on power systems that have been overcompensated with power factor correction capacitors but this would be a very rare occurrence. Their impedance will introduce a proportional voltage drop however, so typically, 5% impedance is the maximum value acceptable.

Inline harmonic filters do contain capacitors which could potentially resonate with the inductive power system. Inline filter designs will vary widely from one manufacturer to another so it is important to understand which designs will suitably limit the potential for resonance.

Fig. 4 shows how resonance occurs in a power system where the capacitive reactance curve crosses the inductive reactance curve. If this occurs at a frequency of a predominant harmonic, the resulting resonance will substantially increase current distortion and voltage distortion at that harmonic.

As mentioned earlier, power systems are typically inductive by nature. Therefore, when connecting a filter to the power system, the resonant frequency with the power system will have this additional inductance. Increasing inductance will move the inductive reactance curve upward which will have the effect of lowering the resonant frequency. If the filter's line side resonance frequency is designed to be below the level of characteristic harmonics (ie. < 5th) then any further shift introduced by the power system inductance will move the resonant frequency further from the predominant harmonics. For example, if the input resonant frequency of the harmonic filter is tuned to the 4.2nd harmonic, any additional power system inductance will shift this tuned frequency closer to the 4th harmonic and away from the 5th, 7th and other rectifier harmonic frequencies.

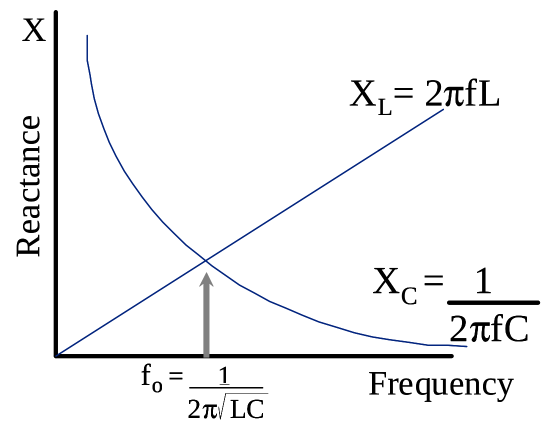


Fig. 4. Resonant frequency relationship

In generator applications, the level of reactive power introduced by the harmonic filter's capacitors also needs to be taken into consideration. If the level of capacitive reactive current is too high (i.e. heavily leading power factor load), the generator's voltage could rise. Generators are designed to adjust for voltage drop as their load increases but typically have limited ability to lower voltage when raised by a leading power factor load. It is therefore important that any filtering device which incorporates capacitors is designed to ensure that the filter's maximum capacitive reactive current (which occurs under no load conditions) is comfortably below the maximum allowed by the generator.

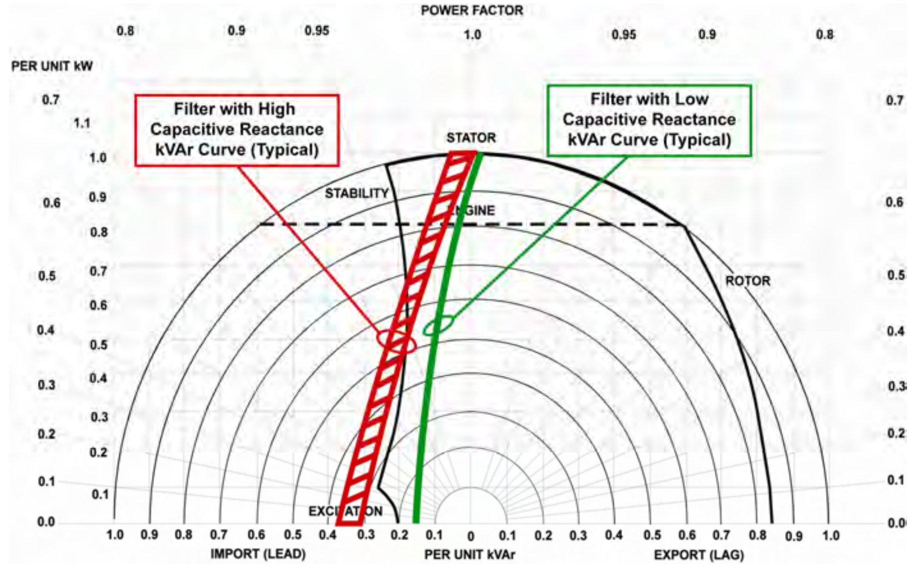


Fig. 5. Typical Generator Reactive Power Capability Curve with acceptable filter (low capacitive reactance design) and unacceptable filter (high capacitive reactance design)

Fig. 5 provides an example of a typical Generator Reactive Power Capability Curve. The x-axis shows per unit reactive power with inductive or lagging kVAR on the right and capacitive or leading kVAR on the left. The y-axis indicates kW loading on the generator. If loading falls within the envelope, the generator will operate properly.

This generator is typical of many generators in that it can tolerate very high inductive reactive power but is sensitive to high capacitive reactive power. At no kW load, the generator can accept over 80% inductive reactive power but only 20% capacitive reactive power. Superimposed on the chart are examples of the reactive power curves for a well designed input filter (low capacitive reactance) and an unacceptable filter design (high capacitive reactance). The unacceptable filter design has much higher capacitive reactance and therefore, falls outside the acceptable operating envelope in the lighter loading region.

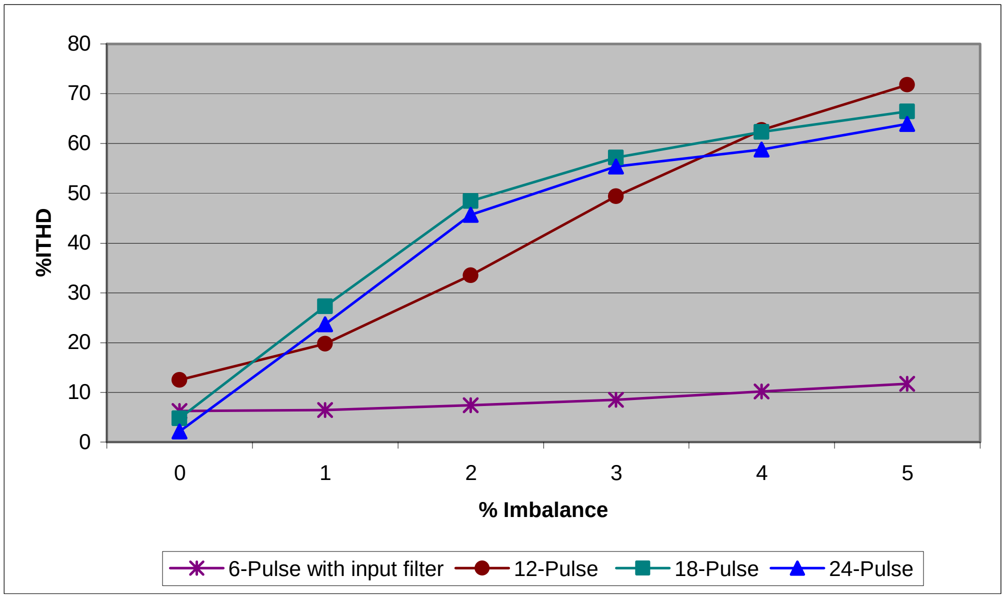


Fig. 6. ITHD for Various forms of harmonic mitigation at various levels of voltage imbalance operating at full load

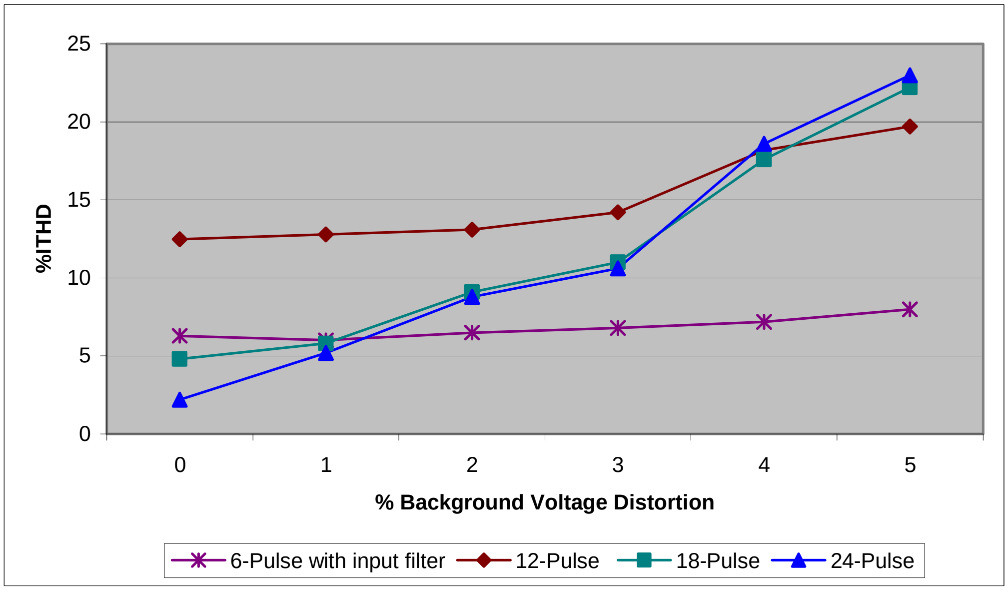


Fig. 7. ITHD for Various forms of harmonic mitigation at various levels of background voltage distortion operating at full load

Typically, filters that are designed with a maximum capacitive reactance of 15% or lower will operate well on most any generator.

VIII. INFLUENCE OF SOURCE IMPEDANCE

A power system's source impedance will have a significant impact on the current harmonics drawn by an ASD, or other non-linear load, and on the voltage harmonics these non-linear loads create on the power system.

Tables 1 and 2 demonstrate the effect that the higher source impedance of a generator can have, especially on voltage distortion. For example, the 6-Pulse ASD with 3% AC line reactor drew current with 34.6% distortion while supplied by the lower impedance or 'stiffer' Utility source but only 31.1% distortion while supplied by the higher impedance or 'weak' generator source. VTHD is also affected with distortion increasing from 3.3% to 5.4% when on generator supply.

The effect is more obvious when the source is made even weaker by using a smaller generator. Supplied from a 500 kVA generator with 16% subtransient reactance, current distortion on the 200HP ASD is 26.7% while voltage distortion is a very high 9.0% (Table 3).

Even with the lower impedance (6.8%) Utility source, voltage distortion increases substantially when the transformer size is decreased to 500 kVA (Table 3). VTHD reaches 5.2% in this simulation which is higher than the commonly accepted limit of 5%.

Therefore, it is important that source impedance be taken into account when doing harmonic analysis on an ASD application. When ASD loading is a relatively high percentage of the overall loading, voltage distortion can be unacceptably high, especially when supplied by a weaker power system.

IX. INFLUENCE OF VOLTAGE IMBALANCE

Unfortunately, real world power systems rarely have perfectly balanced 3-phase voltages. This voltage imbalance can cause degradation in the performance of harmonic mitigation equipment, especially that which uses phase shifting for harmonic current cancellation such as multipulse drive systems. Pre-existing voltage distortion can also cause degradation in harmonic mitigation performance (this will be explained further in the next section). In many industrial systems with nonlinear loads, it is not uncommon to measure 1% to 3% voltage unbalance and/or 2.5% to 5% pre-existing 5th and 7th harmonic voltage distortion when a large percentage of loads are nonlinear.[7]

The computer simulation program used in this analysis allows for the selection of a level of voltage imbalance and background voltage distortion. Figure 6 provides graphs of the various multipulse mitigation methods and 6-pulse with input filter at varying levels of voltage imbalance when operating at full load.

Of particular interest is the fact that all three forms of multipulse systems (12, 18 and 24) perform very poorly as the voltage imbalance increases. In fact, even with imbalance as low as 2%, the multipulse systems perform no better than 6-Pulse systems with reactors. The 6-Pulse with input filter, on the other hand, holds its performance level much better even with an imbalance as high as 5%.

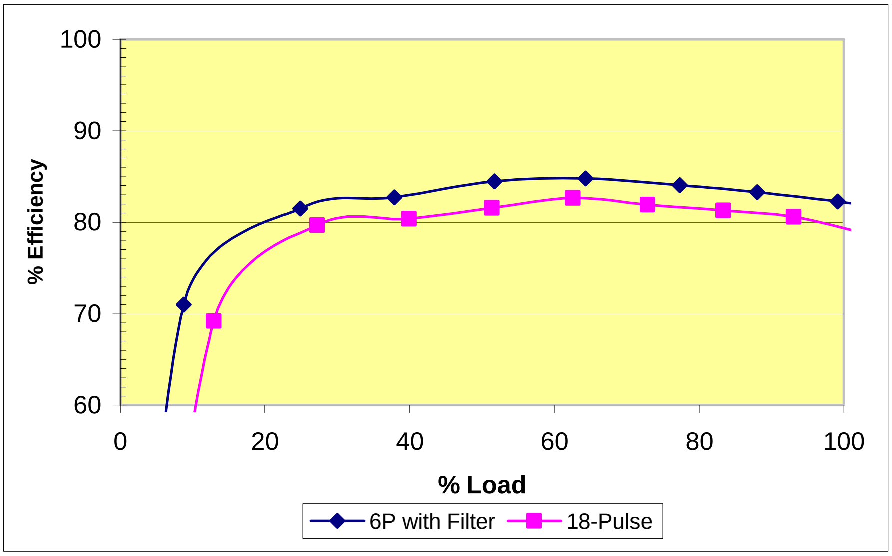


Fig. 8. Efficiency comparison of 18-Pulse vs 6-Pulse with an Input Filter. Efficiency includes filter or transformer, VFD and VFD load.

It should be noted that in addition to increasing the levels of characteristic harmonics in multipulse systems, voltage imbalance will also result in the appearance of uncharacteristic harmonics, including triplens and even order [8]. Therefore, when using phase shift based drive systems, it is important to consider if an acceptable level of mitigation will be achieved under the very likely scenario of voltage imbalance.

X. INFLUENCE OF BACKGROUND VOLTAGE DISTORTION

With the ever increasing presence of harmonic generating non-linear loads such as ASD's, power systems with low levels of voltage distortion are becoming evermore rare. It is prevention of high levels of voltage distortion that demands the use of harmonic mitigation methods but any method used must be analyzed for effectiveness with pre-existing distortion levels if they are present. Determining the effect of background voltage distortion however, is not a simple task.

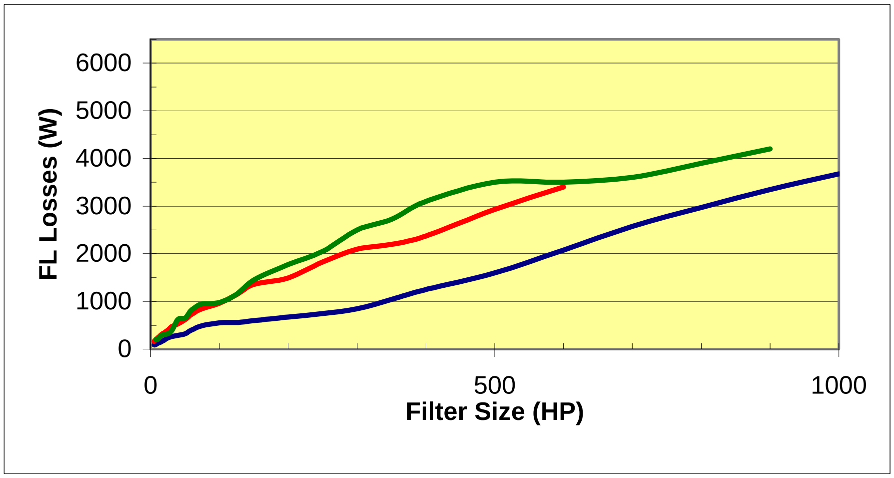


Fig. 9. Loss comparison of 3 different types of harmonic input filters highlighting the superior performance of one type.

The computer simulation program used for this paper does provide the opportunity to insert voltage distortion at the more common voltage harmonics found on today's power systems where ASD's are in use. These are 5th, 7th, 11th, 13th and 17th. Figure 7 provides a comparison of ITHD for the various forms of harmonic mitigation in the presence of background voltage distortion. Levels of voltage distortion at the various harmonic orders were entered in proportions that are commonly found in power systems in order to produce an overall VTHD of 1% to 5% in integer steps.

As with voltage imbalance, background voltage distortion increases both characteristic and uncharacteristic harmonics in multipulse systems. The degradation in performance is not as severe as with voltage imbalance but nonetheless, is quite significant.

As mentioned earlier, designing an input filter for ASD's requires that consideration be given to its ability to prevent importation of harmonics due to background voltage distortion. Any design that is susceptible to background voltage distortion would not only become overloaded with harmonics but would also perform very poorly with respect to ITHD. A good design on the other hand will perform well as shown in Figure 7.

In marine applications such as ships and offshore oil rigs/platforms, background voltage distortion often reaches levels above 10% and measurements above 20% are not uncommon. Therefore, when using phase shift based drive systems, it is important to consider if an acceptable level of mitigation will be achieved under the very likely scenario of high levels of background distortion.

XI. ENERGY EFFICIENCY

Since the energy savings potential of an ASD is often a main consideration for its use, it is important that any harmonic mitigation equipment that is used with the ASD does not significantly increase losses. All forms of harmonic treatment will add some losses but the amount can vary significantly.

All multipulse ASD configurations require a phase shifting transformer to cancel harmonic currents. Transformer efficiencies can vary quite widely. Some multipulse configurations use an autotransformer to create the phase shift while others use isolation transformers. Isolation transformers inherently have higher losses, often totaling 2% to 3%. Fig. 8 compares an 18P with autotransformer configuration to a 6P with an input filter. This input filter is designed to be extremely efficient with total losses < 1%. The particular 18P ASD tested was equipped with an autotransformer so these losses were lower than would be expected if an isolation transformer had been used.

There can also be significant differences in the efficiencies of various input filters. Fig. 9 provides a comparison of 3 different types of input harmonic filters. The filter with the lowest losses was the one used in the 18P comparison. Selecting the proper input harmonic filter should be based not only on harmonic mitigating performance but also on the efficiency of the device.

XII. CONCLUSION

Understanding ASD harmonics and their treatment options requires some fairly thorough analysis. In addition to there being several types of treatment methods to consider, there are several design criteria that should be addressed during selection. All solutions have there pros and cons, but when considering all design parameters, the analysis does seem to favor the inline passive filter. Key advantages include (i) better performance under voltage imbalance and pre-existing voltage distortion and (ii) higher efficiencies.

Of course, not all filters are created equal. A properly designed filter must (i) introduce relatively low capacitive reactance at no load to ensure compatibility with generators, (ii) resist resonance with the power system (iii) prevent importation of harmonics from upstream loads, (iv) introduce minimal voltage boost at no load and voltage drop at full load, and (v) achieve high efficiency in order to maintain the energy saving advantages of the ASD.

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XIV. VITA

Tony Hoevenaars is President and CEO of MIRUS International Inc. a company specializing in the treatment of power system harmonics. Prior to joining MIRUS in 1996, Tony was the Chief Facilities Electrical Engineer at an IBM manufacturing facility in Toronto where he gained extensive experience in solving power quality related problems, particularly in the area of harmonics. Tony is a Professional Engineer, member of IEEE and has published various papers on power quality including papers presented at the PCIC 2003, 2008 and 2009 conferences.

Michael James is an electrical engineer with EDG, Incorporated, a consulting engineering company specializing in offshore and onshore oil and gas processing facilities design. With 20 years of experience, Mike has worked on numerous projects with VFD applications, in both new installations and retrofits, where harmonics were a primary consideration. Mike is a Professional Engineer in LA and FL, and a member of IEEE.

Michael Fahrney is the Product Line Director for Benshaw, a manufacturer of advanced motor controls and drives. Michael has 15 years of experience in the installation, troubleshooting and application of variable speed drives and motor controls. Mike has applied various harmonic mitigation methods in a multitude of applications and markets. Mike currently resides in Pittsburgh, PA, where he works with an engineering team providing motor control solutions.

Michael McGraw is President of NSOEM Inc. a company he founded in 1996 that specializes in transformer and filter harmonic mitigation applications for land and offshore Oil & Gas systems and MV Solid State starting for large motors. Previously Mike was the OEM Sales Manager for MV Switchgear manufactured by Powercon Corp. Mike is a member of the IEEE.