Transformation from Six-Pulse to Low Harmonic, Three-Level, Active Rectification Technologies

Low Harmonic and Regenerative Drive Solutions from Schneider Electric
Abstract

This paper provides an overview of the advances in harmonic mitigation technologies over the years. Modern variable frequency drives (VFDs) must fulfill many requirements. As resources and energy are limited, the efficient use of them becomes increasingly important. Harmonics in electrical systems have been a major concern for engineers and designers since the invention of inverter technologies. The objectives of this paper are to provide a basic understanding of current harmonic mitigation strategies, such as multi-pulse rectification and passive/active filters, and to introduce active front end architecture. This paper also examines the benefits of improved three-level, active rectification technologies, such as those provided by Schneider Electric.

Introduction

All electrical circuits have the potential to provide some level of electrical interference, especially when switching reactive loads. VFDs have input rectifiers which produce an input current that is very non-sinusoidal. These currents can be represented by a sinusoidal fundamental current and additional sinusoidal harmonic currents. A high level of harmonics could affect the efficiency and performance of other electrical devices connected to the same input power supply. To improve power quality in the electrical systems, many types of harmonic mitigation architectures can be deployed.

A current harmonic is a current which is a multiple of the fundamental frequency. For example, in a 60 Hz environment, the fifth harmonic is 300 Hz. Harmonic distortion can cause the power grid or its branch to carry extra power with frequencies that are multiples of 50 or 60 Hz. Harmonics can cause distortion of the normal sine waveform, and can cause equipment overheating and failure. Harmonics in an electrical power system are caused by nonlinear loads, such as diode rectifiers in drives. When a nonlinear load is connected to a power system, it produces non-sinusoidal current. Three-phase systems present an advantage over single-phase systems because the 3rd harmonic and its multiples (6, 9,12,15, etc.) are, typically, self-canceling. Figure 1 shows the harmonics by scale.

Figure 1 – Harmonics Display
The Results of Harmonics

Power distribution systems typically include various types of power components such as reactors and transformers. As current flows through these electrical components, each component introduces a level of impedance. With the introduction of impedance in the system, a certain level of voltage drop is expected. This voltage drop is directly proportional to the total amount of current flowing through the given system.

Harmonic currents cause voltage distortions and power quality issues that impact each electrical component in the system. This can result in unwanted equipment behavior and even power loss. Harmonic content in power distribution systems can lead to various undesired outcomes, such as disturbances in communications, increased operational expenses, and loss of revenue.

In addition, some system loads drawing harmonic current often draw currents which result in increased ground currents and/or induce common mode noise. This can cause increased motor bearing temperatures in three-phase induction or permanent magnet motors. Both of these conditions can negatively impact the service life expectancy of the equipment connected to the power grid.

Mitigation Architectures Overview

The most obvious impacts of harmonic distortion are increased current draw and deterioration of power quality, which have both a technical component and financial impact on end users. A variety of methods can be used to mitigate harmonic distortions. Some involve additional cost in the overall power system. Some methods also provide additional benefits outside of harmonic mitigation. These benefits will be explored in depth.

Multi-pulse Input Rectification

A comparison of 6-, 12-, and 18-pulse rectifiers is presented in the following paragraphs.

6-pulse Rectification

Standard VFDs use 3-phase power with 120° of phase shift and have a full wave rectifier using six diodes, as seen in Figure 2. Whenever the input voltage for a line-to-line phase is higher than the DC bus voltage, two of the diodes will conduct and the current will charge the DC bus.

![Figure 2 – 6-pulse Input Electrical Drawing](image-url)
Because the DC bus voltage is near the peak of the AC line voltage, the diodes only conduct during the peak of the incoming waveform. The amount of peak current will be limited by the power system impedance. The resulting current waveform, as shown in Figure 3, has a double peak pattern with narrow current spikes.

**Figure 3 – 6-pulse Input Current Waveform without Input Impedance**

By adding a line reactor, the peaks can be reduced, but not eliminated, as shown in the waveform in Figure 4. The peaks are reduced and the pulses are wider so the same amount of energy is going into the drive. Although this has lower harmonic content (as compared to not using a line reactor), it still has a significant amount of harmonics—around 40% or more.

**Figure 4 – 6-pulse Input Current Waveform with Input Impedance**

### 12-pulse Rectification

If a Delta-Wye transformer is used, there is a 30° phase shift between each set of the transformer windings. By using a six-diode rectifier on the Delta secondary winding, and another six-diode rectifier on the Wye secondary winding, a current waveform with a stronger middle peak occurs, making it begin to approximate a sine wave. As a result, the first significant harmonic current lobes are displaced from 5th and 7th harmonics to 11th and 13th harmonics. Harmonics are around 12% if the voltages are balanced.
18-pulse Rectification

Increasing to 18 pulses results in even more current smoothing. A special transformer with 9 secondary windings feeding the diode bridges is used. An 18-diode rectifier is used to rectify the power, resulting in an input current waveform that is substantially a sine wave with minor variations. Current harmonics (THD) are around 5% if the voltages are well balanced. If the voltages become unbalanced, the effectiveness of the current harmonic reduction will be minimized. The addition of this special transformer results in additional cost and heat dissipation, which impacts the overall VFD efficiency and makes 18-pulse solutions potentially more expensive than 6-pulse or passive filter solutions.

Figure 5 – 18-pulse Design

Broadband Filter

The broadband filter reduces the harmonics by storing energy in inductors and capacitors. By filtering out the 5th and 7th harmonics, a sine wave can be produced on the input current while still providing adequate charging current to the VFD. However, a leading power factor can occur at light loads, which can be corrected by adding a contactor to disconnect the capacitors. Unbalanced voltages are managed better than in the 18-pulse design. Some broadband filters may boost the voltage too much and cause the drive to trip on overvoltage; others have the filter tuned broadly enough that this does not occur. Figure 6 on page 6 shows a one-line diagram for the broadband filter.

Figure 6 – One-Line Diagram of a Typical Broadband Filter
Active Rectification

By replacing the six input diodes with insulated gate bipolar transistors (IGBTs), such as the ones used on the output of the drive, the input current wave shape can be controlled.

Figure 8(A) is a simplified equivalent model showing how two-level active rectification operates. The utility supplies a voltage source with a sinusoidal voltage $v_N$ with a known operating frequency $f_N$. The converter system generates the voltage $v_r$ and the difference between the two voltages applies across the boost choke. The boost chokes are used as an energy storage element.

A positive voltage across this choke causes the current to increase, while a negative voltage across the choke causes it to decrease. To achieve sinusoidal mains currents $i_N$ in phase with this voltage, the converter system must generate a voltage $v_r$ that shows a small phase shift to the mains voltage $v_N$. The corresponding phasor diagram and voltage and current waveforms are given in Figures 8(B) and 8(C), respectively. This is common among all active rectification topologies.

Figure 8 – Active Front End (AFE) Model
The pulse width modulated (PWM) waveform of the voltage from the IGBTs’ switching is smoothed by the input inductance to closer approximate a pure sine wave.

The Three-Level Design of Schneider Electric Low Harmonic Drives

Three-level active rectification is used to improve input current waveforms. This is achieved by the addition of three bi-directional IGBT switches connected to the midpoint of the DC bus. This three-level topology also uses an additional common mode (CM) filter stage. The CM filter stage allows for high efficiency and behaves like a passive rectifier circuit in terms of CM voltage. Figure 10 illustrates the low harmonic solution using three-level active rectification.

In order to generate sinusoidal input currents in phase with the mains voltage, the current is shaped by the switching actions of the input IGBTs.
Three-level active rectification topologies can generate discrete voltage levels by either closing or opening particular bi-directional IGBT switches. Bi-directional IGBT switches are created by connecting two IGBT switches back-to-back, as shown by T₃ and T₄ in Figure 10. Two-level voltage converter stages with six switches are only able to generate two different voltage levels per phase. However, the three-level topology shown in Figure 10 is designed to generate three voltage levels per phase. Each phase can be connected to the positive DC bus +V_{DC}/2 by closing switch T₁ or, due to the corresponding freewheeling diodes, to the DC bus midpoint M by closing bi-directional switches, such as T₃ and T₄, or to the negative DC bus –V_{DC}/2 by closing switch T₂.

The average value of the converter voltage must implement the required 60 Hz voltage component for current shaping. This is because the converter must match the input voltage with a slightly offset matching voltage in order to arrive at a sinusoidal current flow. However, these slight voltage differences between the discrete voltage levels and the required average values cause additional current ripple in the boost chokes. These voltage differences are smaller in a three-level converter system where three voltage levels are available for current shaping compared to simple two-level topologies.

Schneider Electric’s low harmonic three-level active rectification incorporates a boost-type converter. Boost-type converters allow the DC bus to achieve voltages at higher levels than the mains peak voltage. With a 480 VAC line voltage, the DC bus voltage can reach 720 VDC. Switching losses are directly proportional to the DC bus voltage. Also dependent on DC bus voltage is the magnitude of the ripple currents carried by the boost chokes. Due to the design of the three-level topology with a DC bus midpoint, commutations are only half of the total DC bus voltage, resulting in significantly reduced switching losses. In addition to this reduction in switching losses, the DC bus voltage is not static but dynamic. It is adapted to match the mains behavior by use of a dedicated control algorithm. Due to this design, the switching frequency can be increased, which allows a more optimized, space-saving, active input stage.

**Input Inductor-Capacitor-Inductor (LCL) Filter Design**

Schneider Electric’s low harmonic drive solution incorporates an input LCL filter design. This efficient, low pass input filter allows low-frequency voltage emissions to pass while attenuating (rejecting) high-frequency emissions. See Figure 11(A).

**Figure 11 – LCL Filter**
The performance of three-level drive systems is very dependent on this reduction of total voltage emission at the input terminals. At various multiples of the switching frequency, voltage emissions are reduced to less than 0.5%, substantially less than previous-generation, two-level technologies.

In addition to the attenuation of voltage emissions, there are other benefits. For example, in order to have an efficient input filter design, the amount of high-frequency voltage emission transfer to the mains must be minimized. The input filter design of Schneider Electric’s low harmonic drive systems reduces the level of high-frequency emissions transferred to the mains, resulting in minimal impact on the utility power system. These emission levels are at much lower amplitudes compared to 6-pulse technologies. However, the balance between this attenuation of high-frequency voltage emissions and overall efficiency of the converter must be considered. The size of the LCL filter is directly related to the level of desired attenuation. To achieve higher attenuation levels of voltage emissions, the overall size of the filter must increase. This filter typically operates in the range of several kHz for drive systems. This filter design is smaller than one operating at a lower frequency.

Higher attenuation increases the size of the filter, so a balance between filter attenuation, losses, size, and damping must be found, as shown in Figure 11(B). As shown in Figure 11(A), the LCL filter is composed of filter chokes LF, filter capacitors CF, and boost chokes LN. Together, these elements form a resonant tank. This resonant tank is susceptible to mains voltage variations from the utility, thus it is critical that this filter is properly damped.

However, reliably damping the resonant tank is typically difficult. An insufficiently damped input filter causes high currents in the filter capacitors, which would reduce the filter’s service life or even result in the breakdown of the filter capacitors. The filter chokes LF decouple the input stage from the grid and enable the filter to be well damped in all considered mains conditions. Oscillations of the filter are reduced, so the filter’s performance and service life are not degraded.

Schneider Electric’s low harmonic drive solution actively dampens the LCL filter by deploying a lossless control strategy. (See Figure 12). The control strategy is implemented in the controller software and does not require any additional passive components. The LC tank is directly damped by the converter stage itself. Thus, no additional losses occur due to passive damping elements and the efficiency of the low harmonic drive system is increased. The resonant frequency is determined by the filter choke LF, which establishes the tolerance to varying input mains power conditions.

Figure 12 – Lossless Control Strategy to Actively Damp the Input Filter

This active rectifier controller effectively dampens the LCL filter, resulting in almost no high-frequency oscillations in either the capacitor voltage or in the phase current. The three-level PWM waveform operates at 7 kHz. This higher switching frequency makes it easier to filter out the PWM than two-level AFE drives operating at 4 kHz or lower switching frequencies.
Figure 13 shows the phase currents of the LCL filter when being actively damped by the embedded control strategy. This clearly illustrates the overall effectiveness of the applied active damping strategy.

**Figure 13 – Simulated Capacitor Voltage and Input Current When Damping Control is Active**

![Graph showing phase currents and capacitor voltage](image)

**Noise Voltages**

Schneider Electric's low harmonic drive solution achieves much lower harmonic input current distortion compared to passive diode bridges and previous generation two-level AFE drive solutions. The total harmonic distortion (THDi) of input currents is below 5%. Due to the switching actions of the active converter bridge to shape the input current, the drive generates noise voltages at switching frequency. These emissions are attenuated by an input LCL filter to values below 0.5%, as discussed in the preceding LCL filter design section. This minimizes any harmful impact on adjacent EMI/RFI-sensitive equipment.

In Figure 14, simulated voltage waveforms of Schneider Electric's low harmonic drive are shown together with their averaged low-frequency components (averaged over one switching period). Three voltage levels form the phase voltage $v_{r1}$. Along with the sinusoidal 60 Hz component, a third harmonic component is also visible, which increases the modulation range of the converter system.

**Figure 14 – Simulated Voltage Waveforms of the Three-level Active Bridge Together with the Corresponding Average Value**

![Graph showing simulated voltage waveforms](image)
As a result of the switching actions, both differential mode (DM) and common mode (CM) voltages are generated. A CM voltage is a voltage common to all three phases of the DC bus.

The CM voltage can be measured between the midpoint M of the two DC-bus capacitors and N. See Figure 10 on page 8 and Figure 14(B) on page 11. In addition to the high-frequency CM voltage, the third harmonic signal is also visible in Figure 14(B). In three-phase systems, the total phase voltage \( v_p \) consists of a DM voltage component and a CM voltage component that are equal in all three phases.

The phase-related DM voltage, Figure 14(C) on page 11, can be measured between \( v_p \) and M, resulting in the actual voltage component used to shape the input mains currents. The CM voltage component has no influence on the current shaping of the phase currents, but its associated high-frequency components may cause unwanted effects.

It is common to plot the differential voltage as the voltage measured between two phases, as shown in Figure 14(D) on page 11. This relationship between CM voltage and associated high-frequency components is common when studying active rectification topologies. All voltages show high-frequency components, and their average values (averaged over one switching period) are either used to shape the mains currents or show the third harmonic component used to increase the voltage range.

**Reduction of CM Voltage**

In addition to the intentional DM voltage component, which is used to help shape the input current waveforms, some high-frequency CM voltage is present. This CM voltage adds to the CM voltage already being generated by the inverter stage of the drive. This results in undesirable high-frequency CM voltage variations of both the DC bus and total CM voltage. High-frequency CM voltage and its high dV/dt are the main sources of bearing currents, which are known to reduce the service life of the bearings, or even destroy them in a very short period of time.

A typical, passive diode bridge rectifier has only the CM voltage generated by the inverter stage of the drive present. By contrast, an active rectification drive adds CM voltage, which increases bearing currents. The amount of CM voltage added is dependent on the topology and the implementation. Schneider Electric’s low harmonic drive topology shows considerably smaller CM voltage than other classical two-level topologies, approaching the level that exists with typical passive diode bridge rectifiers.

In Table 1 on page 13, the CM voltage of a two-level AFE is compared to the CM voltage of a three-level design. Whereas the two-level AFE shows CM voltage levels of ± \( V_{DC}/2 \) and ± \( V_{DC}/6 \) and voltage steps of ± \( V_{DC}/3 \), the three-level design shows only voltage levels of ± \( V_{DC}/3 \) and ± \( V_{DC}/6 \), which result in voltage steps of only ± \( V_{DC}/6 \), a total reduction of 55 Vrms. The reduction of CM voltage levels and, consequently, the CM voltage steps applied to the motor, reduces the stress of the insulation and reduces the bearing currents. However, the dV/dt of 2–5 kV/μs still remains—a main cause of the high-frequency currents in the bearings.
Because bearing currents and the service life of bearings are among the main concerns with VFDs, a CM voltage reduction method can be implemented in the three-level topologies. Schneider Electric's low harmonic drive accomplishes this by connecting the DC bus voltage midpoint M to the artificial star-point built by the filter capacitors $C_F$ as shown in Figure 15. With this connection, the additional high-frequency CM voltage is nearly eliminated. An equivalent circuit of the CM filter is shown on the right side of Figure 15. The total CM voltage $V_{CM}$ consists of a high-frequency component $V_{CM, HF}$ and a low-frequency component $V_{CM, \sim}$.

**Table 1 – Comparison of CM Voltage Increase Across Three Designs**

<table>
<thead>
<tr>
<th>Topology</th>
<th>Two-level</th>
<th>Three-level</th>
<th>Three-level with CM Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Levels</td>
<td>$\pm VDC/6, \pm VDC/2$</td>
<td>$0, \pm VDC/6, \pm VDC/3$</td>
<td>Low-frequency 3rd harmonic</td>
</tr>
<tr>
<td>Voltage Steps</td>
<td>$\pm VDC/3$</td>
<td>$\pm VDC/6$</td>
<td>—</td>
</tr>
<tr>
<td>$dV/dt$</td>
<td>$dV/dt = 2–5$ kV/μs</td>
<td>$dV/dt = 2–5$ kV/μs</td>
<td>$dV/dt = 0.050$ V/μs</td>
</tr>
<tr>
<td>RMS Voltage</td>
<td>154 Vrms</td>
<td>99 Vrms</td>
<td>35 Vrms (3rd harmonic)</td>
</tr>
<tr>
<td>CM Voltage</td>
<td>Highest CM voltage</td>
<td>Reduced CM voltage</td>
<td>No high-frequency CM voltage</td>
</tr>
</tbody>
</table>

Because bearing currents and the service life of bearings are among the main concerns with VFDs, a CM voltage reduction method can be implemented in the three-level topologies. Schneider Electric's low harmonic drive accomplishes this by connecting the DC bus voltage midpoint M to the artificial star-point built by the filter capacitors $C_F$ as shown in Figure 15. With this connection, the additional high-frequency CM voltage is nearly eliminated. An equivalent circuit of the CM filter is shown on the right side of Figure 15. The total CM voltage $V_{CM}$ consists of a high-frequency component $V_{CM, HF}$ and a low-frequency component $V_{CM, \sim}$.

**Figure 15 – Three-level Design with CM Filter Reduction**

The elimination of this high-frequency voltage component ($V_{CM, HF}$) is critical for prolonging motor service life. The combination of the boost chokes and filter capacitors results in a second order low pass filter which attenuates the CM voltage components at the switching frequency and at multiples of the switching frequency. Only the low-frequency CM voltage remains across the filter capacitors and can therefore be measured at the DC bus voltage midpoint M.
As described on page 10 of the LCL Filter Design section, a resonant tank for CM signals is built by the filter capacitors $C_F$ and the boost chokes $L_N$. The resonant tank could be excited by the active rectification, which actively damps the input filter stage. Due to this active damping of the CM filter stage by a dedicated controller, damping resistors with high dissipative losses are not required, resulting in no additional losses within the drive.

As shown in the “Three-level with CM Filter” column in Table 1 on page 13, no high-frequency CM voltage caused by the three-level design is present at the DC bus. Only the CM voltage generated by the inverter stage (not shown in Table 1) remains at the same level as that of a drive with a traditional diode bridge, something that has been used in industrial applications for decades. This is a tremendous improvement, as a low-harmonic input stage using this concept doesn't increase CM voltage and doesn't increase bearing currents. With this technology, it is possible to replace a passive diode bridge rectifier with a low-harmonic input stage, with or without energy recovery.

**Performance**

Figure 16 shows the measurements of the mains current of a 160 kW drive with an active input rectifier. The drive is operated at a 400 V mains with 50 Hz mains frequency and at nominal power ($P_{\text{nom}} = 160$ kW). In Figure 16(A), the drive is operated in motor mode, where the energy flows from the utility grid to the motor. In Figure 16(B), the drive is operated in regenerative mode, where the motor feeds energy into the utility grid.

The currents are nearly sinusoidal and in phase with the mains voltage (only mains voltage of phase L1 is shown). In both cases, the measured THDi of the mains currents is around 2%. However, the feeding voltage already shows a THDv of approximately 2%. The THDv of the mains current is primarily determined by the voltage distortion of the power distribution system.

**Figure 16 – Measured Mains Current**

(A) Motor mode, THDi = 2.3%

(B) Regenerative mode, THDi = 1.8%

Energy flow is from the utility grid to the motor.

In addition to measuring input current distortion, the efficiency of Schneider Electric’s low harmonic solution was measured. The result was a high efficiency value of 96.5% for the entire drive at nominal load in motor mode. This high value is primarily due to the reduced switching losses of the three-level topology, the optimized DC bus voltage, and the lossless damping of the optimized LCL input filter.
Generator Testing

Schneider Electric tested an ATV980C31T4N2GNWABN regenerative process drive using an 800 kW diesel generator. Table 2 compares the effectiveness of Schneider Electric’s low harmonic drive solution to other solutions with respect to harmonic mitigation. Figures 17 through 22 provide an overview of the testing performed.

**NOTE:** The measured harmonics for Schneider Electric’s Altivar 680 low harmonic drive would be the same as those for the Altivar 980 regenerative process drive, since both drives have the same input bridge design.

### Table 2 – Harmonic Levels as Measured at the Input Drive Terminals

<table>
<thead>
<tr>
<th>Drive System Configuration</th>
<th>Current Harmonics</th>
<th>Voltage Harmonics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altivar low harmonic drives—ATV680/980</td>
<td>2.3%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Altivar process enclosed broadband filter design system—ATV660</td>
<td>3.2%</td>
<td>4.8%</td>
</tr>
<tr>
<td>Typical diode rectifier with input line reactor design system</td>
<td>38-50%</td>
<td>-/-</td>
</tr>
</tbody>
</table>

**Figure 17 – Input Current of ATV680/980 Low Harmonic Drives**

Note the sinusoidal wave shape and balanced currents.

**Figure 18 – Input Voltage Harmonics of ATV680/980 Low Harmonic Drives**

THD$_v$ is 1.2% of the fundamental (60 Hz) component.

**Figure 19 – Input Current Harmonics of ATV680/980 Low Harmonic Drives**

THD$_v$ is 2.3% of the fundamental (60 Hz) component.
Current waveform is generally sinusoidal but you can see some additional bumps in the waveform.

THDv is 4.8% of the fundamental (60 Hz) component.

THDi is 3.2% of the fundamental (60 Hz) component. This is well below the required 5%, but not as optimal when compared to Schneider Electric’s ATV680 and ATV980 low harmonic drive solutions.

As a comparison for when harmonic mitigation is not used, this is the input current waveform for a system similar to that in Figure 22, but using only an input line reactor. This is the typical current waveform that occurs with a standard drive containing a 3% line reactor or equivalent DC choke. The harmonic content can range from 38% to over 50%.
Harmonic Performance at Various Loads

To determine how the low harmonic drive solution performs when the drive is not fully loaded, testing was conducted to better understand its performance. Figure 24 shows the relationship between partial load and harmonic levels for a large, low-harmonic drive solution.

Figure 24 – Schneider Electric’s Low Harmonic Drive Solutions Harmonic Performance at Partial Loads

As the load current drops from 446 A down to 193 A (43%), the THD$_i$ increases gradually from 2.5% up to 5.2%. Even at 96 A (21% load), the THD$_i$ is only 10%.
Because of the input filtering and the active rectification technology, Schneider Electric’s low harmonic drive solution will work on a wide range of power systems. The maximum prospective short-circuit current is 100 kA. The minimum recommended prospective short-circuit current is 3 kA on the smallest size drive and 17 kA on the largest size drive.

The pulse width modulation from the input is filtered by an LCL filter. This PWM operates at 7 kHz, so it is easier to filter it out than it is with active rectification drives which use a 4 kHz or lower switching frequency.

Filters with multiple components can resonate at certain frequencies, so a method of dampening the oscillations is needed. Two-level designs use resistors to dampen the circuit, but this can waste power. Schneider Electric’s low harmonic drive solution has an improved method of actively dampening the circuit, eliminating the additional components and losses associated with the resistors.

Input line reactors can lower the power factor. Other technologies such as broadband filters have high capacitance so they can have a leading power factor at lighter loads. To prevent leading power factor at low loads, Schneider Electric adds a contactor to disconnect the capacitors until the drive is up to a certain load. By contrast, the low harmonic drive maintains a near unity (1.0) power factor over a wide range of loads.

From Schneider Electric’s generator testing, it can be seen that the power factor stays near unity down to very low levels. A unity power factor has the lowest current level for a given amount of power, so this can reduce the demand current on the system. While any specific generator should be evaluated for operation with a VFD, most are rated to operate properly with unity power factor. In addition, for generator use, the four-quadrant regenerative capability can be turned off to reduce the risk of back-feeding the generator.
Summary

With this technology, it is now possible to replace a passive diode bridge rectifier with a low-harmonic input stage or a regenerative input stage. Schneider Electric’s low harmonic Altivar 680 and 980 drive solutions are flexible for any industry and any application that requires a compact low harmonic solution.

Benefits include no additional high-frequency CM voltage, lower cost of total ownership, and dramatically reduced harmonics. One of the most beneficial elements these low harmonic drives deliver are lower bearing currents when compared to simple two-level active front end drives. This industry-leading, three-level active rectification design results in lower output bearing currents, similar to those found with typical 6-pulse drive systems. These reduced bearing currents increase the service life of the motor bearings.

Due to the optimized LCL input filter, high-frequency emissions caused by the switching actions of the active bridge are well attenuated to values below 0.5%. The possible resonance of the input filter is damped by an innovative lossless active damping control strategy implemented in the controller of the low harmonic drive system. The resonant tank built by the filter elements cannot be excited by the utility grid.

Due to the three-level topology, the lossless damping of the input filter, and the optimized DC bus voltage, this low harmonic solution exhibits very high efficiency. The Altivar 680 and 980 low harmonic drive systems improve reliability and efficiency in generator applications by maintaining a power factor near unity down to 20% of VFD rated full load amps. This high efficiency, combined with the high input current quality, small size, and significant reduction of high-frequency CM voltage caused by the active bridge, make this three-level low harmonic offer by Schneider Electric a good technology selection for a drive system with low harmonic requirements with or without power line regenerative capabilities. Thus begins a new chapter in power conversion devices.
About the authors

This publication was produced by the US Drives Team. Michael Hartmann authored document no. 998-19786993_GMA-US, which was used extensively in this publication. Garrett Abbott-Frey and Jim Crook published this document to help introduce the new ATV680/980 low harmonic drive offer from Schneider Electric and provide an overview of its total benefits.

Garrett received his B.S. in Mechanical Engineering from North Carolina State University and has an extensive background in physics and offer management. Jim received his B.S. in Electrical Engineering from North Carolina State University, holds multiple patents, and has composed numerous technical papers.