Pacific Power Source Application Note

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Line to Line Voltage Considerations with Line Injected Harmonics

Overview

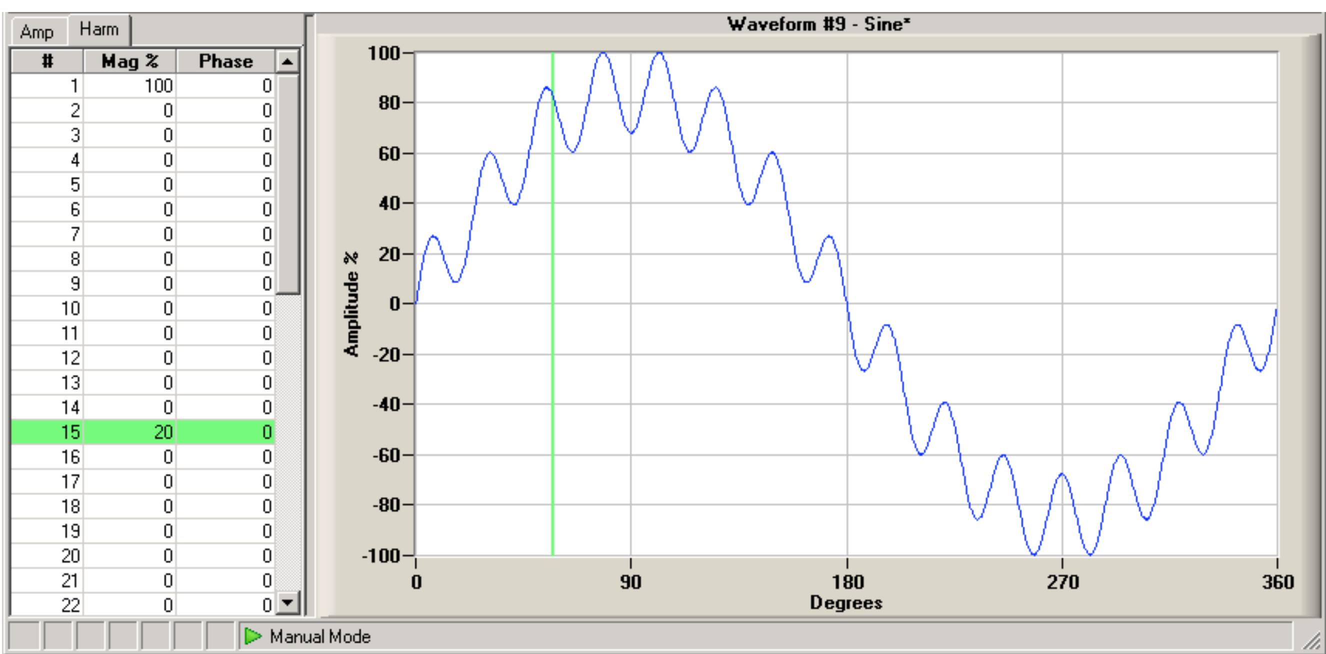
Linear AC power sources feature low-distortion, wide-bandwidth, excellent transient response, and the lowest possible output impedance. The advantage of linear amplifications is faithful reproduction of the (synthesized) oscillator waveforms. This ability to create synthesized waveforms makes Pacific's AMX Series power source ideal for simulating AC Power Line Harmonics and other power perturbations.

The purpose of this application note is to familiarize the reader with how various harmonics injected on individual phases (Line to Neutral) may not produce the expected results when observed Line to Line.

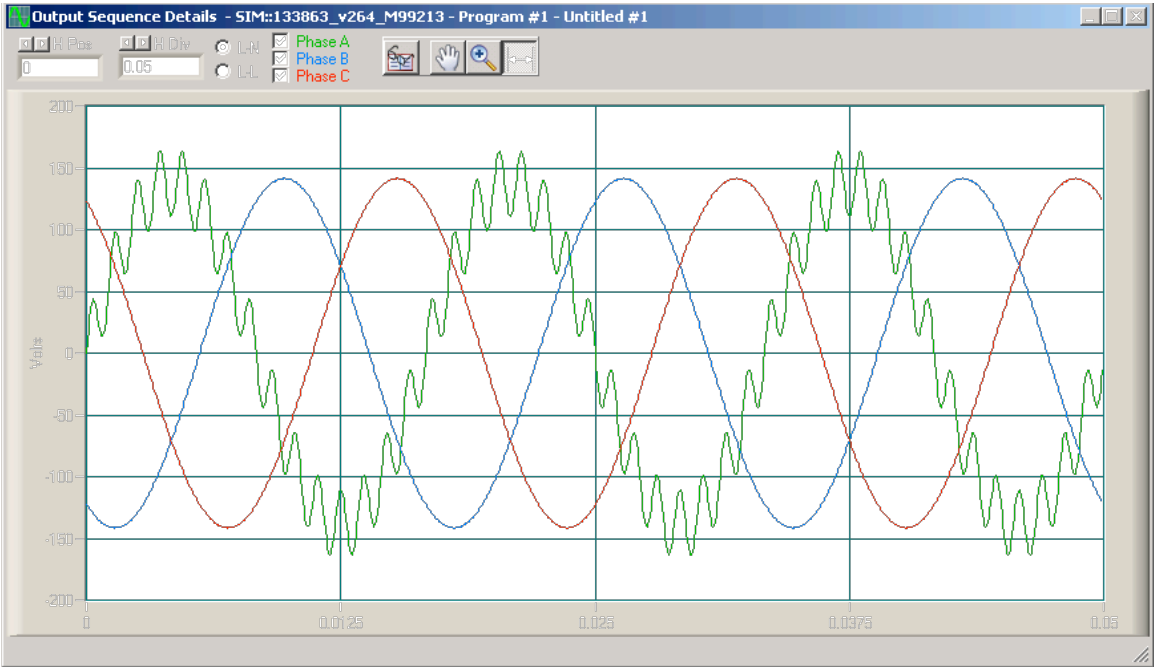
Pacific's AMX Series amplifier has a full power bandwidth of 5kHz with the ability to simulate small signal frequencies of up to 50kHz at up to 10% of the nominal output voltage. Using the full power bandwidth of the amplifier, a customer could create harmonic levels varying from 100% of the 100th harmonic at 50Hz. to 10% of the 10th harmonic at 5kHz.

Pacific's UPC 32 Programmable Controller with the Harmonic Analysis and Synthesis (HAS) option has the ability to create harmonics through the 50th order. Pacific's UPC Software may also be used to create custom waveforms of varying harmonic content and phase angle. These waveforms of varying harmonic content can then be downloaded via the remote interface and executed by the AC Power Source.

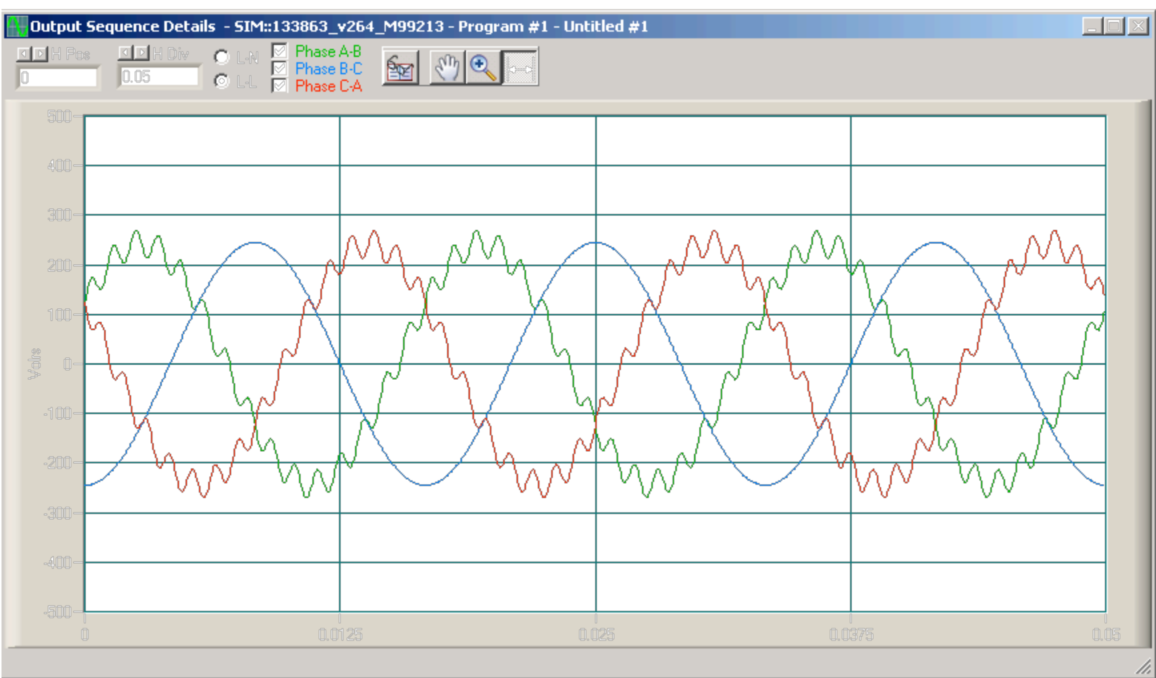
All of Pacific's programmable controllers permit the operator to specify the waveform and amplitude of each phase independently. When executed by the power source, all references are line to neutral. That is to say the operator may select the waveform to be executed on Phase A, B, and C independently. Shown below is a typical waveform where 20% of the 15th harmonic is programmed on the output waveform.



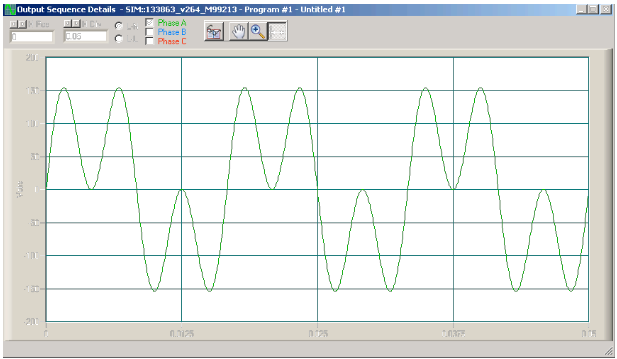
When the harmonic waveform is executed on the output of the power source, the resulting waveforms, measured line to neutral appear as follows:



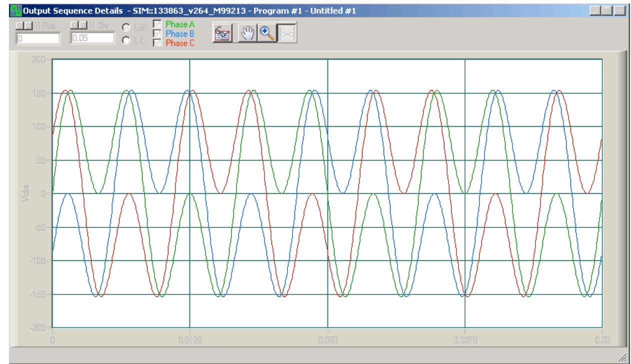
However, the three phases look very different when observed Line to Line. Even though the harmonic was only injected on phase A, both the A-B vector and C-A vectors are distorted. Note also that the B-C vector remains unchanged. The only difference between the two waveform captures is the point of reference. Above we are “referenced” to neutral and looking at the individual phases. Below we are referenced to a given phase relative to the other.



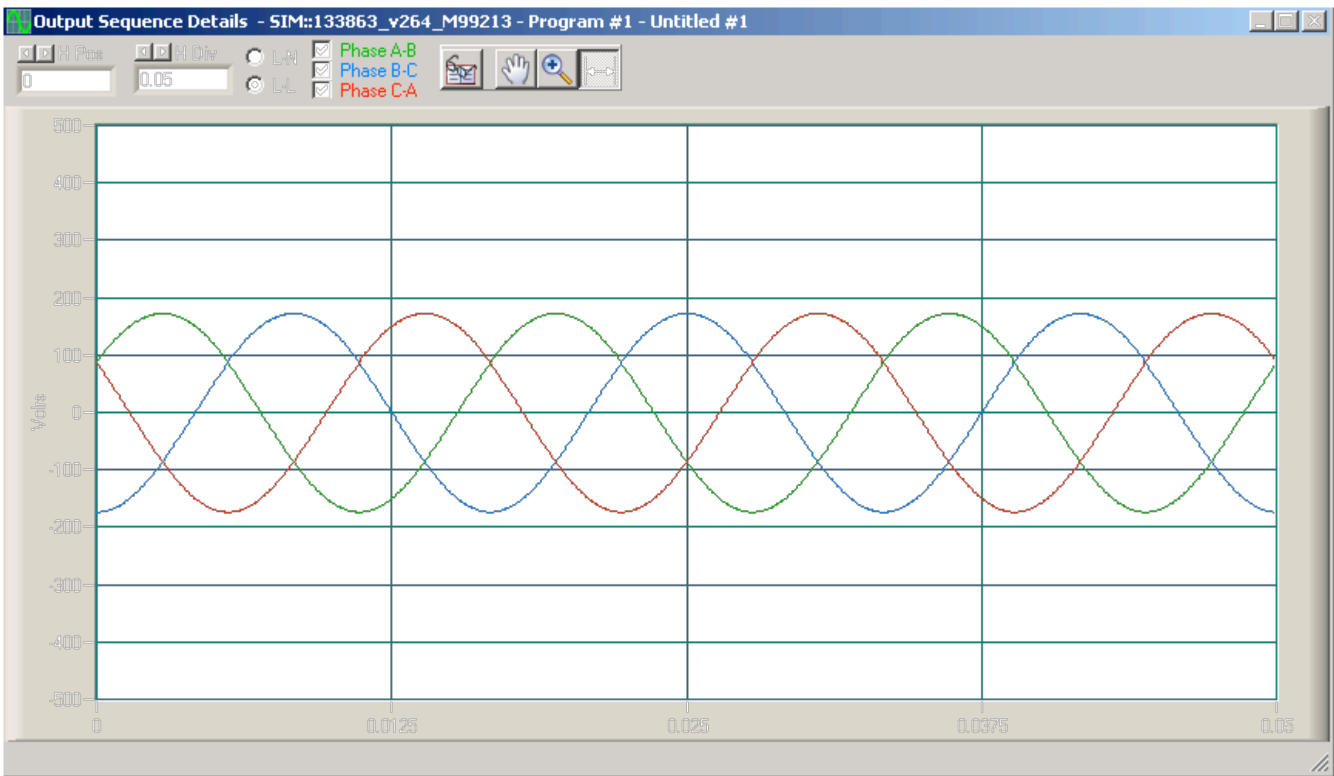
In the previous example, only one phase was modified; therefore the harmonic content is simply added to the non-distorted waveform. However, if two or three phases are modified, then under certain conditions the harmonics may actually cancel one and other when observed line to line.



Phase A to N – 100% 3rd Harmonic



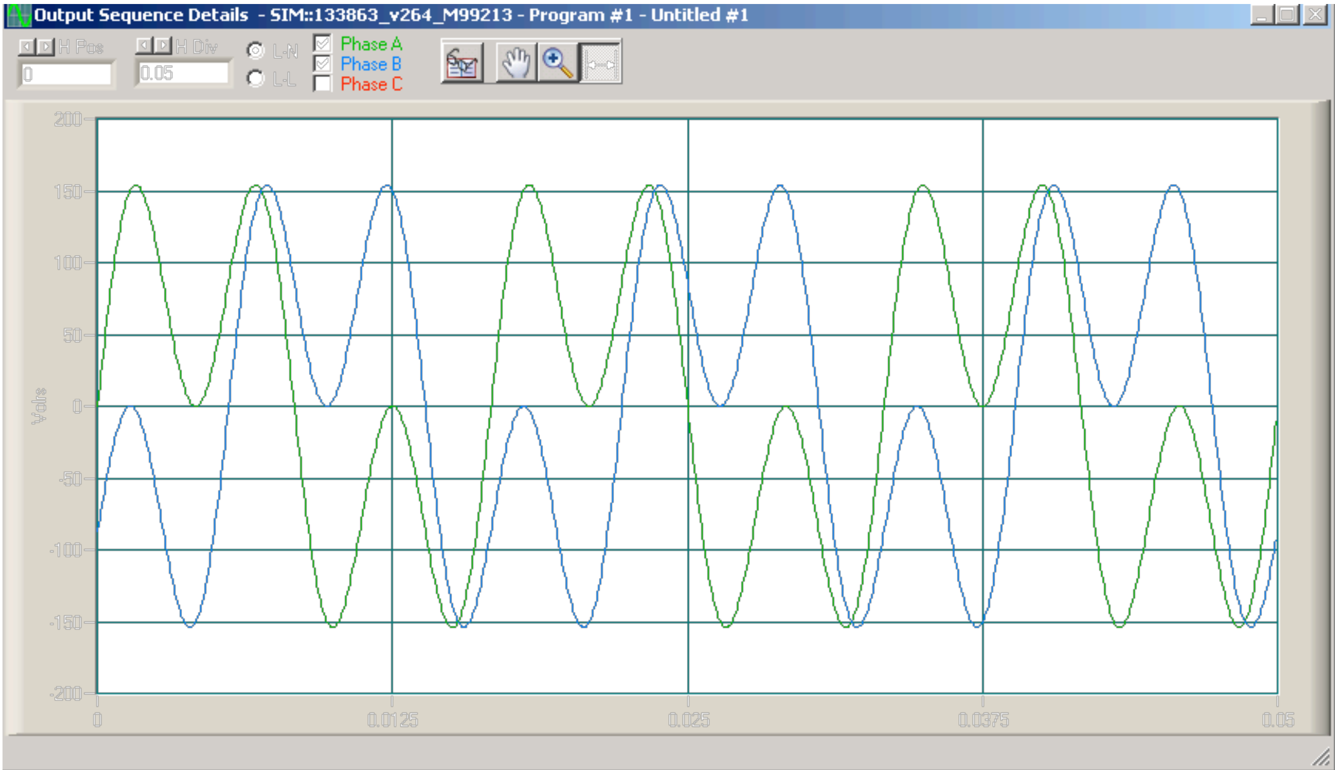
Phases A, B, C to N – 100% 3rd Harmonic



Phases A, B, C Referenced Line to Line

Note that while the Line to Neutral voltages remain highly distorted, the Line to Line waveforms appear to be normal sine waves but of a lesser amplitude. Since the waveforms were executed with a normal 120 degree phase shift, the harmonic order crosses 0 degrees at the same time the fundamental crosses 120 degrees.

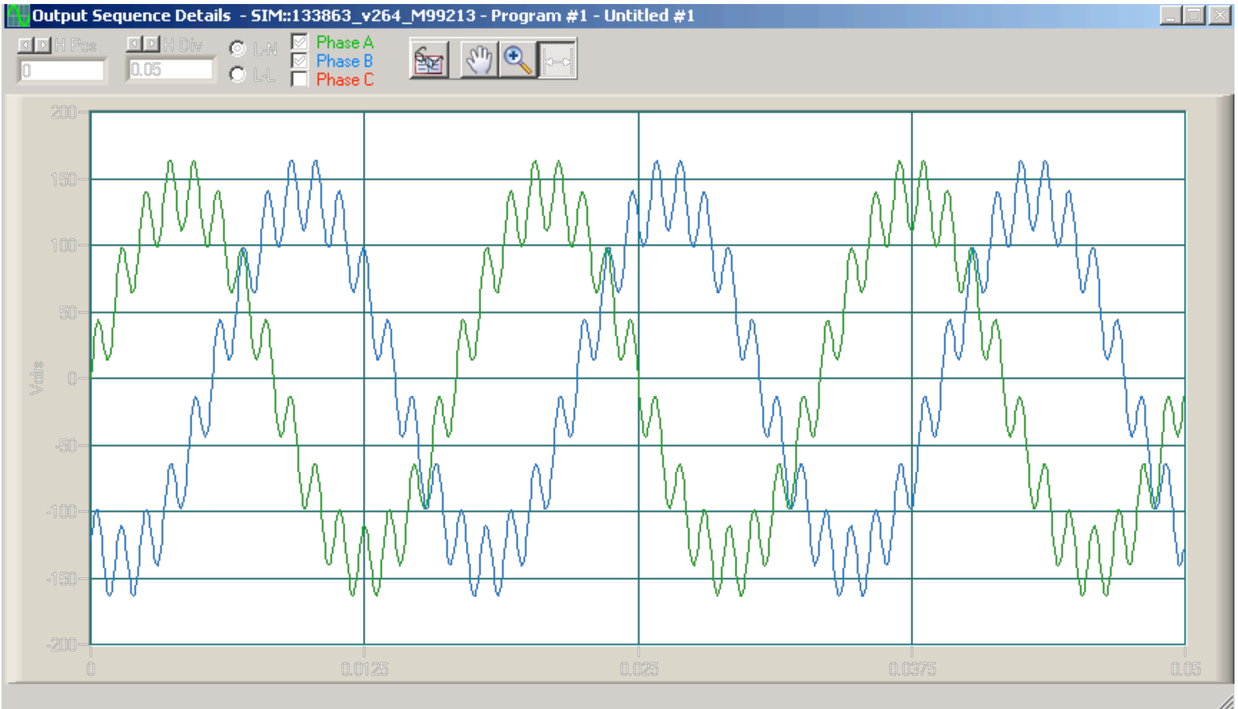
Referring to the phase to neutral waveforms, one can see that while phase A and B are always moving in the same direction, the amplitude of one phase at any point in time is much larger than the other. When these two points are added together, the result is a synchronous but lesser value.



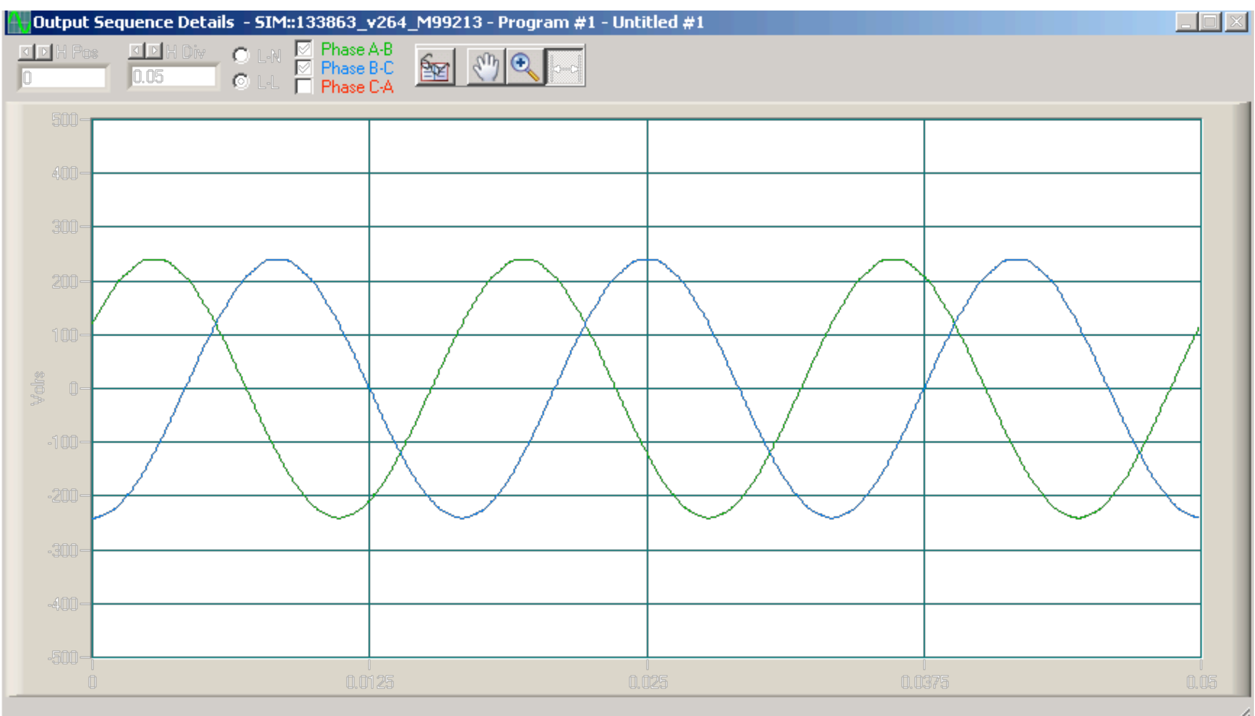
When testing with a 120 degree phase angle between the fundamental phases, one can anticipate that the harmonics will cancel on any harmonic order that is divisible by 3. With 360 degrees in the waveform vector, any harmonic whose zero crossing occurs at 120 degrees on the fundamental waveform will result in common mode cancellation when observed line to line, (i.e. 3^{rd}, 6^{th}, 9^{th}, 12^{th}, etc.). All other harmonic orders will result in either a $1/3^{rd}$ or a $2/3^{rds}$ remainder (5/3=1.666) and thus will cause harmonics that add to the peak of the fundamental waveform (zero crossing of the harmonic order does not occur at 120 degrees on the fundamental).

Two examples that demonstrate this point, one with 20% of the 15^{th} Harmonic and one with 20% of the 17^{th} Harmonic, are shown below.

Harmonic order divisible by 3 creates common mode cancellation when observed Line to Line.

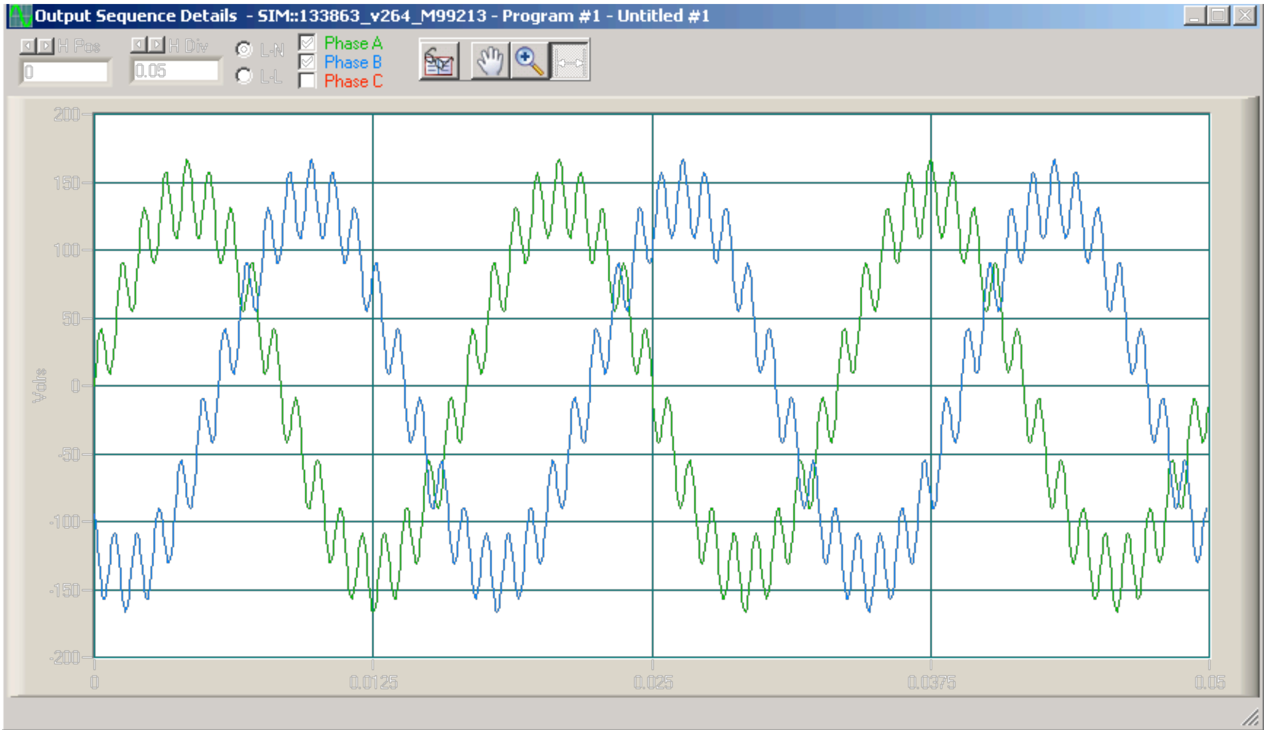


Phases A and B – Line to Neutral 20% 15th Harmonic

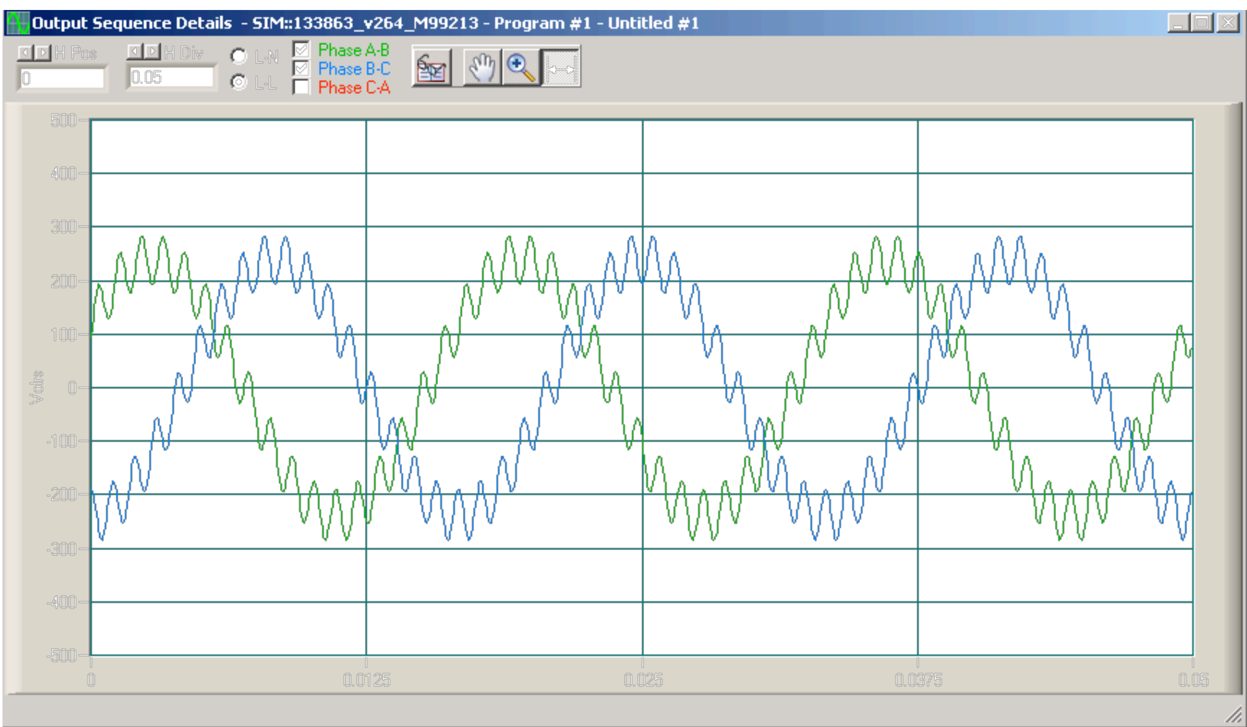


Phases A and B – Line to Line , 20% 15th Harmonic

Harmonic order not divisible by 3 adds harmonic distortion when observed Line to Line.



Phases A and B – Line to Neutral 20% 17th Harmonic



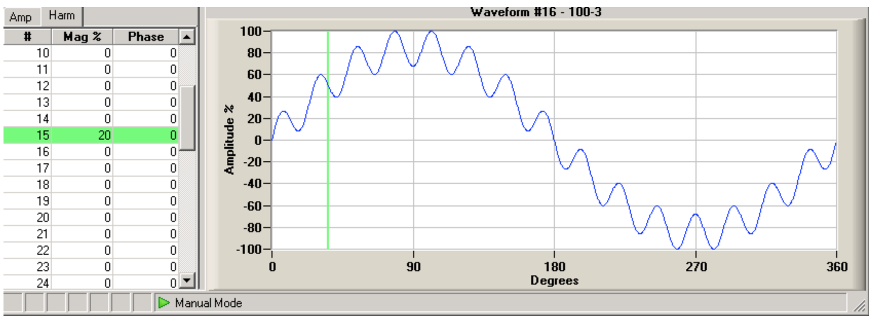
Phases A and B – Line to Line , 20% 15th Harmonic

Test Application – How to create additive, integer (3), line to line harmonics

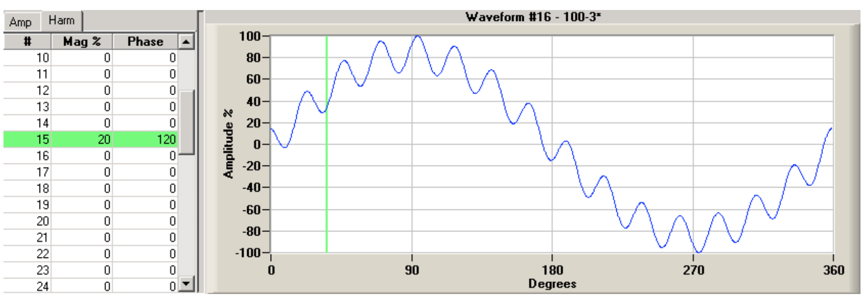
As previously noted, when a waveform of equal harmonic content is executed on all three phases, there are conditions where common mode cancellation will occur on the phase to phase results. This is easily demonstrated when the angle between the phases is 120 degrees and the harmonic order is divisible by 3. Zero crossing of the harmonic occurs at 120 degrees on the fundamental.

Using Pacific's waveform synthesis capabilities, it is possible to create line to line results where the integer (3) harmonics can be forced to add to the peak of the waveform. An additional feature of Pacific's HAS option is the ability to specify not only the harmonic order and percent harmonic, but also the starting phase angle of the harmonic. By using three different waveforms, each with the same harmonic content, but offset by the normal 120 degree phase angle, the zero crossing of the harmonic order is moved off the 120 degree point of the fundamental.

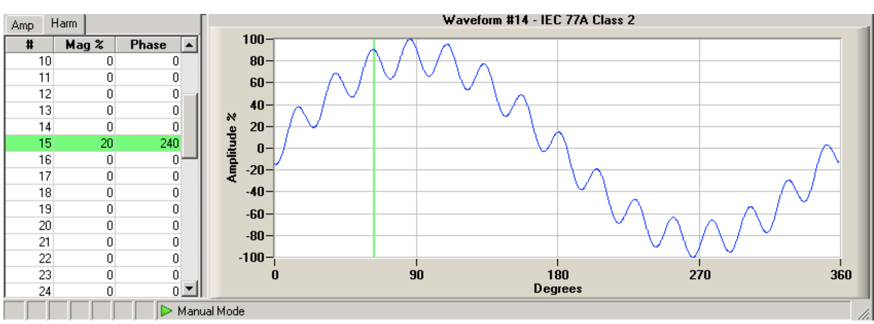
The three waveforms are shown below:



20%, 15th Harmonic with 0 phase shift executed on phase A

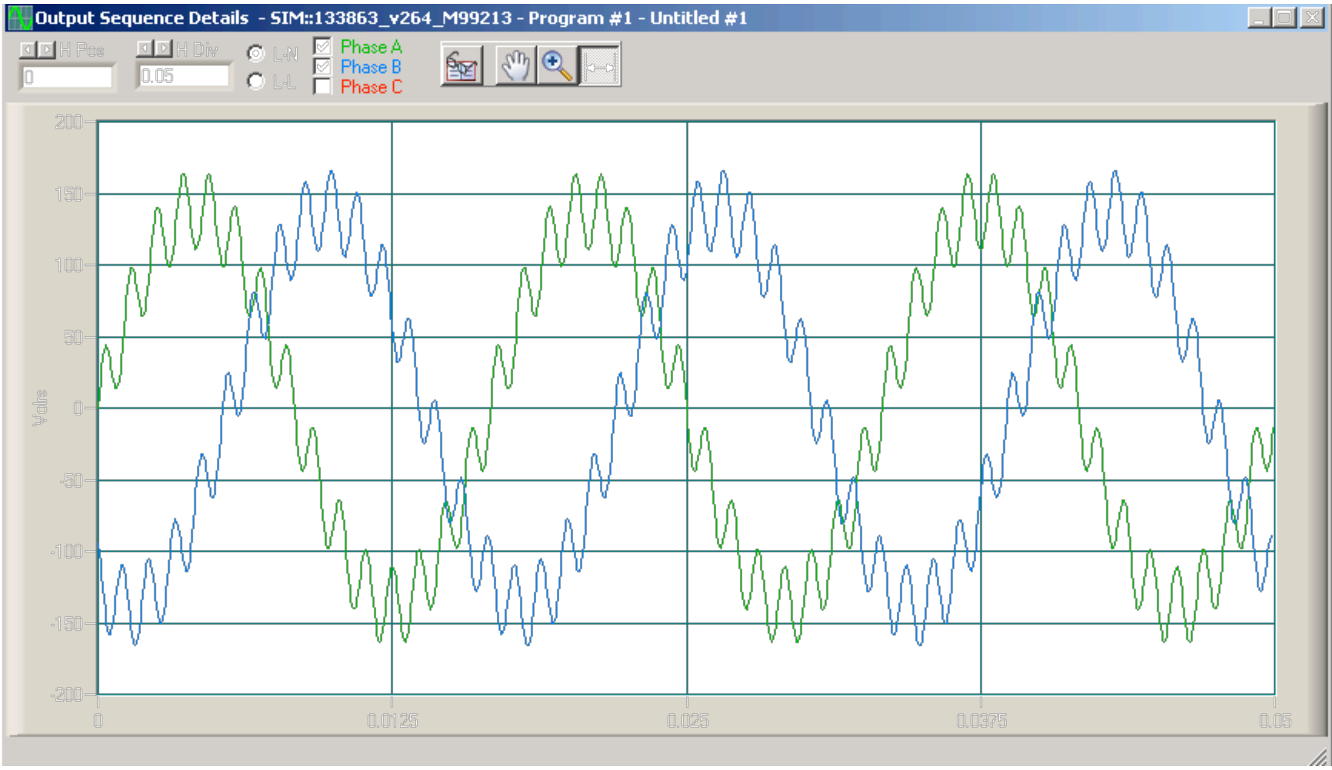


20%, 15th Harmonic with 120 phase shift executed on phase B

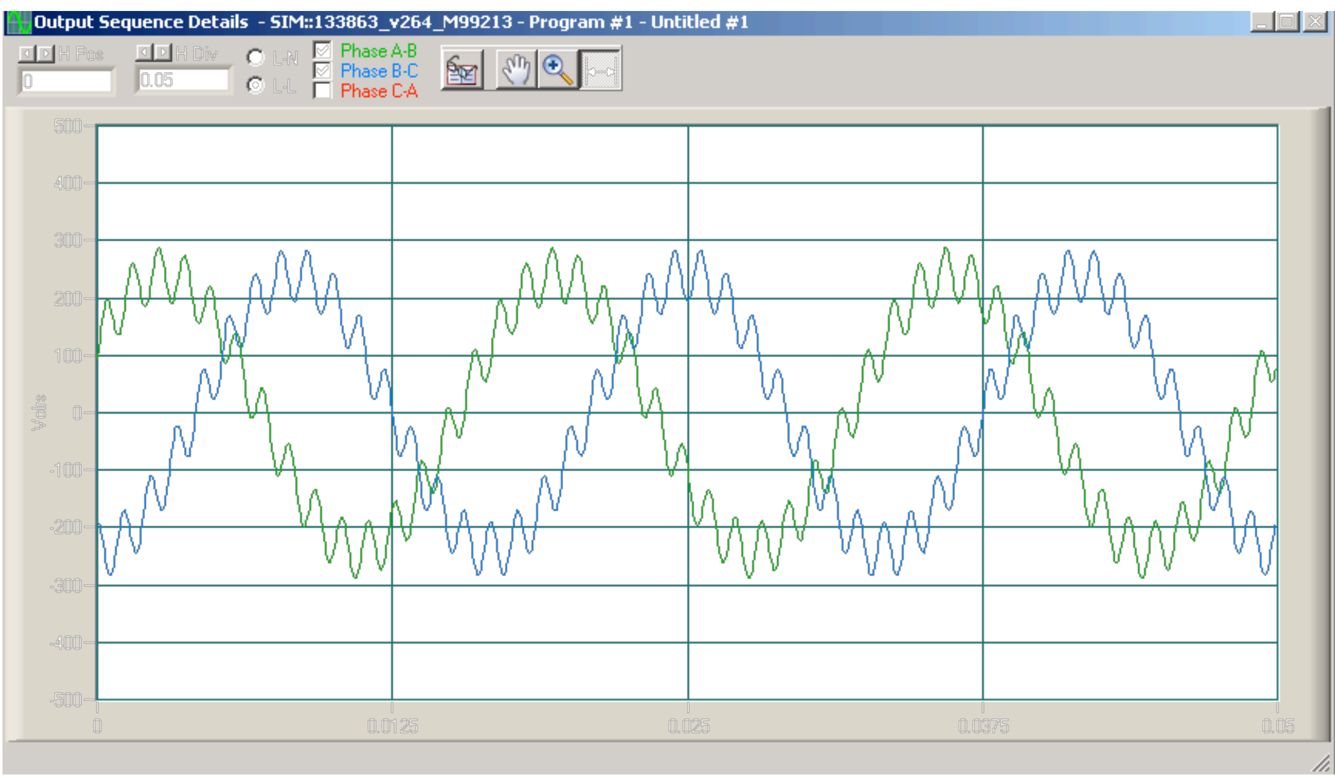


20%, 15th Harmonic with 240 phase shift executed on phase C

Adding 120 degree phase shift to Harmonic order can be used to eliminate common mode cancellation of integer (3) harmonics.



Phases A and B 15th harmonic (phase shifted) results referenced Line to Neutral



Phases A and B 15th harmonic (phase shifted) results referenced Line to Line

Conclusion

Pacific's UPC Controllers provide the test engineer with the best possible power quality and waveform synthesis capability. However, calculation of line to line results, either in harmonic or transient conditions is not always intuitive. It should be noted that in any three phase application, a disturbance placed on a single vector (phase A, B, or C) will always affect both adjacent phase to phase vectors. Careful planning and a thorough understanding of vector addition and line interaction is necessary to fully appreciate the power of Pacific's arbitrary waveform capabilities.

When creating complex waveforms, harmonics, transients and output sequences, Pacific's ***UPC Studio Software*** is an invaluable tool.

The graphic below is a screen capture of the UPC Studio software used to test and evaluate the results of the previous discussion including the Output Sequence Browser, Waveform editor, and the Output Sequence Details view.