AN_6533_011

APPLICATION NOTE

MAY 2009

CE34A11 - 6533 with ID (NC), Harmonic Analysis, & RTP

Introduction

Teridian is introducing a new compute engine (ce) code that supports measured neutral current using the ID input for 6533/34 while retaining vectored-sum calculated neutral current. Seven A/D inputs (IA, VA, IB, VB, IC, VC & ID) are measured instead of six to allow for this measurement. The sample rate for this code is Fs = 2184.53 Hz (32768 Hz/15).

This compute engine firmware supports measuring harmonics present on the voltage, current, and the power measurements to use for analysis. This measurement is performed by using a tracking band-pass filter whose center frequency is programmable in the ce code. A broadband VAR calculation using a digital all pass filter is utilized in this ce code to improve the frequency response of VAR over the standard phase shift bilinear integrator.

This compute engine firmware also supports a real time pulse output for *EQU* = 2 and *EQU* = 5 with the following capabilities:

1. A zero latency pulse output for WPULSE pulse generator based on net Wh, sum Wh, net VARh, or sum VARh.
2. A zero latency pulse output for VPULSE pulse generator based on Net VARh.
3. Real time pulse works with adjustments for non-linearities using *QUANT* for Wh and *QUANT_VAR* for VARh.

MPU I/O RAM settings

The following modifications are required from the standard MPU code for 6533/34.

1. MUX_DIV = 7 (I/O RAM location 209D[3:0]).
2. SEL_IDN = 0 (I/O RAM location 20AD[5]) if using ID in single-ended input configuration as in 6533/34 Demo Board.
3. SLOT6_SEL = 6 (I/O RAM location 2093[3:0]).
4. **Note**: **the length of the ADC decimation FIR filter remains the same, FIR_LEN = 1 (288) (I/O RAM location 2007[3:2]).**
5. PLS_MAXWIDTH = 0xFF (I/O RAM location 2080[7:0]).
6. PLS_INTERVAL = 0 (I/O RAM location 2081[7:0]).
7. PLS_INV = 1 (I/O RAM location 2004[6]).
8. The ce code must be run with CE10MHZ = 1 (I/O RAM location 2000[3]).

Tests were run to show the performance of Wh, Varh, ID Neutral Current, and harmonic analysis.

CE Variables

The following table shows only the ce variables that were either added or required changes in conversion factors from the standard ce code described in the 6533/34 data sheet.

Note: I3SQSUM_X was added for ID, but W3SUM_X (0x89) and VAR3SUM_X (0x8E) are not used when measuring neutral current.

Energy Transfer Variables

CE Address	Name	Description
0x85	*WSUM_X*	The signed sum: *W0SUM_X+W1SUM_X+W2SUM_X*.
0x86	*W0SUM_X*	The sum of Wh samples from each wattmeter element. LSB = 1.0851*10^{-12} V*MAX IMAX* / *In_8* Wh.
0x87	*W1SUM_X*	
0x88	*W2SUM_X*	
0x8A	*VARSUM_X*	The signed sum: *VAR0SUM_X+VAR1SUM_X+VAR2SUM_X*.
0x8B	*VAR0SUM_X*	The sum of VARh samples from each wattmeter element. LSB = 1.0851*10^{-12} *VMAX IMAX* / *In_8* VARh.
0x8C	*VAR1SUM_X*	
0x8D	*VAR2SUM_X*	

Harmonic Energy Transfer Variables

CE Address	Name	Description
0xA0	*WSUM_H_X*	The signed sum: *W0SUM_X+W1SUM_X+W2SUM_X*.
0xA1	*W0SUM_H_X*	The sum of Wh samples from each wattmeter element through the tracking band pass filter. LSB = 1.0851*10^{-12} V*MAX IMAX* / *In_8* Wh.
0xA2	*W1SUM_H_X*	
0xA3	*W2SUM_H_X*	

Measurement Transfer Variables

CE Address	Name	Description
0x8F	*I0SQSUM_X*	The sum of squared current samples from each element. LSB = 1.0851*10^{-12} IMAX^2 / *In_8*^{2} A^{2}h
0x90	*I1SQSUM_X*	
0x91	*I2SQSUM_X*	
0x92	*INSQSUM_X*	The sum of squared current samples from the calculated neutral: $\sum (I_0 + I_1 + I_2)^2$ LSB=1.0851*10^{-12} IMAX^2 / *In_8*^{2} A^{2}h
0x9E	*I3SQSUM_X*	The sum of squared current samples from measured neutral (ID). LSB = 1.0851*10^{-12} IMAX^2 / *In_8*^{2} A^{2}h
0x93	*V0SQSUM_X*	The sum of squared voltage samples from each element. LSB= 1.0851*10^{-12} VMAX^2 V^{2}h
0x94	*V1SQSUM_X*	
0x95	*V2SQSUM_X*	

Harmonic Measurement Transfer Variables

CE Address	Name	Description
0xA4	*I0SUM_H_X*	The sum of squared current samples from each element through the tracking band pass filter. LSB = $1.0851*10^{-12}$ $IMAX^2$ / In_8^2 A^2h
0xA5	*I1SUM_H_X*	
0xA6	*I2SUM_H_X*	
0xA7	*V0SUM_H_X*	The sum of squared voltage samples from each element through the tracking band pass filter. LSB= $1.0851*10^{-12}$ $VMAX^2$ V^2h
0xA8	*V1SUM_H_X*	
0xA9	*V2SUM_H_X*	

Other Transfer Variables

CE Address	Name	Description
0x82	*FREQ_X*	Fundamental frequency: LSB $\equiv \frac{F_S}{2^{32}} \approx 0.5087 \cdot 10^{-6}$ *Hz*
0x97	*PH_AtoB_X*	Phase lag from VA to VB. The angle in degrees is (0 to 360): *PH_AtoB_X* * 360/(V_ANG_CNT*N_{ACC}) + 2.4*(15/13) The selection of the reference phase is based on *FREQSEL1* and *FREQSEL0* in the *CECONFIG* register.
0x98	*PH_AtoC_X*	Phase lag from VA to VC. Angle in degrees is (0 to 360): *PH_AtoC_X* * 360/(V_ANG_CNT*N_{ACC}) + 4.8*(15/13)
0x83	*MAINEDGE_X*	The number of edge crossings of the selected voltage in the previous accumulation interval. Edge crossings are either direction and are debounced.

CE Pulse Generation Parameters

CE Address	Name	Default	Description
0x21	*WRATE*	227	Kh = VMAX*IMAX*76.3594 / (*In_8***WRATE**N_{ACC}*X) Wh/pulse. **Only used for XPULSE and YPULSE.**
0x23	*SUM_PRE*	2184	*PRE_SAMPS* * *SUM_CYCLES* (N_{ACC})
0x3C	*PULSEWIDTH1*	12	Register for pulse width control for XPULSE and YPULSE. MAX PULSE WIDTH = (2*PULSEWIDTH1+1)* (1/F_S). The default value will generate pulses of 11.4 ms width at FS = 2184.53Hz.
0x3E	*PULSEMAX*	23629395	K_h = ($1.0851*10^{-12}$ * *VMAX* * *IMAX*) * *PULSEMAX* *Wh/Pulse*. The default value results in a Kh of 3.2 Wh/pulse when 2520 samples are taken in each accumulation interval (*VMAX* = 600, *IMAX* = 208).
0x3F	*RPULSEMAX*	23629395	K_h = ($1.0851*10^{-12}$ * *VMAX* * *IMAX*) * *PULSEMAX* *Varh/Pulse*. The default value results in a Kh of 3.2 Wh/pulse when 2184 samples are taken in each accumulation interval (*VMAX* = 600, *IMAX* = 208).
0x38	*PULSEWIDTH*	100	The *PULSEWIDTH* controls the width of the output pulse. A *PULSEWIDTH* = 1 results in a 457.8us pulse. The pulse is always negative going. That is the CE drives the pulse to output active low for a defined period of (*PULSEWIDTH* * 457.8)us. The default value results in a pulse width of 39.67milliseconds.

CE Address	Name	Default	Description
0x3D	*PULSESTART*	110790	*PULSESTART* = (WATTSTART * 2048)/(1.0851*10^{-12} * 3600 * *VMAX* * *IMAX* * *Fs)* Where WATTSTART is the wattage for defined starting current and rated voltage. The default value results in WATTSTART = 57.6 Watts for 3 phase system (19.2 watts/phase) (*VMAX*=600, *IMAX* = 208, *Fs* = 2520.6Hz)
0x20[22:21]	*PULSESTATE*	01	*PULSESTATE* bits in CECONFIG[22:21] controls the configuration for selectable pulse output for net Wh, sum Wh, net VARh, and sum VARh on WPULSE. *PULSESTATE* — *WPULSE* 0 — Net VARh 1 — Net Wh 2 — Sum VARh 3 — Sum Wh

CE Parameters

CE Address	Name	Default	Description
0x18	*PHADJ_A*	0	These constants control the CT phase compensation. No compensation occurs when *PHADJ_X* = 0. As *PHADJ_X* is increased, more compensation (lag) is introduced. The range is $\pm 2^{15} - 1$. If it is desired to delay the current by the angle Φ, the equations are: $PHADJ\_X = 2^{20} \frac{0.029965 \cdot TAN\Phi}{0.1714 - 0.0168 \cdot TAN\Phi}$ at 60Hz $PHADJ\_X = 2^{20} \frac{0.0206 \cdot TAN\Phi}{0.1430 - 0.01226 \cdot TAN\Phi}$ at 50Hz
0x19	*PHADJ_B*	0	
0x1A	*PHADJ_C*	0	
0x49	*NFREQ*	-1	When *NFREQ* = -1 the tracking band-pass filter is tuned to the fundamental frequency of measurement and provides the data for fundamental component only. When *NFREQ*>0, the meter is centered on Fpk (Hz) based on the formula *NFREQ=2^14 SQRT((2-gamma)*(1-cos(2pi fpk/fs)))* where gamma=2^-7 fs=32768/13 fpk = Tracking frequency

Variables that were eliminated from this new compute engine firmware and not supported are *APULSEW*, *APULSER*, and *EXT_PULSE*. All other CE variables are described in the latest 6533/34 data sheet.

Real Time Pulse Outputs

A watt-hour meter can be visualized as a device that rotates a disk a certain number of degrees for each unit of energy it measures.

The previous code integrates energy for a complete accumulation interval and then during the next accumulation interval, rotated its pulse generator wheel at a uniform rate so at the end of the accumulation cycle, the wheel had rotated the exact number of degrees corresponding to the accumulated energy. The result is an exact meter, but with a latency equivalent to the accumulation interval.

The new code rotates the pulse generator as power is accumulated, removing the latency time of the previous compute engine firmware revisions. The WPULSE pulse generator can be configured to pulse on net Wh, sum Wh, net VARh, or sum VARh. The VPULSE pulse generator is also permanently configured to Net VARh measurement only.

This configuration for selectable pulse output is controlled by the *PULSESTATE* bits in CECONFIG[22:21] (0x20) variable according to following table.

WPULSE Pulse generator options

PULSESTATE	*EQU* = 5	*EQU* = 2
0	Net VARh = $\lvert SUM(I_AV_{A90} + I_BV_{B90} + I_CV_{C90}) \rvert$	Net VARh = $\lvert SUM(I_AV_{A90} + I_BV_{B90}) \rvert$
1	Net Wh = $\lvert SUM(I_AV_A + I_BV_B + I_CV_C) \rvert$	Net Wh = $\lvert SUM(I_AV_A + I_BV_B) \rvert$
2	Sum VARh = $SUM(\lvert I_AV_{A90} \rvert + \lvert I_BV_{B90} \rvert + \lvert I_CV_{C90} \rvert)$	Sum VARh = $SUM(\lvert I_AV_{A90} \rvert + \lvert I_BV_{B90} \rvert)$
3	Sum Wh = $SUM(\lvert I_AV_A \rvert + \lvert I_BV_B \rvert + \lvert I_CV_C \rvert)$	Sum Wh = $SUM(\lvert I_AV_A \rvert + \lvert I_BV_B \rvert)$

The following control parameters can affect the WPULSE/VPULSE output characteristic.

a. *PULSEMAX & RPULSEMAX*
b. *PULSEWIDTH*
c. *PULSESTART*

PULSEMAX & RPULSEMAX

The *PULSEMAX* (0x3E) value controls the WPULSE pulse rate and *RPULSEMAX* (0x3F) controls the VPULSE pulse rate. That is the value is useful to compute Kh as shown in the following equations:

WPULSE

$K_h = (1.0851*10^{-12} * VMAX * IMAX) * PULSEMAX$ *Wh/Pulse*

VPULSE

$K_h = (1.0851*10^{-12} * VMAX * IMAX) * RPULSEMAX$ *Varh/Pulse*

PULSEWIDTH

The *PULSEWIDTH* (0x38) controls the width of the output pulse. A *PULSEWIDTH* = 1 results in a 457.8us pulse. The pulse is always negative going. That is the CE drives the pulse to output active low for a defined period of (*PULSEWIDTH* * 457.8)us.

Care must be taken to ensure *PULSEWIDTH* is less than the minimum period between pulses otherwise the pulses will bridge together. When *PULSEWIDTH* = 1, the maximum pulse rate is 1260Hz.

PULSESTART (Creep Control Register)

This parameter is useful in controlling the pulse output during the meter in creep mode. For a defined starting current for a meter the *PULSESTART* (0x3D) can be programmed for generating pulses accordingly

$PULSESTART = (WATTSTART * 2048)/(1.0851*10^{-12} * 3600 * VMAX * IMAX * Fs)$

Where

WATTSTART is the wattage for defined starting current (STI) and rated voltage (RV)
WATTSTART = Number of Phases*STI*RV
Fs = 2520.6Hz

Example 1:

STI = 0.08A rms, RV = 240V rms, *VMAX* = 600 V rms, *IMAX* = 208A rms, *Fs* = 2184Hz
EQU 2:

WATTSTART = 2 * 0.08 * 240 = 38.4 Watts

PULSESTART = (38.4 * 2048)/(1.0851*10^{-12} * 3600 * 600 * 208 * 2184) = 73862

Example 2:

STI = 0.08A rms, RV = 240V rms, *VMAX* = 600 V rms, *IMAX* = 208A rms, *Fs* = 2184Hz
EQU 5:

WATTSTART = 3 * 0.08 * 240 = 57.6 Watts
PULSESTART = (57.6 * 2048)/(1.0851*10^{-12} * 3600 * 600 * 208 * 2184) = 110793

Harmonic Analysis

Input and output registers are available from Compute Engine to perform and analyze harmonics present on the voltage and current inputs along with the power measurements are presented below.

Input Register *NFREQ* (0x49)

The Compute Engine measures harmonic contents on voltage and current using tracking band-pass filter whose center frequency is programmable thru the *NFREQ* (0x49) register. When *NFREQ* = -1 the compute engine tunes the band-pass filter to the fundamental frequency of measurement and provides the data for fundamental component only. The compute engine provides watt-hour, *ISQSUM* and *VSQSUM* data utilizing the band-pass filters.

Following is the formula for computing *NFREQ* register values for harmonic components.

NFREQ=2^14 SQRT((2-gamma)(1-cos(2pi fpk/fs)))*

Where

gamma=2^-7
fs=32768/15
fpk = Tracking frequency

Overall the CE code implements two meters. One is our standard 3ph meter with VAR. The other is a frequency selectable meter that measures RMS and Watt-hour. The second meter can either be a tracking meter centered at the fundamental or a fixed frequency meter centered at a frequency programmed by *NFREQ*. When *NFREQ*<0, the meter is a tracking meter. When *NFREQ*>0, the meter is centered on Fpk (Hz) according to the above formula.

When NFREQ>0, the tracking filter, centered on Fpk, introduces a feedthrough component at the fundamental frequency, Fx(0). This feedthrough is the result from the gain attenuation of the filter. The following tables show this attenuation of the fundamental frequency for 50Hz and 60Hz.

Number of Harmonic	Fundamental Frequency	Frequency	NFREQ	Fundamental Atternuation Fx(0)
1	50	50	-1	1
2	50	100	4687	0.00033381
3	50	150	7000	4.7781E-05
4	50	200	9277	1.39249E-05
5	50	250	11506	5.61232E-06
6	50	300	13676	2.74177E-06
7	50	350	15775	1.52565E-06
8	50	400	17792	9.33744E-07
9	50	450	19718	6.14916E-07
10	50	500	21541	4.29713E-07
11	50	550	23253	3.15387E-07
12	50	600	24845	2.41375E-07
13	50	650	26309	1.91595E-07
14	50	700	27637	1.57103E-07
15	50	750	28822	1.3266E-07
16	50	800	29857	1.15095E-07
17	50	850	30739	1.02371E-07
18	50	900	31462	9.32306E-08
19	50	950	32022	8.68443E-08
20	50	1000	32416	8.26768E-08
21	50	1050	32644	8.03793E-08

Number of Harmonic	Fundamental Frequency	Frequency	NFREQ	Fundamental Atternuation Fx(0)
1	60	60	-1	1
2	60	120	5616	0.000232868
3	60	180	8371	3.35945E-05
4	60	240	11065	9.89335E-06
5	60	300	13676	4.0434E-06
6	60	360	16185	2.00994E-06
7	60	420	18574	1.14156E-06
8	60	480	20825	7.15493E-07
9	60	540	22920	4.84467E-07
10	60	600	24845	3.49287E-07
11	60	660	26586	2.65518E-07
12	60	720	28128	2.11397E-07
13	60	780	29461	1.75342E-07
14	60	840	30575	1.50951E-07
15	60	900	31462	1.34506E-07
16	60	960	32114	1.2383E-07
17	60	1020	32527	1.17614E-07
18	60	1080	32699	1.15141E-07
19	60	1140	32627	1.16168E-07
20	60	1200	32312	1.208E-07
21	60	1260	31757	1.29539E-07

Note: Even though the NFREQ register data follows a formula for harmonic analysis, the MPU firmware should use a look up table for feeding the desired harmonic component to the compute engine. The Fx(0) term shown in the tables is the amount of attenuation factor of the fundamental left in the measurement of signal at the selected harmonic. The contribution due to the fundamental for measurement decreases with movement of the tracking filter away from the fundamental component.

Output Registers
When using the tracking filter centered on Fpk (NFREQ>0), the WxSUM_X, IxSUM_X, and VxSUM_X registers contain the wideband information. The WxSUM_H_X, IxSUM_H_X, and VxSUM_H_X registers contain narrowband information for the harmonic frequency based on NFREQ value.

If the tracking filter is centered on the fundamental frequency (NFREQ<0), the WxSUM_X, IxSUM_X, and VxSUM_X registers still contain the wideband information. However, The WxSUM_H_X, IxSUM_H_X, and VxSUM_H_X registers contain narrowband information for the fundamental frequency.

The RMS values can be computed by the MPU from the squared current and voltage samples as per the formulae for both broadband and at any desired harmonic frequency.

Equation 1:

$$Ix_{RMS} = \sqrt{\frac{\{IxSQSUM - (Fx(0) * IxSQSUM(0))\} * \cdot LSB \cdot 3600 \cdot F_S}{N_{ACC}}}$$

Where:
IxSQSUM measured at the selected harmonic
Fx(0) – Attenuation of fundamental component from the table
IxSQSUM(0) -- IxSQSUM measured at fundamental.

Equation 2:

$$Vx_{RMS} = \sqrt{\frac{\{VxSQSUM - (Fx(0) * VxSQSUM(0))\} * \cdot LSB \cdot 3600 \cdot F_S}{N_{ACC}}}$$

Where:
VxSQSUM measured at the selected harmonic
Fx(0) – Attenuation of fundamental component from the table
VxSQSUM(0) -- VxSQSUM measured at fundamental.

Delay Compensation Gain Effects
The ce code uses internal delay compensation on the phase voltage signal path to align it with the associated phase current. This compensation introduces a slight gain (DCG) at Fpk as shown in the following tables..

Delay Compensation Gain for 50Hz Harmonic Components

Harmonic	Freq (Hz)	NFREQ	Delay Compensation Gain(dB)	10^(-DCG/20)
2	100	4687	0.026642472	0.996937
3	150	7000	0.036948138	0.995755
4	200	9277	0.048315538	0.994453
5	250	11506	0.05834708	0.993305
6	300	13676	0.064767297	0.992571
7	350	15775	0.065822255	0.992451
8	400	17792	0.060598035	0.993048

Harmonic	Freq (Hz)	NFREQ	Delay Compensation Gain(dB)	10^(-DCG/20)
9	450	19718	0.049210995	0.99435
10	500	21541	0.032837207	0.996227
11	550	23253	0.01356497	0.998439
12	600	24845	-0.005923941	1.000682
13	650	26309	-0.022808671	1.002629
14	700	27637	-0.034648124	1.003997
15	750	28822	-0.039862451	1.0046
16	800	29857	-0.038065653	1.004392
17	850	30739	-0.030161492	1.003479
18	900	31462	-0.018170287	1.002094
19	950	32022	-0.004823105	1.000555
20	1000	32416	0.006983739	0.999196
21	1050	32644	0.014755255	0.998303

Delay Compensation Gain for 60Hz Harmonic Components

Harmonic	Freq (Hz)	NFREQ	Delay Compensation Gain (dB)	10^(-DCG/20)
2	120	5616	0.030491546	0.996496
3	180	8371	0.043792782	0.994971
4	240	11065	0.056562008	0.993509
5	300	13676	0.064767297	0.992571
6	360	16185	0.065291553	0.992511
7	420	18574	0.056739887	0.993489
8	480	20825	0.039868949	0.99542
9	540	22920	0.01752776	0.997984
10	600	24845	-0.005923941	1.000682
11	660	26586	-0.025645833	1.002957
12	720	28128	-0.037579505	1.004336
13	780	29461	-0.039595976	1.004569
14	840	30575	-0.032147309	1.003708
15	900	31462	-0.018170287	1.002094
16	960	32114	-0.002249471	1.000259
17	1020	32527	0.010691029	0.99877
18	1080	32699	0.016761236	0.998072

This gain can be accounted for in RMS voltage values calculated in Equation 1 for instance applying a correction factor as shown in Equation 3 for RMS voltage.

Equation 3:

$$Vxc_{RMS} = SQRT(10^{(-DCG_{Fpk}/20)})*Vx_{RMS}$$

Where

DCG_{Fpk} = Delay Compensation Gain @ Fpk in dB

Vx_{RMS} = RMS voltage value from Equation 1

As shown in the previous tables, values for DCG for different NFREQ could be stored in a lookup table in memory to be applied by the MPU.

Broadband VAR

The VAR CE standard code shifted the fundamental and all harmonics by 90 degrees, but exhibited a 1/f amplitude characteristic on harmonics. Specifically, the fundamental, regardless of frequency, was always shifted at unity gain. The third harmonic was attenuated by 3x, the fifth by 5x, etc.
The new code utilizes a digital all-pass filter having exact unity gain at all frequencies and nearly 90º-phase shift from 40Hz to 1220Hz. The exact performance of this filter is as follows:

Frequency (Hz)	Phase Error (Deviation from 90 degrees)
40 to 1220	<3.7degrees
48.5 to 63	<0.05 degrees
50	<0.0002 degrees
60	<0.0005 degrees

The phase error introduced by this filter is digitally compensated.

CKCE Clock Speed

This ce code utilizes 653X feature of changing CKCE from 5MHz to 10MHz to increase the CE processing capacity. The is feature is enabled by setting the CE10MHz bit in I/O RAM register CE0[3] (0x2000). Note: this feature is only available when M40MHz = 1 and M26MHz = 0 bits (refer to data sheet, Clock Summary Table) of I/O RAM register CONFIG1 (CONFIG1[0] and CONFIG1[2] at 0x2005).

CE Code Resources

Based on ce34a10
CE DRAM:
402 32-bit words (1608 bytes)
CE Program:
1837 16-bit words (3674 bytes)
CE Cycles:
2697

Upgrading Firmware

The following files can be used for the CE specifications described above

1. ce34a10.ce
2. ce34a10.dat
3. ce34a10_ce.c
4. ce34a10_dat.c

How to use these files:
Upgrade the CE code to the new version by the following techniques:

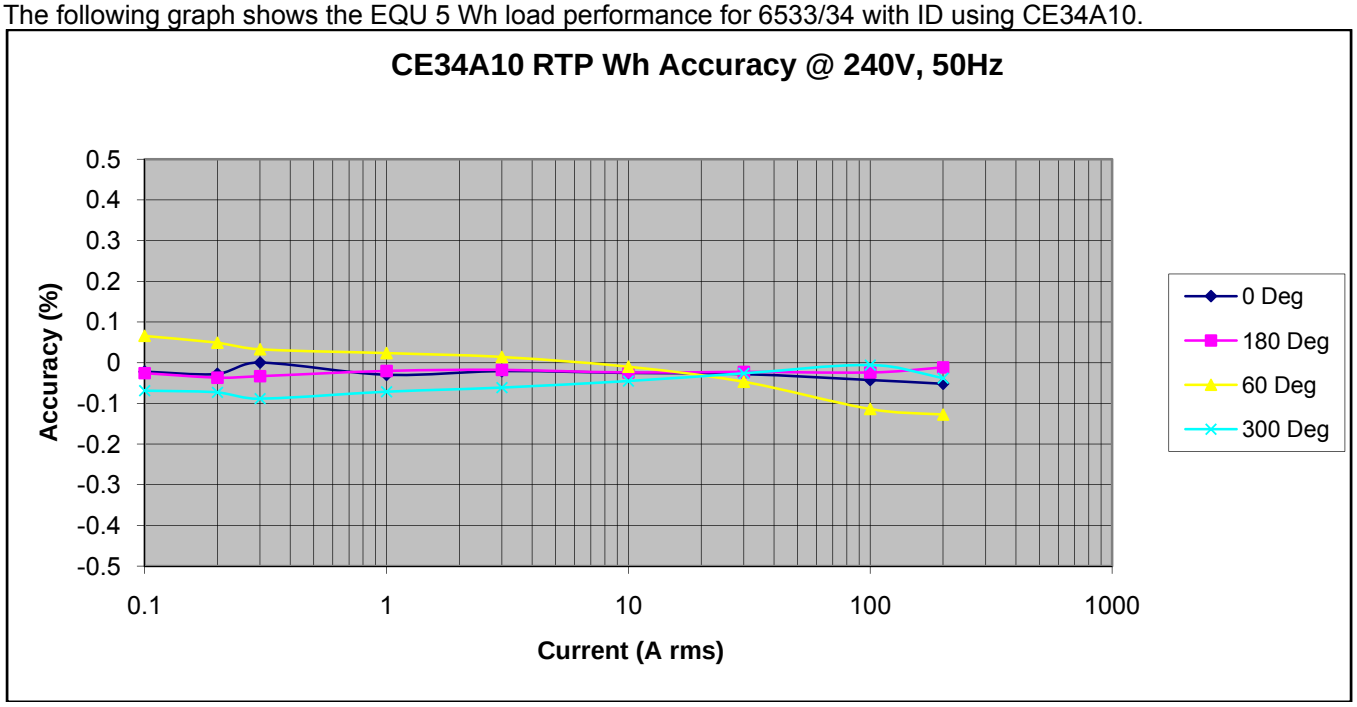
1. Using CE_MERGE technique and upgrade the current hexadecimal file. That is the existing CE files (*.ce and *.dat) files will be updated to the new hex file without modifying the existing hex file.
2. If in the development stage, use the include files (*ce.c & *dat.c) for building project in the compiler environment.

Test Results:

Tests were run to show the performance of Wh, Varh, ID Neutral Current, current measurement without the presence of line voltage, and the tracking band pass filter.

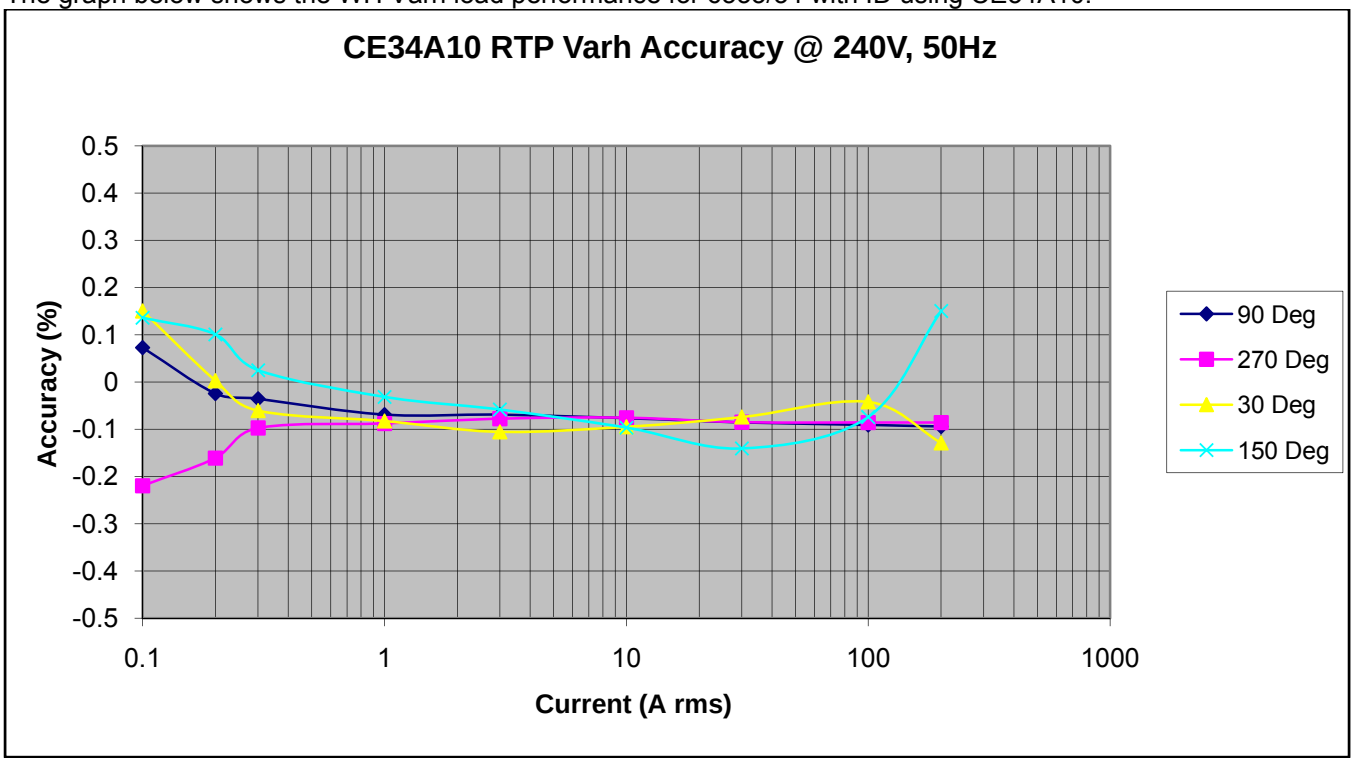
Wh Performance

The following graph shows the EQU 5 Wh load performance for 6533/34 with ID using CE34A10.



Varh Performance

The graph below shows the WH Varh load performance for 6533/34 with ID using CE34A10.



Neutral Current ID

The following table shows measurements taken after an accumulation period for the measured neutral current ID attached to a CT sensor.

	Measured Neutral I	
Current (A rms)	I3SQSUM_X	I3
200	236806738	200.0537
100	59142346	99.9767
50	14793888	50.0024
30	5325686	30.0011
10	590467	9.9896
3	53242	2.9997
1	5938	1.0018
0.5	1492	0.5022
0.3	536	0.3010
0.1	65	0.1048
0.05	19	0.0567
0.03	10	0.0411
0.01	5	0.0291

Current in The Presence of Line Voltage

These test results show the current registers with and without the presence of line voltage.

	@ Vline = 240V			@ Vline = 0V		
Current (A rms)	I0SQSUM_X	I1SQSUM_X	I2SQSUM_X	I0SQSUM_X	I1SQSUM_X	I2SQSUM_X
10	558847	558645	558717	558832	558679	558662
5	139704	139657	139711	139694	139610	139696
1	5591	5590	5591	5589	5591	5590

Harmonics Analysis Test Results

As per the IEC 62052/IEC 62053 and ANSI C12.20 metering standards, the Voltage applied to the meter was fed with 20% fundamental voltage harmonic component along with 40% of fundamental current fed to the meter that is upgraded with the CE firmware to support harmonics. The Fluke 6100A with phantom load with harmonic generation capability was used for verifying the performance.

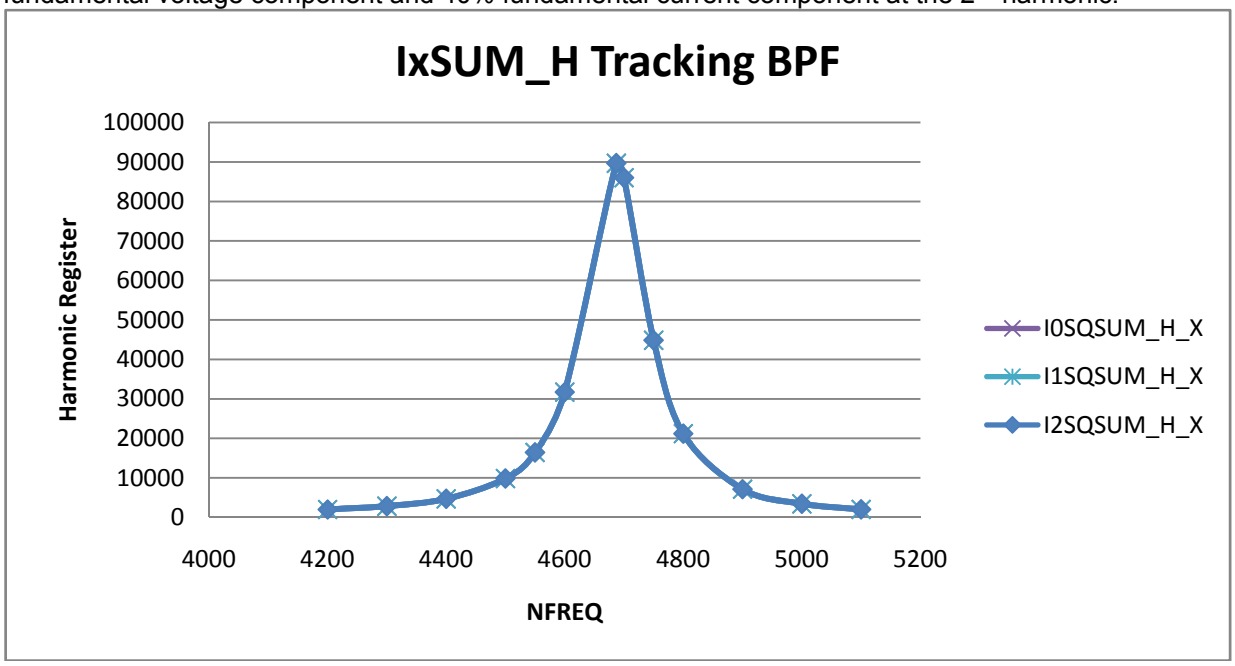
Please note that the harmonic performance of the measurement can be accurate from 1% of the fundamental component onwards.

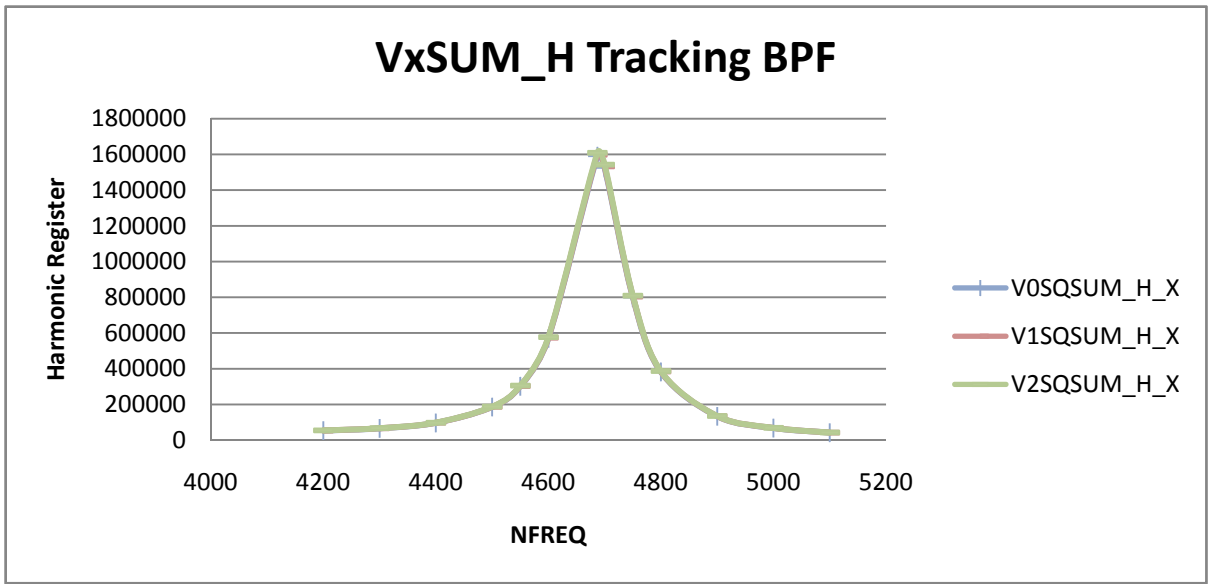
Tracking Band Pass Filter with Center @ Fpk

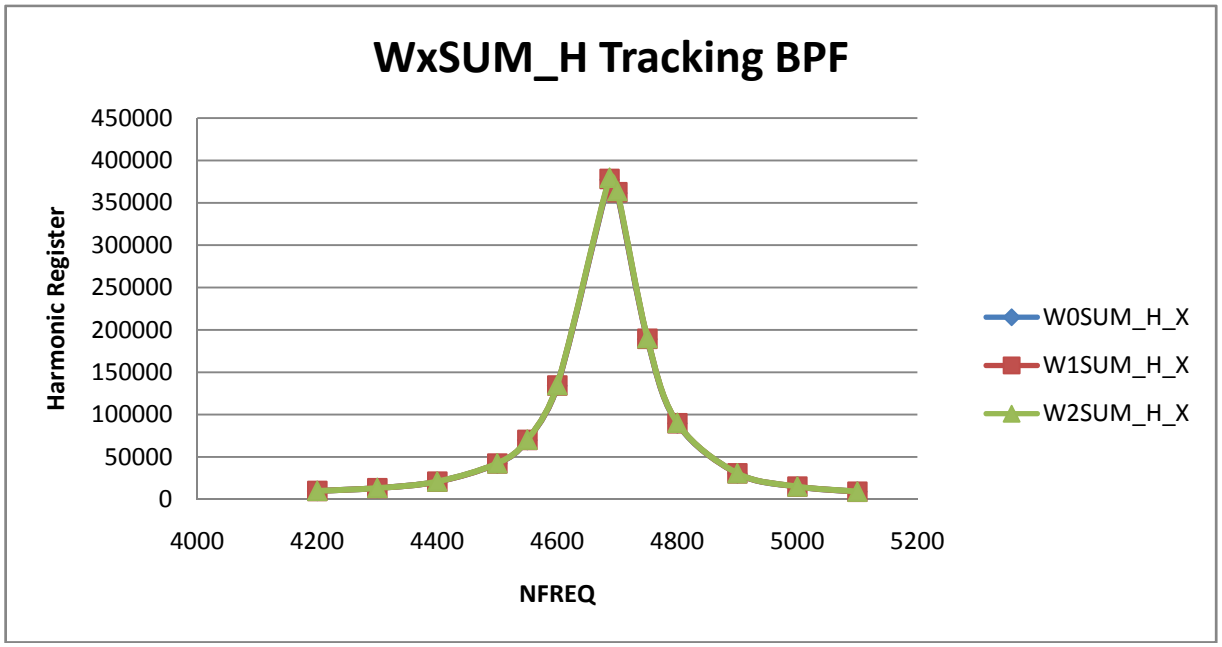
Recall that when using the tracking filter centered on Fpk (NFREQ>0), the WxSUM_X, IxSUM_X, and VxSUM_X registers contain the wideband information. The WxSUM_H_X, IxSUM_H_X, and VxSUM_H_X registers contain narrowband information for the harmonic frequency based on NFREQ value.

Filter Response

The following graphs show the tracking band pass filter response for the case of 240V, 10A, 50HZ, with 20% fundamental voltage component and 40% fundamental current component at the 2nd harmonic.

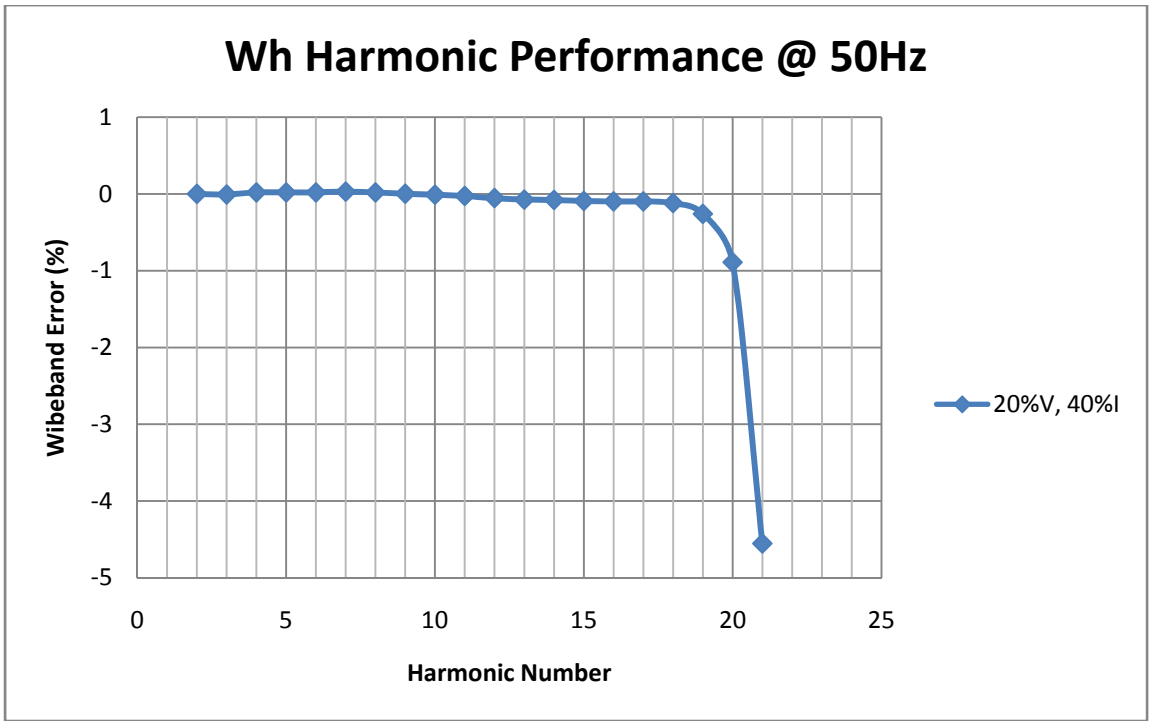


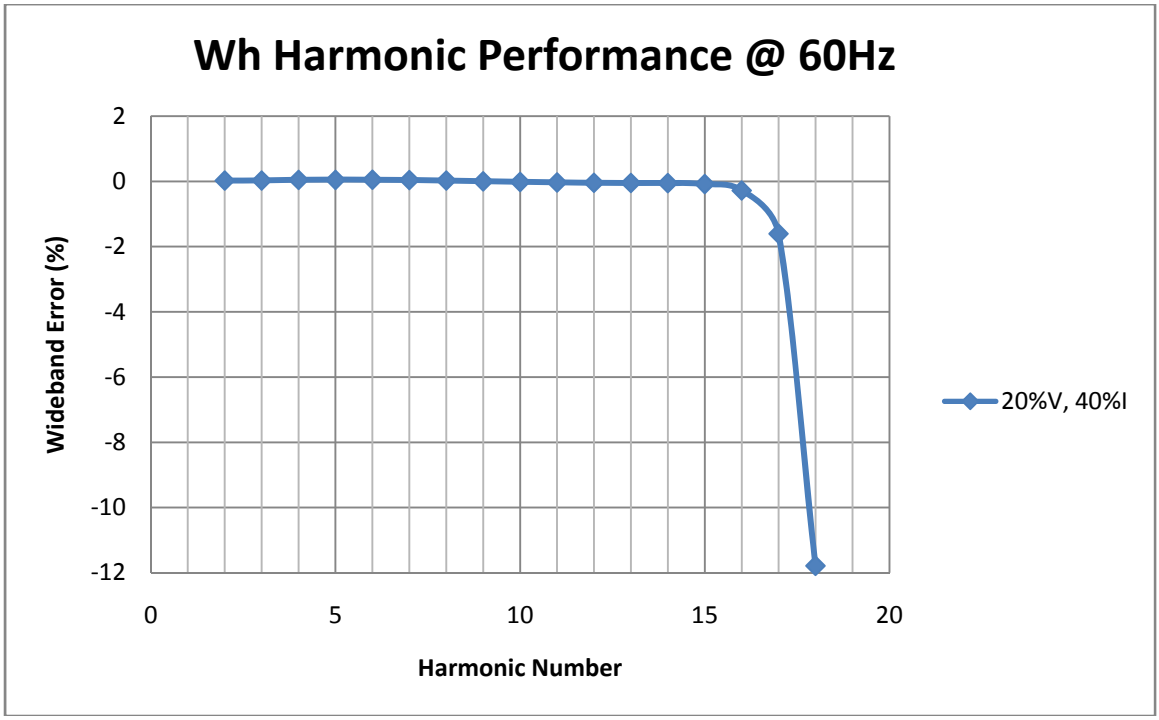




Wideband Harmonic Performance

The following graph shows the wideband Wh performance with the 240V, 10A, 50/60HZ, with 20% fundamental voltage component and 40% fundamental current component.





Tracking Band Pass Filter with Center @ Fpk (NFREQ>0)

W0SUM Using TBPF with NREQ>0

This table below shows the results of the tracking filter at 240V,10A, 50Hz, with 40% fundamental current component and 20% fundamental voltage component on the harmonics for Phase A.

The wideband ratio (WB Ratio) represents:

WB Error = W0SUM_X_Fn/(α*W0SUM_X_F0)

Where:

Fn – Harmonic frequency
F0 – Fundamental frequency
W0SUM_X_Fn – Wideband with fundamental and harmonic frequency present
W0SUM_X_F0 – Wideband with fundamental frequency present
α - amplitude factor the includes the fundamental + harmonic component

WB Ratio shows how well the wideband register measures in the presence of harmonics. The amplitude factor α for this case is 1+0.2*0.4 = 1.08. The expected ratio is 1.0.

The narrowband ratio (NB Ratio) represents:

NB Ratio = W0SUM_H_X_Fn/W0SUM_X_F0

Where:

Fn – Harmonic frequency
F0 – Fundamental frequency
W0SUM_H_X_Fn – Narrowband with fundamental and harmonic frequency present
W0SUM_X_F0 – Wideband with fundamental frequency present only

NB Ratio shows how well the narrowband register rejects other frequencies Fpk. The ideal ratio is based on the amount of harmonic component present. In this case the expected ratio is 8% (0.2V*0.4V=0.08).

The NBc Ratio shows narrow band rejection after correcting for the Fx(0) attenuation and delay compensation gain.

W0SUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	100	4687	1.000335	8.05%	0.00033381	0.026642472	0.9969	7.99%
3	150	7000	1.000415	8.02%	4.7781E-05	0.036948138	0.9958	7.98%
4	200	9277	1.000638	8.03%	1.39249E-05	0.048315538	0.9945	7.99%
5	250	11506	1.000869	8.05%	5.61232E-06	0.05834708	0.9933	7.99%
6	300	13676	1.000919	8.05%	2.74177E-06	0.064767297	0.9926	7.99%
7	350	15775	1.000727	8.04%	1.52565E-06	0.065822255	0.9925	7.98%
8	400	17792	1.000709	8.04%	9.33744E-07	0.060598035	0.9930	7.99%
9	450	19718	1.000577	8.02%	6.14916E-07	0.049210995	0.9944	7.98%
10	500	21541	1.000437	8.01%	4.29713E-07	0.032837207	0.9962	7.98%
11	550	23253	0.999969	7.98%	3.15387E-07	0.01356497	0.9984	7.97%
12	600	24845	1.000592	7.97%	2.41375E-07	-0.005923941	1.0007	7.97%
13	650	26309	1.000168	7.95%	1.91595E-07	-0.022808671	1.0026	7.97%
14	700	27637	0.999868	7.92%	1.57103E-07	-0.034648124	1.0040	7.96%

W0SUM								
15	750	28822	0.999836	7.93%	1.3266E-07	-0.039862451	1.0046	7.96%
16	800	29857	0.999916	7.92%	1.15095E-07	-0.038065653	1.0044	7.95%
17	850	30739	0.999534	7.91%	1.02371E-07	-0.030161492	1.0035	7.94%
18	900	31462	0.999849	7.88%	9.32306E-08	-0.018170287	1.0021	7.90%
19	950	32022	0.997461	7.73%	8.68443E-08	-0.004823105	1.0006	7.74%
20	1000	32416	0.991368	7.04%	8.26768E-08	0.006983739	0.9992	7.04%
21	1050	32644	0.955705	3.11%	8.03793E-08	0.014755255	0.9983	3.11%

I0SUM & V0SUM Using TBPF with NREQ>0
The description for WB Ratio and NB Ratio are the same for I0SUM and V0SUM except

WB Ratio = I0SUM_X_Fn/(1.16*I0SUM_X_F0)
WB Ratio = V0SUM_X_Fn/(1.04*V0SUM_X_F0)

Expected Ratios
I0SUM_X
WB Ratio = 1.0, NB Ratio = 16%
V0SUM_X
WB Ratio = 1.0, NB Ratio = 4%

The NBc Ratio shows narrow band rejection after correcting for the Fx(0) attenuation and delay compensation gain for V0SUM.

The following tables show the results for I0SUM & V0SUM for the case of 240V, 10A, @ 50Hz, with 40% fundamental current component and 20% fundamental voltage component on the harmonics for Phase A.

I0SQSUM				
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio
2	100	4687	1.000523	16.05%
3	150	7000	1.000801	16.00%
4	200	9277	1.000008	16.02%
5	250	11506	1.000559	16.01%
6	300	13676	1.000474	16.00%
7	350	15775	1.000806	16.01%
8	400	17792	1.001122	16.00%
9	450	19718	1.001054	16.00%
10	500	21541	1.000906	15.96%
11	550	23253	1.000292	15.97%
12	600	24845	1.000922	15.97%
13	650	26309	1.000426	15.98%
14	700	27637	1.000358	15.97%
15	750	28822	1.000352	15.97%
16	800	29857	1.001187	15.93%
17	850	30739	1.000931	15.94%
18	900	31462	0.999425	15.93%
19	950	32022	1.000087	15.89%

I0SQSUM				
20	1000	32416	0.999926	15.87%
21	1050	32644	0.999186	15.60%

V0SQSUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	100	4687	1.000282	4.05%	0.00033381	0.026642472	0.9969	4.00%
3	150	7000	1.00018	4.02%	4.7781E-05	0.036948138	0.9958	4.00%
4	200	9277	1.000466	4.03%	1.39249E-05	0.048315538	0.9945	4.01%
5	250	11506	1.00053	4.04%	5.61232E-06	0.05834708	0.9933	4.01%
6	300	13676	1.000618	4.05%	2.74177E-06	0.064767297	0.9926	4.02%
7	350	15775	1.0006	4.05%	1.52565E-06	0.065822255	0.9925	4.01%
8	400	17792	1.000573	4.04%	9.33744E-07	0.060598035	0.9930	4.01%
9	450	19718	1.000438	4.03%	6.14916E-07	0.049210995	0.9944	4.00%
10	500	21541	1.00039	4.01%	4.29713E-07	0.032837207	0.9962	4.00%
11	550	23253	1.000198	3.99%	3.15387E-07	0.01356497	0.9984	3.99%
12	600	24845	1.000003	3.97%	2.41375E-07	-0.005923941	1.0007	3.98%
13	650	26309	0.999859	3.96%	1.91595E-07	-0.022808671	1.0026	3.97%
14	700	27637	0.999728	3.94%	1.57103E-07	-0.034648124	1.0040	3.96%
15	750	28822	0.999647	3.94%	1.3266E-07	-0.039862451	1.0046	3.95%
16	800	29857	0.999592	3.94%	1.15095E-07	-0.038065653	1.0044	3.96%
17	850	30739	0.999697	3.94%	1.02371E-07	-0.030161492	1.0035	3.96%
18	900	31462	0.999814	3.95%	9.32306E-08	-0.018170287	1.0021	3.96%
19	950	32022	0.999847	3.96%	8.68443E-08	-0.004823105	1.0006	3.96%
20	1000	32416	0.99989	3.97%	8.26768E-08	0.006983739	0.9992	3.96%
21	1050	32644	1.000016	3.91%	8.03793E-08	0.014755255	0.9983	3.90%

Appendix A shows the tracking filter results for Phase B and Phase C @ 50Hz and all phases at 60Hz.

Tracking Band Pass Filter with Center @ Fundamental Frequency (NFREQ<0)

Recall that when using the tracking filter centered fundamental frequency (NFREQ<0), the WxSUM_X, IxSUM_X, and VxSUM_X registers contain the wideband information. The WxSUM_H_X, IxSUM_H_X, and VxSUM_H_X registers contain narrowband information for the information for the fundamental frequency.

W0SUM

This table below shows the results of the tracking filter (NFREQ<0) at 240V,10A, 50Hz with 40% fundamental current component and 20% fundamental voltage component on the harmonics.

The narrowband error (NB Ratio) represents the ratio of

NB Ratio = W0SUM_H_X/W0SUM_X

Where:

W0SUM_H_X – Narrowband with fundamental and harmonic frequency present
W0SUM_X – Wideband with fundamental frequency present only

NB Ratio shows how well the narrowband register rejects the harmonic frequencies. The expected ratio is 1.0.

			NB Ratio		
Harmonic	Freq (Hz)	NFREQ	W0SUM_H	W1SUM_H	W2SUM_H
2	100	-1	0.999962	1.000019	1.000208
3	150	-1	0.999748	0.999847	0.999925
4	200	-1	0.999747	0.999918	1.000121
5	250	-1	0.999783	0.999738	1.000049
6	300	-1	0.999847	0.999945	1.000143
7	350	-1	1.000086	1.000108	1.000157
8	400	-1	0.999965	0.999983	1.000114
9	450	-1	0.999586	0.999696	1.000123
10	500	-1	0.999547	0.999579	0.999979
11	550	-1	0.999666	0.999751	0.999927
12	600	-1	0.999706	0.999559	0.999955
13	650	-1	0.999748	0.999825	1.000030
14	700	-1	0.999985	1.000133	1.000139
15	750	-1	0.999953	1.000394	1.000074
16	800	-1	0.999673	1.000180	1.000004
17	850	-1	0.999327	0.999813	1.000117
18	900	-1	0.999284	0.999770	1.000042
19	950	-1	1.000348	0.999928	1.000131
20	1000	-1	1.000307	0.999992	1.000048
21	1050	-1	0.999630	0.999481	1.000057

I0SUM & V0SUM

The description for NB Ratio is the same for I0SUM and V0SUM except

The following tables show the results for I0SUM & V0SUM for the case of 240V, 10A, @ 50Hz, with 40% fundamental current component and 20% fundamental voltage component on the harmonics.

			NB Ratio		
Harmonic	Freq (Hz)	NFREQ	I0SQSUM_H	I1SQSUM_H	I2SQSUM_H
2	100	-1	0.999993	1.000029	1.000063
3	150	-1	0.999561	0.999560	0.999814
4	200	-1	0.999349	0.999368	0.999961
5	250	-1	0.999903	1.000090	0.999864
6	300	-1	0.999268	0.999253	1.000047
7	350	-1	0.999744	0.999735	0.999950
8	400	-1	1.000116	1.000150	1.000011
9	450	-1	1.000725	1.000740	1.000063
10	500	-1	0.999744	0.999998	1.000021
11	550	-1	0.999570	0.999506	0.999662
12	600	-1	0.998969	0.999438	0.999876
13	650	-1	0.999604	0.999642	0.999828
14	700	-1	1.000662	1.000446	0.999909
15	750	-1	1.001033	1.000902	0.999864
16	800	-1	1.000700	1.001010	0.999986
17	850	-1	0.999291	1.000032	0.999943
18	900	-1	0.998803	0.998555	0.999952
19	950	-1	0.998889	0.999667	1.000172
20	1000	-1	0.999676	0.998834	1.000013
21	1050	-1	1.000091	1.000295	0.999986

			NB Ratio		
Harmonic	Freq (Hz)	NFREQ	V0SQSUM_H	V1SQSUM_H	V2SQSUM_H
2	100	-1	0.999945	0.999944	0.999957
3	150	-1	0.999795	0.999775	0.999788
4	200	-1	1.000019	1.000017	1.000020
5	250	-1	0.999994	0.999992	1.000001
6	300	-1	1.000054	1.000050	1.000041
7	350	-1	0.999978	0.999966	0.999960
8	400	-1	1.000010	0.999932	0.999936
9	450	-1	1.000000	0.999976	0.999985
10	500	-1	1.000007	0.999994	1.000013
11	550	-1	0.999930	0.999875	0.999907
12	600	-1	0.999975	0.999975	0.999951
13	650	-1	0.999943	0.999911	0.999933

			NB Ratio		
Harmonic	Freq (Hz)	NFREQ	V0SQSUM_H	V1SQSUM_H	V2SQSUM_H
14	700	-1	1.000001	0.999991	0.999992
15	750	-1	0.999998	0.999979	0.999985
16	800	-1	1.000021	0.999970	0.999988
17	850	-1	0.999996	0.999955	0.999966
18	900	-1	1.000013	0.999986	1.000002
19	950	-1	1.000068	1.000052	1.000065
20	1000	-1	1.000011	1.000010	1.000021
21	1050	-1	1.000061	1.000043	1.000001

Appendix B shows the tracking band pass filter with NFREQ<0 results for 60Hz.

Testing with Lower Harmonic Percentages @ 50Hz, NFREQ<0

W0SUM
The narrowband ratio (NB Ratio) represents:

NB Ratio = (W0SUM_X - W0SUM_H_X)/W0SUM_H_X

Where:

W0SUM_H_X – Narrowband with fundamental and harmonic frequency present
W0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

			NB Ratio			
Harmonic	VHarm (%)	IHarm (%)	Expected	W0SUM	W1SUM	W2SUM
3	1	1	0.010%	0.009%	0.013%	0.008%
3	1	2	0.020%	0.017%	0.012%	0.026%
3	2	2	0.040%	0.039%	0.042%	0.046%
3	3	3	0.090%	0.093%	0.088%	0.090%
3	4	4	0.160%	0.157%	0.158%	0.165%
3	5	5	0.250%	0.248%	0.255%	0.252%
3	8	8	0.640%	0.642%	0.637%	0.639%
3	10	10	1.000%	1.007%	1.006%	0.996%

I0SUM
The narrowband ratio (NB Ratio) represents:

NB Ratio = (I0SUM_X - I0SUM_H_X)/I0SUM_H_X

Where:

I0SUM_H_X – Narrowband with fundamental and harmonic frequency present
I0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

			NB Ratio			
Harmonic	VHarm (%)	IHarm (%)	Expected	I0SQSUM	I1SQSUM	I2SQSUM
3	1	1	0.010%	0.012%	0.041%	0.032%
3	1	2	0.040%	0.050%	0.071%	0.053%
3	2	2	0.040%	0.072%	0.056%	0.058%
3	3	3	0.090%	0.101%	0.112%	0.087%
3	4	4	0.160%	0.181%	0.181%	0.173%
3	5	5	0.250%	0.258%	0.262%	0.245%
3	8	8	0.640%	0.646%	0.632%	0.654%
3	10	10	1.000%	0.988%	0.980%	1.017%

V0SUM
The narrowband ratio (NB Ratio) represents:

NB Ratio = (V0SUM_X - V0SUM_H_X)/V0SUM_H_X

Where:

V0SUM_H_X – Narrowband with fundamental and harmonic frequency present
V0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

			NB Ratio			
Harmonic	VHarm (%)	IHarm (%)	Expected	V0SQSUM	V1SQSUM	V2SQSUM
3	1	1	0.010%	0.022%	0.022%	0.024%
3	1	2	0.010%	0.017%	0.018%	0.019%
3	2	2	0.040%	0.044%	0.040%	0.041%
3	3	3	0.090%	0.087%	0.085%	0.085%
3	4	4	0.160%	0.161%	0.161%	0.160%
3	5	5	0.250%	0.266%	0.265%	0.265%
3	8	8	0.640%	0.641%	0.645%	0.641%
3	10	10	1.000%	1.008%	1.009%	1.009%

Appendix C shows the NFREQ<0 testing with lower harmonic percentages @ 60Hz.
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Testing with Larger Voltage Harmonic Percentages @ 50Hz, NFREQ<0

W0SUM
The narrowband ratio (NB Ratio) represents:

NB Ratio = (W0SUM_X - W0SUM_H_X)/W0SUM_H_X

Where:

W0SUM_H_X – Narrowband with fundamental and harmonic frequency present
W0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

				NB Ratio			
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	W0SUM	W1SUM	W2SUM
100	1	0	0	0.000%	-0.007%	0.006%	-0.001%
100	2	40	40	16.000%	16.012%	16.019%	16.018%
100	4	40	40	16.000%	16.045%	16.039%	16.048%
100	4	50	40	20.000%	20.057%	20.065%	20.077%
60	1	0	0	0.000%	0.020%	0.017%	0.024%
60	4	50	40	20.000%	20.094%	20.089%	20.089%
20	4	50	40	20.000%	20.047%	20.053%	20.084%

I0SUM
The narrowband ratio (NB Ratio) represents:

NB Ratio = (I0SUM_X - I0SUM_H_X)/I0SUM_H_X

Where:

I0SUM_H_X – Narrowband with fundamental and harmonic frequency present
I0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

				NB Ratio			
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	I0SQSUM	I1SQSUM	I2SQSUM
100	1	0	0	0.000%	-0.002%	0.015%	-0.008%
100	2	40	40	16.000%	15.967%	15.949%	16.009%
100	4	40	40	16.000%	16.033%	16.013%	15.999%
100	4	50	40	16.000%	16.058%	16.065%	16.016%
60	1	0	0	0.000%	-0.010%	-0.013%	0.015%
60	4	50	40	16.000%	15.943%	15.958%	16.015%
20	4	50	40	16.000%	16.002%	15.986%	16.017%

V0SUM

The narrowband ratio (NB Ratio) represents:

NB Ratio = (V0SUM_X - V0SUM_H_X)/V0SUM_H_X

Where:

V0SUM_H_X – Narrowband with fundamental and harmonic frequency present
V0SUM_X – Wideband with fundamental frequency present and harmonic frequency present

				NB Ratio			
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	V0SQSUM	V1SQSUM	V2SQSUM
100	1	0	0	0.000%	-0.001%	-0.001%	-0.010%
100	2	40	40	16.000%	16.019%	16.010%	16.021%
100	4	40	40	16.000%	16.110%	16.117%	16.122%
100	4	50	40	25.000%	25.182%	25.186%	25.184%
60	1	0	0	0.000%	0.008%	0.002%	0.005%
60	4	50	40	25.000%	25.173%	25.183%	25.179%
20	4	50	40	25.000%	25.161%	25.193%	25.194%

Appendix D shows the NFREQ<0 testing with larger harmonic percentages @ 60Hz.

Application of RMS Harmonic Formula

This section shows the results of applying the formula in Equation 2 for voltage rms measurements. The fundamental reading used in these calculations is value of V0SQSUM(0) = 39450124 @ 240V rms, 50Hz.

					Voltage Harmonic	
Harmonic Number	NFREQ	Applied Harmonic Voltage	V0SQSUM_H	Attenuation Fx(0)	Fx(0) = No	Fx(0) = Yes
2	4687	30	3575146	0.00033381	30.10%	30.05%
2	4687	20	1596425	0.00033381	20.12%	20.03%
2	4687	15	903846	0.00033381	15.14%	15.03%
2	4687	10	409028	0.00033381	10.18%	10.02%
2	4687	9	333676	0.00033381	9.20%	9.01%
2	4687	8	266443	0.00033381	8.22%	8.01%
2	4687	7	207095	0.00033381	7.25%	7.01%
2	4687	6	155714	0.00033381	6.28%	6.01%
2	4687	5	112172	0.00033381	5.33%	5.01%
2	4687	4	76498	0.00033381	4.40%	4.01%
2	4687	3	48787	0.00033381	3.52%	3.00%
2	4687	2	28976	0.00033381	2.71%	2.00%
2	4687	1	17121	0.00033381	2.08%	1.00%
2	4687	0.5	14155	0.00033381	1.89%	0.50%
2	4687	0.1	13211	0.00033381	1.83%	0.10%
2	4687	0	13171	0.00033381	1.83%	0.02%
3	7000	30	3567123	4.7781E-05	30.07%	30.06%
3	7000	20	1585383	4.7781E-05	20.05%	20.03%
3	7000	15	892023	4.7781E-05	15.04%	15.02%
3	7000	10	396996	4.7781E-05	10.03%	10.01%
3	7000	9	321781	4.7781E-05	9.03%	9.00%
3	7000	8	254482	4.7781E-05	8.03%	8.00%
3	7000	7	195157	4.7781E-05	7.03%	7.00%
3	7000	6	143763	4.7781E-05	6.04%	6.00%
3	7000	5	100271	4.7781E-05	5.04%	4.99%
3	7000	4	64724	4.7781E-05	4.05%	3.99%
3	7000	3	37110	4.7781E-05	3.07%	2.99%
3	7000	2	17438	4.7781E-05	2.10%	1.99%
3	7000	1	5694	4.7781E-05	1.20%	0.98%
3	7000	0.5	2801	4.7781E-05	0.84%	0.48%
3	7000	0.1	1912	4.7781E-05	0.70%	0.08%
3	7000	0	1890	4.7781E-05	0.69%	0.04%

Appendix A – Tracking Band Pass Filter with NFREQ>0 Results

Phase B @ 50Hz, 20%V, 40%I

W1SUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	100	4687	1.000815	8.05%	0.00033381	0.026642472	0.9969	7.99%
3	150	7000	1.00086	8.03%	4.7781E-05	0.036948138	0.9958	7.99%
4	200	9277	1.001105	8.04%	1.39249E-05	0.048315538	0.9945	7.99%
5	250	11506	1.001354	8.05%	5.61232E-06	0.05834708	0.9933	7.99%
6	300	13676	1.001538	8.05%	2.74177E-06	0.064767297	0.9926	7.99%
7	350	15775	1.00119	8.05%	1.52565E-06	0.065822255	0.9925	7.99%
8	400	17792	1.001164	8.05%	9.33744E-07	0.060598035	0.9930	7.99%
9	450	19718	1.001064	8.03%	6.14916E-07	0.049210995	0.9944	7.99%
10	500	21541	1.001004	8.02%	4.29713E-07	0.032837207	0.9962	7.99%
11	550	23253	1.000718	7.99%	3.15387E-07	0.01356497	0.9984	7.97%
12	600	24845	1.001017	7.98%	2.41375E-07	-0.005923941	1.0007	7.98%
13	650	26309	1.000783	7.95%	1.91595E-07	-0.022808671	1.0026	7.97%
14	700	27637	1.000423	7.94%	1.57103E-07	-0.034648124	1.0040	7.97%
15	750	28822	1.000156	7.94%	1.3266E-07	-0.039862451	1.0046	7.97%
16	800	29857	1.000641	7.93%	1.15095E-07	-0.038065653	1.0044	7.97%
17	850	30739	0.999868	7.92%	1.02371E-07	-0.030161492	1.0035	7.95%
18	900	31462	1.000531	7.90%	9.32306E-08	-0.018170287	1.0021	7.91%
19	950	32022	0.998201	7.77%	8.68443E-08	-0.004823105	1.0006	7.77%
20	1000	32416	0.992333	7.11%	8.26768E-08	0.006983739	0.9992	7.10%
21	1050	32644	0.957368	3.25%	8.03793E-08	0.014755255	0.9983	3.24%

Phase B @ 50Hz, 20%V, 40%I

I1SQSUM				
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio
2	100	4687	1.000427	16.05%
3	150	7000	1.000538	16.00%
4	200	9277	1.000098	16.02%
5	250	11506	1.000417	16.00%
6	300	13676	1.000349	15.99%
7	350	15775	1.000612	16.01%
8	400	17792	1.000965	15.98%
9	450	19718	1.000856	15.98%
10	500	21541	1.000596	15.97%
11	550	23253	1.000734	15.94%
12	600	24845	1.001181	15.98%
13	650	26309	1.000187	15.95%

I1SQSUM				
14	700	27637	1.000061	15.94%
15	750	28822	1.000281	15.96%
16	800	29857	1.00049	15.94%
17	850	30739	1.001178	15.90%
18	900	31462	0.999087	15.89%
19	950	32022	0.999971	15.91%
20	1000	32416	0.999599	15.90%
21	1050	32644	0.999477	15.62%

Phase B @ 50Hz, 20%V, 40%I

V1SQSUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	100	4687	1.000279	4.05%	0.00033381	0.026642472	0.9969	4.00%
3	150	7000	1.00016	4.02%	4.7781E-05	0.036948138	0.9958	4.00%
4	200	9277	1.000459	4.03%	1.39249E-05	0.048315538	0.9945	4.01%
5	250	11506	1.000529	4.04%	5.61232E-06	0.05834708	0.9933	4.01%
6	300	13676	1.000599	4.05%	2.74177E-06	0.064767297	0.9926	4.02%
7	350	15775	1.000583	4.05%	1.52565E-06	0.065822255	0.9925	4.02%
8	400	17792	1.000571	4.04%	9.33744E-07	0.060598035	0.9930	4.01%
9	450	19718	1.000421	4.03%	6.14916E-07	0.049210995	0.9944	4.01%
10	500	21541	1.000394	4.01%	4.29713E-07	0.032837207	0.9962	4.00%
11	550	23253	1.000207	4.00%	3.15387E-07	0.01356497	0.9984	3.99%
12	600	24845	0.999995	3.98%	2.41375E-07	-0.005923941	1.0007	3.98%
13	650	26309	0.999876	3.96%	1.91595E-07	-0.022808671	1.0026	3.97%
14	700	27637	0.999731	3.95%	1.57103E-07	-0.034648124	1.0040	3.96%
15	750	28822	0.999681	3.94%	1.3266E-07	-0.039862451	1.0046	3.96%
16	800	29857	0.9996	3.94%	1.15095E-07	-0.038065653	1.0044	3.96%
17	850	30739	0.999709	3.95%	1.02371E-07	-0.030161492	1.0035	3.96%
18	900	31462	0.99983	3.96%	9.32306E-08	-0.018170287	1.0021	3.96%
19	950	32022	0.999884	3.97%	8.68443E-08	-0.004823105	1.0006	3.97%
20	1000	32416	0.999936	3.97%	8.26768E-08	0.006983739	0.9992	3.97%
21	1050	32644	0.999973	3.91%	8.03793E-08	0.014755255	0.9983	3.90%

Phase C @ 50Hz, 20%V, 40%I

W2SUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	100	4687	1.004204	8.08%	0.00033381	0.026642472	0.9969	8.02%
3	150	7000	1.004228	8.06%	4.7781E-05	0.036948138	0.9958	8.02%
4	200	9277	1.004423	8.07%	1.39249E-05	0.048315538	0.9945	8.02%
5	250	11506	1.00459	8.08%	5.61232E-06	0.05834708	0.9933	8.02%
6	300	13676	1.004652	8.08%	2.74177E-06	0.064767297	0.9926	8.02%
7	350	15775	1.00459	8.08%	1.52565E-06	0.065822255	0.9925	8.02%
8	400	17792	1.004673	8.08%	9.33744E-07	0.060598035	0.9930	8.02%
9	450	19718	1.004481	8.06%	6.14916E-07	0.049210995	0.9944	8.02%
10	500	21541	1.004415	8.05%	4.29713E-07	0.032837207	0.9962	8.02%
11	550	23253	1.004358	8.02%	3.15387E-07	0.01356497	0.9984	8.01%
12	600	24845	1.004075	8.00%	2.41375E-07	-0.005923941	1.0007	8.01%
13	650	26309	1.00391	7.99%	1.91595E-07	-0.022808671	1.0026	8.01%
14	700	27637	1.003752	7.97%	1.57103E-07	-0.034648124	1.0040	8.00%
15	750	28822	1.003707	7.96%	1.3266E-07	-0.039862451	1.0046	8.00%
16	800	29857	1.0036	7.97%	1.15095E-07	-0.038065653	1.0044	8.00%
17	850	30739	1.00371	7.96%	1.02371E-07	-0.030161492	1.0035	7.99%
18	900	31462	1.003377	7.93%	9.32306E-08	-0.018170287	1.0021	7.95%
19	950	32022	1.00203	7.79%	8.68443E-08	-0.004823105	1.0006	7.80%
20	1000	32416	0.995944	7.13%	8.26768E-08	0.006983739	0.9992	7.13%
21	1050	32644	0.960418	3.24%	8.03793E-08	0.014755255	0.9983	3.23%

Phase C @ 50Hz, 20%V, 40%I

I2SQSUM				
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio
2	100	4687	1.000607	16.04%
3	150	7000	1.000627	16.02%
4	200	9277	1.000524	16.02%
5	250	11506	1.000689	16.02%
6	300	13676	1.000687	16.02%
7	350	15775	1.000656	16.02%
8	400	17792	1.000576	16.02%
9	450	19718	1.00063	16.01%
10	500	21541	1.00074	16.00%
11	550	23253	1.000869	15.99%
12	600	24845	1.000777	15.99%
13	650	26309	1.000656	15.98%
14	700	27637	1.000734	15.97%
15	750	28822	1.000535	15.97%

I2SQSUM				
16	800	29857	1.000533	15.98%
17	850	30739	1.000476	15.97%
18	900	31462	1.000368	15.95%
19	950	32022	1.000146	15.94%
20	1000	32416	1.000206	15.93%
21	1050	32644	1.000372	15.64%

Phase C @ 50Hz, 20%V, 40%I

V2SQSUM								
Harmonic	Freq (Hz)	NFREQ	WB Error	NB Error	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	100	4687	1.000295	4.05%	0.00033381	0.026642472	0.9969	4.00%
3	150	7000	1.000149	4.02%	4.7781E-05	0.036948138	0.9958	4.00%
4	200	9277	1.000457	4.03%	1.39249E-05	0.048315538	0.9945	4.01%
5	250	11506	1.000542	4.04%	5.61232E-06	0.05834708	0.9933	4.01%
6	300	13676	1.000633	4.05%	2.74177E-06	0.064767297	0.9926	4.02%
7	350	15775	1.000587	4.05%	1.52565E-06	0.065822255	0.9925	4.02%
8	400	17792	1.000578	4.04%	9.33744E-07	0.060598035	0.9930	4.01%
9	450	19718	1.000429	4.03%	6.14916E-07	0.049210995	0.9944	4.01%
10	500	21541	1.000397	4.01%	4.29713E-07	0.032837207	0.9962	4.00%
11	550	23253	1.000183	4.00%	3.15387E-07	0.01356497	0.9984	3.99%
12	600	24845	1.000003	3.98%	2.41375E-07	-0.005923941	1.0007	3.98%
13	650	26309	0.999865	3.96%	1.91595E-07	-0.022808671	1.0026	3.97%
14	700	27637	0.999717	3.95%	1.57103E-07	-0.034648124	1.0040	3.96%
15	750	28822	0.999658	3.94%	1.3266E-07	-0.039862451	1.0046	3.96%
16	800	29857	0.999609	3.94%	1.15095E-07	-0.038065653	1.0044	3.96%
17	850	30739	0.999722	3.95%	1.02371E-07	-0.030161492	1.0035	3.96%
18	900	31462	0.999861	3.96%	9.32306E-08	-0.018170287	1.0021	3.96%
19	950	32022	0.999883	3.97%	8.68443E-08	-0.004823105	1.0006	3.97%
20	1000	32416	0.999961	3.97%	8.26768E-08	0.006983739	0.9992	3.97%
21	1050	32644	0.999931	3.91%	8.03793E-08	0.014755255	0.9983	3.90%

Phase A @ 60Hz, 20%V, 40%I

W0SUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	120	5616	0.999826	8.03%	0.000232868	0.030491546	0.9965	7.98%
3	180	8371	1.000056	8.01%	3.35945E-05	0.043792782	0.9950	7.96%
4	240	11065	1.000129	7.98%	9.89335E-06	0.056562008	0.9935	7.93%
5	300	13676	1.00037	8.03%	4.0434E-06	0.064767297	0.9926	7.97%
6	360	16185	1.000347	7.97%	2.00994E-06	0.065291553	0.9925	7.91%
7	420	18574	1.000256	7.96%	1.14156E-06	0.056739887	0.9935	7.91%
8	480	20825	1.000054	8.00%	7.15493E-07	0.039868949	0.9954	7.96%
9	540	22920	0.999662	7.93%	4.84467E-07	0.01752776	0.9980	7.92%
10	600	24845	0.999415	7.84%	3.49287E-07	-0.005923941	1.0007	7.84%
11	660	26586	0.999654	7.64%	2.65518E-07	-0.025645833	1.0030	7.66%
12	720	28128	0.998589	7.76%	2.11397E-07	-0.037579505	1.0043	7.79%
13	780	29461	0.99974	7.80%	1.75342E-07	-0.039595976	1.0046	7.84%
14	840	30575	0.999434	7.87%	1.50951E-07	-0.032147309	1.0037	7.90%
15	900	31462	0.998328	7.84%	1.34506E-07	-0.018170287	1.0021	7.85%
16	960	32114	0.997225	6.78%	1.2383E-07	-0.002249471	1.0003	6.78%
17	1020	32527	0.983863	6.13%	1.17614E-07	0.010691029	0.9988	6.12%
18	1080	32699	0.884854	-4.38%	1.15141E-07	0.016761236	0.9981	-4.37%

Phase A @ 60Hz, 20%V, 40%I

I0SQSUM				
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio
2	120	5616	0.999617	16.02%
3	150	8371	0.99935	15.95%
4	200	11065	0.999751	15.95%
5	250	13676	1.000325	15.95%
6	300	16185	1.000174	15.84%
7	350	18574	1.000567	15.84%
8	400	20825	1.000566	15.97%
9	450	22920	1.000599	15.76%
10	500	24845	0.999157	15.70%
11	550	26586	0.999962	15.49%
12	600	28128	1.000268	15.56%
13	650	29461	0.999731	15.68%
14	700	30575	0.999543	15.87%
15	750	31462	1.000516	15.91%
16	800	32114	0.999024	14.49%
17	850	32527	0.998879	14.73%
18	900	32699	0.999652	15.92%

Phase A @ 60Hz, 20%V, 40%I

V0SQSUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	120	5616	0.999913	4.04%	0.000232868	0.030491546	0.9965	4.00%
3	180	8371	0.999868	4.01%	3.35945E-05	0.043792782	0.9950	3.98%
4	240	11065	1.000219	4.02%	9.89335E-06	0.056562008	0.9935	3.99%
5	300	13676	1.000251	4.03%	4.0434E-06	0.064767297	0.9926	4.00%
6	360	16185	1.000265	4.00%	2.00994E-06	0.065291553	0.9925	3.97%
7	420	18574	1.000237	3.99%	1.14156E-06	0.056739887	0.9935	3.97%
8	480	20825	0.999992	4.01%	7.15493E-07	0.039868949	0.9954	3.99%
9	540	22920	0.99985	3.94%	4.84467E-07	0.01752776	0.9980	3.93%
10	600	24845	0.999621	3.90%	3.49287E-07	-0.005923941	1.0007	3.91%
11	660	26586	0.999386	3.83%	2.65518E-07	-0.025645833	1.0030	3.84%
12	720	28128	0.999296	3.84%	2.11397E-07	-0.037579505	1.0043	3.85%
13	780	29461	0.999491	3.87%	1.75342E-07	-0.039595976	1.0046	3.88%
14	840	30575	0.999538	3.92%	1.50951E-07	-0.032147309	1.0037	3.93%
15	900	31462	0.999533	3.95%	1.34506E-07	-0.018170287	1.0021	3.96%
16	960	32114	0.999806	3.60%	1.2383E-07	-0.002249471	1.0003	3.61%
17	1020	32527	0.999804	3.67%	1.17614E-07	0.010691029	0.9988	3.67%
18	1080	32699	0.999749	3.97%	1.15141E-07	0.016761236	0.9981	3.97%

Phase B @ 60Hz, 20%V, 40%I

W1SUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	120	5616	0.999822	8.03%	0.000232868	0.030491546	0.9965	7.98%
3	180	8371	0.999981	8.01%	3.35945E-05	0.043792782	0.9950	7.97%
4	240	11065	1.00008	7.98%	9.89335E-06	0.056562008	0.9935	7.93%
5	300	13676	1.000376	8.03%	4.0434E-06	0.064767297	0.9926	7.97%
6	360	16185	1.000268	7.97%	2.00994E-06	0.065291553	0.9925	7.91%
7	420	18574	1.0003	7.96%	1.14156E-06	0.056739887	0.9935	7.91%
8	480	20825	0.999998	8.00%	7.15493E-07	0.039868949	0.9954	7.97%
9	540	22920	0.999835	7.94%	4.84467E-07	0.01752776	0.9980	7.92%
10	600	24845	0.99921	7.84%	3.49287E-07	-0.005923941	1.0007	7.84%
11	660	26586	0.999523	7.64%	2.65518E-07	-0.025645833	1.0030	7.66%
12	720	28128	0.998814	7.76%	2.11397E-07	-0.037579505	1.0043	7.80%
13	780	29461	0.99973	7.81%	1.75342E-07	-0.039595976	1.0046	7.85%
14	840	30575	0.999476	7.89%	1.50951E-07	-0.032147309	1.0037	7.92%
15	900	31462	0.998521	7.85%	1.34506E-07	-0.018170287	1.0021	7.87%
16	960	32114	0.997259	6.82%	1.2383E-07	-0.002249471	1.0003	6.82%
17	1020	32527	0.985009	6.22%	1.17614E-07	0.010691029	0.9988	6.21%
18	1080	32699	0.88627	-4.25%	1.15141E-07	0.016761236	0.9981	-4.24%

Phase B @ 60Hz, 20%V, 40%I

I1SQSUM				
Harmonic	Freq (Hz)	NFREQ	WB Error	NB Error
2	120	5616	0.999752	16.02%
3	180	8371	0.999511	15.96%
4	240	11065	0.999806	15.95%
5	300	13676	1.000451	15.96%
6	360	16185	1.000292	15.84%
7	420	18574	1.000375	15.84%
8	480	20825	1.000763	15.97%
9	540	22920	1.000647	15.74%
10	600	24845	0.998931	15.71%
11	660	26586	1.0007	15.47%
12	720	28128	1.000488	15.56%
13	780	29461	0.999582	15.66%
14	840	30575	0.999604	15.83%
15	900	31462	0.999905	15.94%
16	960	32114	0.998536	14.46%
17	1020	32527	0.999	14.70%
18	1080	32699	0.999811	15.91%

Phase B @ 60Hz, 20%V, 40%I

V1SQSUM								
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Ratio
2	120	5616	0.999939	4.04%	0.000232868	0.030491546	0.9965	4.00%
3	150	8371	0.999897	4.01%	3.35945E-05	0.043792782	0.9950	3.98%
4	200	11065	1.000248	4.02%	9.89335E-06	0.056562008	0.9935	3.99%
5	250	13676	1.00027	4.03%	4.0434E-06	0.064767297	0.9926	4.00%
6	300	16185	1.000306	4.00%	2.00994E-06	0.065291553	0.9925	3.97%
7	350	18574	1.000265	4.00%	1.14156E-06	0.056739887	0.9935	3.97%
8	400	20825	1.000041	4.01%	7.15493E-07	0.039868949	0.9954	3.99%
9	450	22920	0.999894	3.94%	4.84467E-07	0.01752776	0.9980	3.94%
10	500	24845	0.999638	3.91%	3.49287E-07	-0.005923941	1.0007	3.91%
11	550	26586	0.999442	3.84%	2.65518E-07	-0.025645833	1.0030	3.85%
12	600	28128	0.99933	3.84%	2.11397E-07	-0.037579505	1.0043	3.86%
13	650	29461	0.999534	3.87%	1.75342E-07	-0.039595976	1.0046	3.89%
14	700	30575	0.999598	3.92%	1.50951E-07	-0.032147309	1.0037	3.94%
15	750	31462	0.999598	3.96%	1.34506E-07	-0.018170287	1.0021	3.97%
16	800	32114	0.999855	3.61%	1.2383E-07	-0.002249471	1.0003	3.61%
17	850	32527	0.999861	3.68%	1.17614E-07	0.010691029	0.9988	3.67%
18	900	32699	0.999876	3.99%	1.15141E-07	0.016761236	0.9981	3.98%

Phase C @ 60Hz, 20%V, 40%I

W2SUM								
Harmonic	Freq (Hz)	NFREQ	WB Error	NB Error	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Error
2	120	5616	0.999802	8.04%	0.000232868	0.030491546	0.9965	7.98%
3	180	8371	0.99988	8.01%	3.35945E-05	0.043792782	0.9950	7.97%
4	240	11065	1.00015	7.98%	9.89335E-06	0.056562008	0.9935	7.93%
5	300	13676	1.000233	8.04%	4.0434E-06	0.064767297	0.9926	7.98%
6	360	16185	1.000238	7.97%	2.00994E-06	0.065291553	0.9925	7.91%
7	420	18574	1.000186	7.96%	1.14156E-06	0.056739887	0.9935	7.91%
8	480	20825	1.000002	8.01%	7.15493E-07	0.039868949	0.9954	7.97%
9	540	22920	0.999845	7.94%	4.84467E-07	0.01752776	0.9980	7.92%
10	600	24845	0.999582	7.84%	3.49287E-07	-0.005923941	1.0007	7.85%
11	660	26586	0.999319	7.65%	2.65518E-07	-0.025645833	1.0030	7.67%
12	720	28128	0.999236	7.76%	2.11397E-07	-0.037579505	1.0043	7.80%
13	780	29461	0.999433	7.81%	1.75342E-07	-0.039595976	1.0046	7.85%
14	840	30575	0.999389	7.88%	1.50951E-07	-0.032147309	1.0037	7.91%
15	900	31462	0.999159	7.86%	1.34506E-07	-0.018170287	1.0021	7.87%
16	960	32114	0.997254	6.81%	1.2383E-07	-0.002249471	1.0003	6.82%
17	1020	32527	0.984532	6.21%	1.17614E-07	0.010691029	0.9988	6.20%
18	1080	32699	0.886303	-4.27%	1.15141E-07	0.016761236	0.9981	-4.26%

Phase C @ 60Hz, 20%V, 40%I

I2SQSUM				
Harmonic	Freq (Hz)	NFREQ	WB Ratio	NB Ratio
2	120	5616	0.999556	16.03%
3	180	8371	0.999719	15.95%
4	240	11065	0.999659	15.94%
5	300	13676	0.999707	15.96%
6	360	16185	0.999915	15.85%
7	420	18574	0.999909	15.84%
8	480	20825	0.999835	15.96%
9	540	22920	0.999838	15.76%
10	600	24845	0.999736	15.71%
11	660	26586	0.999614	15.50%
12	720	28128	0.999567	15.56%
13	780	29461	0.999742	15.69%
14	840	30575	0.999587	15.86%
15	900	31462	0.99942	15.95%
16	960	32114	0.999465	14.50%
17	1020	32527	0.999258	14.73%
18	1080	32699	0.999475	15.95%

Phase C @ 60Hz, 20%V, 40%I

V2SQSUM								
Harmonic	Freq (Hz)	NFREQ	WB Error	NB Error	Fx(0)	Delay Compensation Gain (dB)	Correction	NBc Error
2	120	5616	0.99996	4.04%	0.000232868	0.030491546	0.9965	4.00%
3	150	8371	0.999907	4.01%	3.35945E-05	0.043792782	0.9950	3.98%
4	200	11065	1.000215	4.02%	9.89335E-06	0.056562008	0.9935	3.99%
5	250	13676	1.000285	4.03%	4.0434E-06	0.064767297	0.9926	4.00%
6	300	16185	1.000288	4.00%	2.00994E-06	0.065291553	0.9925	3.97%
7	350	18574	1.000261	4.00%	1.14156E-06	0.056739887	0.9935	3.97%
8	400	20825	1.000069	4.01%	7.15493E-07	0.039868949	0.9954	3.99%
9	450	22920	0.999888	3.94%	4.84467E-07	0.01752776	0.9980	3.93%
10	500	24845	0.999655	3.91%	3.49287E-07	-0.005923941	1.0007	3.91%
11	550	26586	0.999445	3.84%	2.65518E-07	-0.025645833	1.0030	3.85%
12	600	28128	0.999345	3.84%	2.11397E-07	-0.037579505	1.0043	3.86%
13	650	29461	0.999537	3.87%	1.75342E-07	-0.039595976	1.0046	3.89%
14	700	30575	0.999584	3.92%	1.50951E-07	-0.032147309	1.0037	3.94%
15	750	31462	0.9996	3.96%	1.34506E-07	-0.018170287	1.0021	3.97%
16	800	32114	0.99986	3.61%	1.2383E-07	-0.002249471	1.0003	3.61%
17	850	32527	0.99984	3.68%	1.17614E-07	0.010691029	0.9988	3.67%
18	900	32699	0.999857	3.98%	1.15141E-07	0.016761236	0.9981	3.97%

Appendix B – Tracking Band Pass Filter with NFREQ<0 Results for 60Hz

			NB error		
Harmonic	Freq (Hz)	NFREQ	W0SUM_H	W1SUM_H	W2SUM_H
2	120	-1	0.999902	0.999906	0.999835
3	180	-1	0.999862	0.999831	0.999801
4	240	-1	1.000062	1.000073	1.000043
5	300	-1	0.999560	0.999490	0.999594
6	360	-1	0.999576	0.999567	0.999872
7	420	-1	0.999729	0.999778	0.999821
8	480	-1	1.000018	1.000087	0.999775
9	540	-1	0.999485	0.999641	0.999922
10	600	-1	0.999841	0.999742	0.999723
11	660	-1	0.999649	0.999591	0.999666
12	720	-1	1.000195	1.000062	0.999987
13	780	-1	0.999811	0.999667	0.999819
14	840	-1	0.999763	0.999823	0.999742
15	900	-1	0.999956	0.999963	0.999844
16	960	-1	0.999925	0.999959	0.999878
17	1020	-1	0.999617	0.999879	0.999850
18	1080	-1	0.999655	0.999740	0.999994

			NB error		
Harmonic	Freq (Hz)	NFREQ	I0SQSUM_H	I1SQSUM_H	I2SQSUM_H
2	120	-1	1.000009	1.000000	1.000036
3	150	-1	0.999621	0.999579	0.999377
4	200	-1	1.000088	1.000174	0.999674
5	250	-1	1.000252	1.000312	0.999819
6	300	-1	0.999792	0.999851	0.999755
7	350	-1	1.000224	0.999884	0.999753
8	400	-1	0.998912	0.999071	0.999830
9	450	-1	0.999050	0.999477	0.999576
10	500	-1	0.998948	0.998987	0.999844
11	550	-1	0.999875	0.999633	0.999481
12	600	-1	0.999513	0.999388	0.999449
13	650	-1	0.999633	0.999678	0.999621
14	700	-1	0.999649	0.999515	0.999495
15	750	-1	1.000005	1.000192	0.999383
16	800	-1	0.999689	1.000256	0.999721
17	850	-1	1.000759	0.999728	0.999755
18	900	-1	0.999277	0.998903	0.999902

			NB error		
Harmonic	Freq (Hz)	NFREQ	V0SQSUM_H	V1SQSUM_H	V2SQSUM_H
2	120	-1	0.999963	0.999995	1.000021
3	180	-1	0.999664	0.999640	0.999653
4	240	-1	0.999817	0.999836	0.999860
5	300	-1	0.999905	0.999928	0.999907
6	360	-1	0.999850	0.999872	0.999854
7	420	-1	0.999966	0.999980	1.000009
8	480	-1	0.999859	0.999855	0.999876
9	540	-1	0.999712	0.999766	0.999761
10	600	-1	0.999952	0.999965	0.999968
11	660	-1	0.999678	0.999704	0.999711
12	720	-1	0.999605	0.999605	0.999610
13	780	-1	0.999809	0.999821	0.999821
14	840	-1	0.999681	0.999671	0.999693
15	900	-1	0.999657	0.999661	0.999652
16	960	-1	0.999833	0.999831	0.999829
17	1020	-1	0.999830	0.999828	0.999807
18	1080	-1	0.999983	0.999987	0.999992

Appendix C - Testing with Lower Harmonic Percentages @ 60Hz, NFREQ <0.

			NB Ratio			
Harmonic	VHarm (%)	IHarm (%)	Expected	W0SUM	W1SUM	W2SUM
3	1	1	0.010%	0.037%	0.043%	0.033%
3	1	2	0.020%	0.064%	0.057%	0.055%
3	2	2	0.040%	0.053%	0.047%	0.057%
3	3	3	0.090%	0.106%	0.108%	0.103%
3	4	4	0.160%	0.157%	0.161%	0.168%
3	5	5	0.250%	0.267%	0.267%	0.270%
3	8	8	0.640%	0.657%	0.666%	0.662%
3	10	10	1.000%	1.002%	0.988%	0.993%

			NB Ratio			
Harmonic	VHarm (%)	IHarm (%)	Expected	I0SQSUM	I1SQSUM	I2SQSUM
3	1	1	0.010%	0.066%	0.071%	0.050%
3	1	2	0.040%	0.058%	0.036%	0.054%
3	2	2	0.040%	0.086%	0.093%	0.071%
3	3	3	0.090%	0.103%	0.099%	0.108%
3	4	4	0.160%	0.201%	0.199%	0.182%
3	5	5	0.250%	0.299%	0.289%	0.297%
3	8	8	0.640%	0.685%	0.657%	0.651%
3	10	10	1.000%	1.074%	1.060%	1.084%

			NB Ratio			
Harmonic	VHarm (%)	IHarm (%)	Expected	V0SQSUM	V1SQSUM	V2SQSUM
3	1	1	0.010%	0.039%	0.035%	0.039%
3	1	2	0.010%	-0.234%	0.021%	0.020%
3	2	2	0.040%	0.050%	0.051%	0.054%
3	3	3	0.090%	0.107%	0.107%	0.110%
3	4	4	0.160%	0.198%	0.198%	0.198%
3	5	5	0.250%	0.254%	0.252%	0.254%
3	8	8	0.640%	0.650%	0.650%	0.651%
3	10	10	1.000%	1.012%	1.012%	1.013%

Appendix D - Testing with Larger Harmonic Percentages @ 60Hz, NFREQ<0.

				NB Ratio			
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	W0SUM	W1SUM	W2SUM
100	1	0	0	0.000%	0.023%	0.024%	0.026%
100	2	40	40	16.000%	16.022%	16.016%	16.033%
100	4	40	40	16.000%	16.103%	16.107%	16.104%
100	4	50	40	20.000%	20.083%	20.071%	20.099%
60	1	0	0	0.000%	0.012%	-0.004%	0.012%
60	4	50	40	20.000%	20.158%	20.153%	20.147%
20	4	50	40	20.000%	20.123%	20.117%	20.100%

				NB Ratio			
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	I0SQSUM	I1SQSUM	I2SQSUM
100	1	0	0	0.000%	0.008%	0.010%	0.008%
100	2	40	40	16.000%	16.015%	16.000%	15.993%
100	4	40	40	16.000%	16.106%	16.103%	16.078%
100	4	50	40	16.000%	16.020%	15.981%	16.022%
60	1	0	0	0.000%	0.036%	0.027%	0.038%
60	4	50	40	16.000%	16.084%	16.075%	16.026%
20	4	50	40	16.000%	16.007%	16.015%	16.023%

				NB Ratio			
Voltage (V)	Harmonic	VHarm (%)	IHarm (%)	Expected	V0SQSUM	V1SQSUM	V2SQSUM
100	1	0	0	0.000%	0.047%	0.031%	0.025%
100	2	40	40	16.000%	16.045%	16.043%	16.045%
100	4	40	40	16.000%	16.146%	16.147%	16.149%
100	4	50	40	25.000%	25.261%	25.256%	25.255%
60	1	0	0	0.000%	0.017%	0.010%	0.014%
60	4	50	40	25.000%	25.261%	25.269%	25.266%
20	4	50	40	25.000%	25.218%	25.222%	25.211%

Revision History

Revision	Date	Description
Rev. 1.0	05/14/09	First publication.

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