Harmonic Analysis Report

Date: 13 September 2011

Client: DEMO REPORT

Project: Multiple Loads (Linear & Non-Linear)

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Technical • Industrial • International

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Table of Contents

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EXECUTIVE SUMMARY

The purpose of this analysis is to evaluate the contribution of harmonic current and voltage distortion expected from four variable frequency drives (VFD), one DC rectifier and two linear loads (across-the-line started motors) which are proposed to be connected to a new power system. It is necessary to comply with IEEE std 519 limits for both current and voltage distortion. In the event that the proposed system does not meet these requirements, an alternative solution shall be recommended.

Objectives:

1) Perform simulation of simultaneously operating linear and non-linear loads to determine harmonic distortion contribution and check for compliance with the voltage and current distortion limits of IEEE-519.
2) Consider the Point of Common Connection (PCC) at the secondary (480V) side of the 1000kVA transformer. Check compliance with IEEE-519 voltage and current distortion limits at this point.
3) Evaluate total power factor under full load operating conditions.

Procedure:

Construct a circuit model complete with 6-pulse and 18-pulse type drives, SCR type DC rectifier and pure motor loads. Construct a model of 5% THD-i harmonic filter. Where possible use actual component values (ie: VFD bus capacitor, VFD DC bus choke, filter components) otherwise use generic circuit models as per IEEE-399. Power sources such as transformers are modeled as inductances.

Conclusion:

Based upon simulation results, the proposed system consisting of two linear loads plus five non-linear loads, is in compliance with IEEE std 519 when evaluated at the PCC which is defined as the secondary terminals of the1000kVA transformer.

	IEEE std 519 limit	Predicted THD	Status
Current Distortion:	8% THD-i	4.69%	PASS
Voltage Distortion:	5% THD-i	1.71%	PASS

Recommendations:

Simulation results indicate that the proposed system will comply with the current and voltage distortion limits of IEEE-519. If there are no other loads on the system that will contribute to harmonic distortion, then the system as proposed, will also meet the most stringent THD-I limit of 5%, and therefore exceeds the actual requirements for this project.

Monetary savings could be realized, while meeting the appropriate THD-i and THD-v limits for this system, if the 5% harmonic filter was replaced with a 8% filter and if the18-pulse converter were replaced with a 12-pulse converter.

Method of Harmonic Analysis

1) Analysis is performed as per IEEE 399 using both hand calculations and digital simulations. Simulations are performed using Simplorer® Circuit Simulation software by ANSYS.

2) The motor Full Load Ampere ratings are those contained in Appendix I and II. Unless stated otherwise, we use the FLA for standard efficiency motors.

3) We refer to IEEE-519 Table 10.3 for Current Distortion limits, unless otherwise stated. This table is included in Appendix IV.

4) We refer to IEEE-519 Table 10.2 for Voltage Distortion limits, unless otherwise stated. This table is included in Appendix IV.

5) Our analysis is performed to determine THD based upon VFD/motor and motor FLA, unless otherwise stated. Our analysis does not consider panel boards that do not contain motors or drives. Our analysis does not include loads that have not included in this report.

6) Our analysis is performed without the consideration for circuit conductor impedance. This yields a degree of conservatism in our analysis.

7) We calculate percent impedance for line reactors based on rated system voltage and frequency, rated impedance and motor FLA as per tables in appendix I and II. Effective impedance of reactors and transformers is reduced when current is less than rated FLA.

8) Our typical simulations are based on a generic model for a typical 6-pulse (12-pulse or 18-pulse) converters, unless the dc bus capacitance, ac line reactance and dc bus inductance are known. This simulation is based on a generic model for 6-pulse and 18-pulse converters.

9) Our typical simulations are based on generic models for various harmonic mitigation equipment (filters) unless specific circuit and component values have been provided or determined through our own filter design. This analysis is based on a generic filter model.

10) Our analysis and simulations are based on nominal values of circuit voltage as well as all circuit components, with balanced line voltages, balanced phase currents and 0% background voltage distortion. Actual distortion levels will be higher if voltage sources are either distorted or unbalanced.

11) Our analysis and simulations provide an estimate of harmonic distortion based on information supplied by the client and our assumptions as necessary when complete data is not available. The results of our distortion analysis may differ from actual system performance due to site and application variables, operating conditions, component tolerances or other unanticipated conditions. There is no guarantee associated with this analysis or set of simulations.

12) For this analysis the PCC is considered to be at the secondary (480V) side of the 1000 kVA transformer in accordance with IEEE-519. Voltage distortion on the primary (MV) side of the distribution transformer will be lower than the values predicted for the secondary side.

Background Data

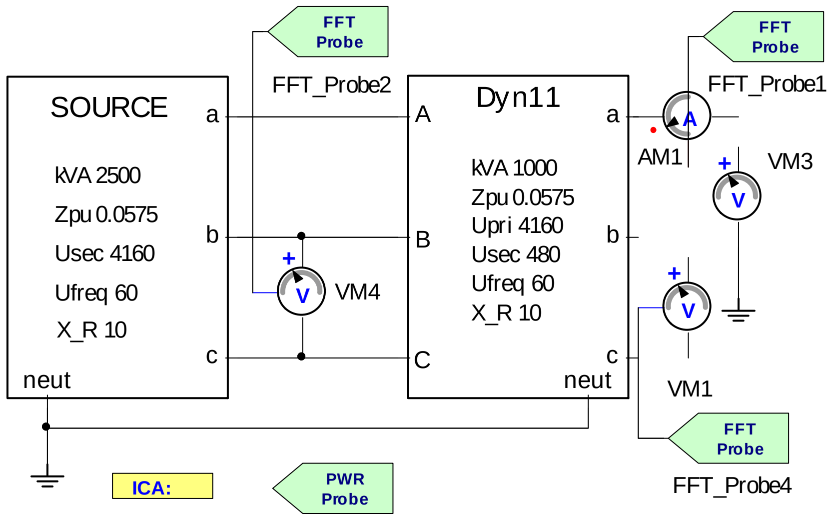
Utility Power Source:	2500	KVA	5.75%	% imped.
		V pri	4160	V sec
	60	Hz	6034.35	I_{SC}
Demand:			60.18	I_L
IEEE-519 Limit:	12%	%THD-i	100.5	I_S / I_L
IEEE-519 Limit	5%	%THD-v		

PCC Transformer 2:	**1000**	KVA	**5.75%**	% imped.
	4160	V pri	**480**	V sec
	60	Hz	**20,919**	I_{SC}
Demand:			**510.41**	I_L
IEEE-519 Limit:	**8%**	%THD-i	**40.98**	I_S / I_L
IEEE-519 Limit	**5%**	%THD-v		

Generator 1:	n/a	KVA		% imped.
				Vrms
		Hz		I_{SC}
Demand:				I_L
IEEE-519 Limit:		%THD-i		I_S / I_L
IEEE-519 Limit		%THD-v		

Simulation Results at Power Source

Secondary LV side of 1000 KVA Transformer



Summary of Harmonic Distortion:

Low Voltage PCC (480V side of 1000kVA power transformer):

Current Distortion: 4.69% THD-I [PASS]

Voltage Distortion: 1.71% THD-v [PASS]

Total Power Factor: 0.92 lagging [acceptable]

Secondary Current

Name	Value
FFT_Probe1.THD [%]	4.69
FFT_Probe1.RMSAC	510.97
FFT_Probe1.RMS1	510.41

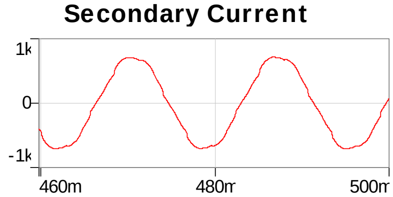
Secondary Voltage

Name	Value
FFT_Probe4.THD [%]	1.71
FFT_Probe4.RMSAC	471.72
FFT_Probe4.RMS1	471.65

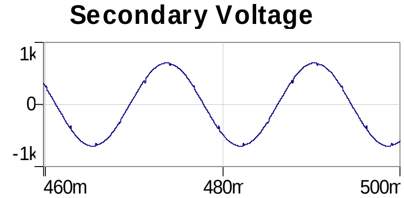
Input Power Factor

Name	Value
PWR_Probe1.PF[0]	921.27m

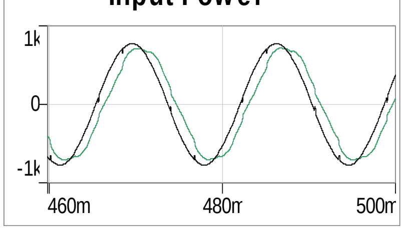
Secondary Current



Secondary Voltage



Input Power



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Harmonic Current Distortion (1st thru 100th harmonics)

at secondary (480V) side of transformer

Harmonic Current Distortion

Harmonic	f(Hz)	I (peak)	I (rms)	Phi(deg)	% distortion
Total			**510.78**		**4.70%**
1	60	721.67	510.22	293.39	100.00%
2	120	3.48	2.46	89.67	0.48%
3	180	4.37	3.09	324.41	0.61%
4	240	0.60	0.43	139.95	0.08%
5	300	30.31	21.43	169.68	4.20%
6	360	0.28	0.20	337.62	0.04%
7	420	3.19	2.25	263.79	0.44%
8	480	0.12	0.08	103.32	0.02%
9	540	0.17	0.12	61.11	0.02%
10	600	0.09	0.06	330.55	0.01%
11	660	7.41	5.24	166.52	1.03%
12	720	0.06	0.04	241.95	0.01%
13	780	5.80	4.10	2.79	0.80%
14	840	0.12	0.09	112.68	0.02%
15	900	0.37	0.26	266.08	0.05%
16	960	0.25	0.18	36.49	0.03%
17	1020	6.89	4.87	251.15	0.95%
18	1080	0.46	0.33	358.10	0.06%
19	1140	2.13	1.51	112.24	0.30%
20	1200	0.22	0.16	286.18	0.03%
21	1260	0.02	0.02	186.18	0.00%
22	1320	0.02	0.01	274.36	0.00%
23	1380	3.71	2.62	299.92	0.51%
24	1440	0.09	0.06	90.74	0.01%
25	1500	2.21	1.56	141.77	0.31%
26	1560	0.05	0.04	330.28	0.01%
27	1620	0.08	0.06	310.86	0.01%
28	1680	0.04	0.03	7.02	0.01%
29	1740	2.57	1.82	353.83	0.36%
30	1800	0.02	0.02	331.62	0.00%
31	1860	1.83	1.29	196.36	0.25%
32	1920	0.09	0.06	285.24	0.01%
33	1980	0.15	0.11	59.98	0.02%
34	2040	0.07	0.05	193.52	0.01%
35	2100	2.09	1.48	57.00	0.29%
36	2160	0.16	0.11	174.47	0.02%
37	2220	1.12	0.79	251.44	0.15%
38	2280	0.10	0.07	68.07	0.01%
39	2340	0.04	0.03	24.22	0.01%
40	2400	0.01	0.01	204.23	0.00%
41	2460	1.55	1.09	100.26	0.21%
42	2520	0.04	0.03	239.01	0.01%
43	2580	1.30	0.92	303.27	0.18%
44	2640	0.05	0.03	97.72	0.01%
45	2700	0.06	0.04	114.31	0.01%
46	2760	0.02	0.01	266.76	0.00%
47	2820	1.35	0.95	154.86	0.19%
48	2880	0.03	0.02	296.41	0.00%
49	2940	1.20	0.85	0.99	0.17%
50	3000	0.06	0.04	94.08	0.01%

Harmonic Current Distortion

Harmonic	f(Hz)	I (peak)	I (rms)	Phi(deg)	% distortion
51	3060	0.09	0.06	235.10	0.01%
52	3120	0.06	0.04	13.94	0.01%
53	3180	1.10	0.78	218.14	0.15%
54	3240	0.13	0.09	7.23	0.02%
55	3300	0.85	0.60	52.39	0.12%
56	3360	0.05	0.04	267.83	0.01%
57	3420	0.03	0.02	233.97	0.00%
58	3480	0.02	0.02	317.57	0.00%
59	3540	0.94	0.66	268.21	0.13%
60	3600	0.03	0.02	55.57	0.00%
61	3660	0.84	0.60	113.06	0.12%
62	3720	0.02	0.02	262.93	0.00%
63	3780	0.06	0.04	314.26	0.01%
64	3840	0.04	0.03	14.88	0.01%
65	3900	0.79	0.56	325.43	0.11%
66	3960	0.03	0.02	31.52	0.00%
67	4020	0.69	0.49	168.65	0.10%
68	4080	0.06	0.04	278.84	0.01%
69	4140	0.07	0.05	35.87	0.01%
70	4200	0.04	0.03	167.41	0.01%
71	4260	0.58	0.41	22.21	0.08%
72	4320	0.09	0.06	173.35	0.01%
73	4380	0.54	0.38	210.44	0.08%
74	4440	0.05	0.03	55.12	0.01%
75	4500	0.04	0.03	28.51	0.01%
76	4560	0.00	0.00	76.27	0.00%
77	4620	0.54	0.38	65.89	0.08%
78	4680	0.03	0.02	244.41	0.00%
79	4740	0.59	0.42	273.76	0.08%
80	4800	0.02	0.01	78.91	0.00%
81	4860	0.04	0.03	99.20	0.01%
82	4920	0.02	0.01	168.03	0.00%
83	4980	0.51	0.36	126.44	0.07%
84	5040	0.01	0.01	244.58	0.00%
85	5100	0.50	0.35	337.01	0.07%
86	5160	0.05	0.03	71.94	0.01%
87	5220	0.05	0.03	211.34	0.01%
88	5280	0.03	0.02	341.32	0.00%
89	5340	0.35	0.25	190.98	0.05%
90	5400	0.07	0.05	355.06	0.01%
91	5460	0.35	0.25	22.07	0.05%
92	5520	0.01	0.01	245.73	0.00%
93	5580	0.02	0.01	229.72	0.00%
94	5640	0.01	0.01	323.13	0.00%
95	5700	0.27	0.19	238.23	0.04%
96	5760	0.03	0.02	38.72	0.00%
97	5820	0.32	0.23	74.97	0.04%
98	5880	0.01	0.01	269.93	0.00%
99	5940	0.03	0.02	282.64	0.00%
100	6000	0.03	0.02	358.93	0.00%

This spectrum is based on analysis of the waveform for the last cycle of simulation.

Harmonic Voltage Distortion (1st thru 100th harmonics)

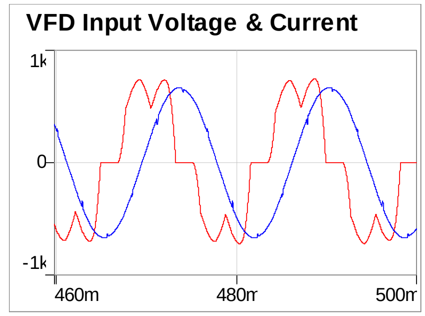
At secondary (480V) side of transformer

Harmonic Voltage Distortion					
Harmonic	**f(Hz)**	**V (peak)**	**V (rms)**	**Phi(deg)**	**% distortion**
Total			**471.79**		**1.67%**
1	60	667.22	471.72	226.08	100.00%
2	120	0.15	0.11	286.43	0.02%
3	180	0.03	0.02	50.36	0.00%
4	240	0.08	0.06	157.08	0.01%
5	300	4.68	3.31	164.63	0.70%
6	360	0.03	0.02	200.78	0.00%
7	420	0.75	0.53	84.31	0.11%
8	480	0.06	0.05	107.04	0.01%
9	540	0.01	0.01	137.67	0.00%
10	600	0.06	0.05	211.02	0.01%
11	660	2.69	1.90	164.15	0.40%
12	720	0.01	0.01	161.79	0.00%
13	780	2.28	1.61	181.43	0.34%
14	840	0.05	0.03	207.85	0.01%
15	900	0.02	0.02	122.27	0.00%
16	960	0.06	0.04	38.83	0.01%
17	1020	3.75	2.65	250.91	0.56%
18	1080	0.05	0.04	69.76	0.01%
19	1140	1.19	0.84	290.43	0.18%
20	1200	0.10	0.07	136.44	0.01%
21	1260	0.02	0.01	143.54	0.00%
22	1320	0.03	0.02	277.33	0.00%
23	1380	2.83	2.00	295.01	0.42%
24	1440	0.02	0.02	181.18	0.00%
25	1500	1.74	1.23	319.75	0.26%
26	1560	0.06	0.04	252.14	0.01%
27	1620	0.00	0.00	231.14	0.00%
28	1680	0.05	0.03	329.35	0.01%
29	1740	2.45	1.73	350.29	0.37%
30	1800	0.06	0.04	327.84	0.01%
31	1860	1.70	1.20	14.86	0.26%
32	1920	0.03	0.02	352.73	0.00%
33	1980	0.03	0.02	299.45	0.00%
34	2040	0.04	0.03	284.60	0.01%
35	2100	2.31	1.63	55.59	0.35%
36	2160	0.03	0.02	182.80	0.00%
37	2220	1.24	0.87	63.82	0.19%
38	2280	0.10	0.07	316.51	0.01%
39	2340	0.03	0.02	330.48	0.01%
40	2400	0.03	0.02	138.82	0.00%
41	2460	2.19	1.55	94.63	0.33%
42	2520	0.05	0.04	269.75	0.01%
43	2580	1.72	1.22	118.88	0.26%
44	2640	0.06	0.04	15.22	0.01%
45	2700	0.01	0.01	56.53	0.00%
46	2760	0.02	0.01	55.59	0.00%
47	2820	2.16	1.53	150.28	0.32%
48	2880	0.05	0.03	74.51	0.01%
49	2940	1.71	1.21	178.09	0.26%
50	3000	0.05	0.04	69.35	0.01%

Harmonic Voltage Distortion					
Harmonic	**f(Hz)**	**V (peak)**	**V (rms)**	**Phi(deg)**	**% distortion**
51	3060	0.02	0.02	124.99	0.00%
52	3120	0.10	0.07	104.98	0.02%
53	3180	1.86	1.32	214.26	0.28%
54	3240	0.05	0.03	120.47	0.01%
55	3300	1.38	0.98	225.20	0.21%
56	3360	0.12	0.08	145.88	0.02%
57	3420	0.04	0.03	140.50	0.01%
58	3480	0.03	0.02	268.12	0.00%
59	3540	1.94	1.37	261.26	0.29%
60	3600	0.01	0.01	1.27	0.00%
61	3660	1.52	1.08	287.84	0.23%
62	3720	0.04	0.03	156.34	0.01%
63	3780	0.01	0.01	166.39	0.00%
64	3840	0.01	0.01	125.46	0.00%
65	3900	1.75	1.24	318.10	0.26%
66	3960	0.01	0.01	42.52	0.00%
67	4020	1.32	0.93	343.21	0.20%
68	4080	0.09	0.06	186.45	0.01%
69	4140	0.04	0.03	299.47	0.01%
70	4200	0.12	0.08	268.17	0.02%
71	4260	1.27	0.90	15.41	0.19%
72	4320	0.07	0.05	240.79	0.01%
73	4380	1.21	0.85	20.10	0.18%
74	4440	0.13	0.10	303.52	0.02%
75	4500	0.05	0.04	331.73	0.01%
76	4560	0.02	0.02	324.22	0.00%
77	4620	1.51	1.07	60.00	0.23%
78	4680	0.03	0.02	302.77	0.01%
79	4740	1.37	0.97	86.73	0.21%
80	4800	0.04	0.03	338.80	0.01%
81	4860	0.02	0.01	334.19	0.00%
82	4920	0.03	0.02	316.39	0.00%
83	4980	1.49	1.05	120.17	0.22%
84	5040	0.02	0.01	126.57	0.00%
85	5100	1.14	0.81	150.95	0.17%
86	5160	0.09	0.06	345.24	0.01%
87	5220	0.02	0.02	76.96	0.00%
88	5280	0.11	0.08	70.31	0.02%
89	5340	1.01	0.71	183.09	0.15%
90	5400	0.04	0.03	73.64	0.01%
91	5460	0.89	0.63	189.03	0.13%
92	5520	0.09	0.07	100.45	0.01%
93	5580	0.06	0.04	149.74	0.01%
94	5640	0.05	0.03	98.52	0.01%
95	5700	0.97	0.69	229.78	0.15%
96	5760	0.02	0.01	54.82	0.00%
97	5820	0.90	0.64	245.36	0.14%
98	5880	0.06	0.04	119.79	0.01%
99	5940	0.02	0.02	160.57	0.00%
100	6000	0.04	0.03	112.37	0.01%

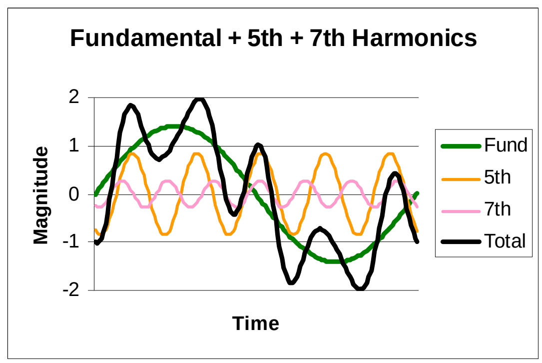
This spectrum is based on analysis of the waveform for the last cycle of simulation.

Explanation of Harmonics



Harmonic distortion is produced in the AC-DC conversion process commonly used in modern power electronics equipment for commercial and industrial applications. This type of equipment is referred to as non-linear loads, because of the non-linear relationship between the input voltage (typically sinusoidal) and the current drawn by these loads (typically non-sinusoidal).

Examples of non-linear loads includes: AC variable frequency drives (VFD), DC adjustable speed drives (ASD), uninterruptible power supplies (UPS), switching power supplies, battery chargers, welders, SCR controls and dimmers, computers and computerized equipment, office equipment, ballasts, industrial power supplies, etc.



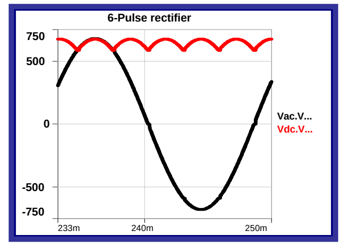
Harmonics are either current or voltage components of frequencies which are multiples of the fundamental frequency and are superimposed on the fundamental waveform. Although individually the harmonic components are sinusoidal, their superposition onto the fundamental waveform results in a distorted waveform. The higher the harmonic content, the greater is the waveform distortion. Typical measured values of harmonic voltage distortion are in the range of 0% to 10% THD-v and typical current distortion ranges from 0% to more than 100% THD-i. When harmonic distortion is relatively high, the RMS value of circuit current and voltage can increase significantly. This can impose stress on electrical equipment and wiring and cause additional heating and reduced life expectancy.

There are several factors that influence the magnitude of harmonic distortion and the harmonic orders produced by a given piece of equipment. These include: input impedance, type of AC-DC rectification method, load current, pre-existing power system distortion (caused by other loads), and voltage imbalance. The actual harmonic frequencies that are present in a waveform are highly dependent upon the type of rectification. Generally speaking, the more rectifiers used in the AC-DC converter, the fewer harmonic frequencies present and the lesser the distortion.

Converter		Harmonic Orders (n) where n represents n x fundamental frequency																	
No. of Pulses	No. of phases	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37
2	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
6	3		✓	✓		✓	✓		✓	✓		✓	✓		✓	✓			
12	3					✓	✓					✓	✓					✓	✓
18	3								✓	✓								✓	✓

Table 1 – Harmonic orders produced by various types of rectifiers

Types of Converters



6-Pulse Converters: This term refers to the number of pulses of DC ripple voltage that occur on the DC bus and correspond to one cycle of AC input voltage. The converter also consists of six (6) diode rectifiers. This is the most common type of AC-DC converter used for three phase equipment such as variable frequency drives. The input harmonic current distortion will vary (typically 25% to 100% THD-i) depending on the magnitude of total input circuit impedance, load and dc bus capacitor value.

Table 2 indicates the approximate total harmonic current distortion based on total effective source impedance. This impedance consists of all impedance from the utility to the DC bus inside the drive, including transformer, line reactor, and DC bus choke. Typically nameplate impedance (transformers and reactors) is based on full load current. Effective impedance refers to the impedance realized in a circuit based on actual operating conditions. For example, a 5% impedance line reactor offers only 3% impedance if the drive is operating at 60% load. Therefore, when a drive operates at light load, the percent of THD-i will be higher (although the magnitude of harmonic current will be lower) than when it operates at full load.

Zeff	0.5%	1.0%	1.5%	2.0%	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	6.0%	7.0%	8.0%	9.0%	10%
% THD-i	100%	72%	60%	52%	48%	44%	41%	39%	37%	35%	33%	31%	29%	28%	27%

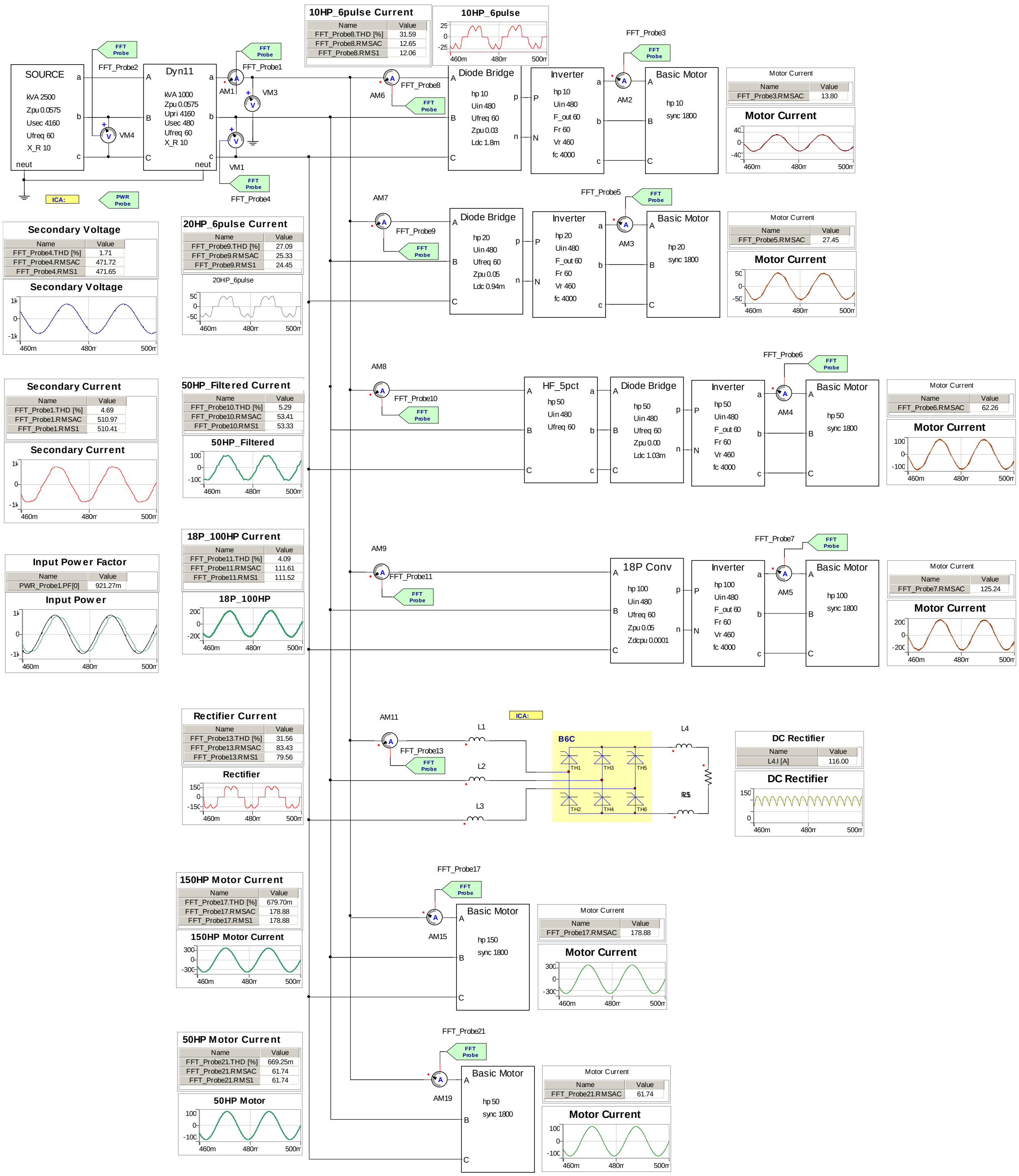
Table 2 – Typical total harmonic current distortion for 6-pulse rectifier depending on total input impedance.

12-pulse Converters: This converter uses two 6-pulse bridge rectifiers (for a total of twelve diode rectifiers) connected either in series or in parallel. Each of the two bridge rectifiers is supplied from a voltage source that is 30 degrees phase shifted from the other bridge rectifier. For each cycle of AC input voltage, there are twelve pulses of ripple voltage on the DC bus. This configuration cancels out certain harmonics such as 5^{th} and 7^{th}. Total harmonic distortion for 12-pulse converters is typically in the range of about 10% to 15% THD-i, depending on circuit configuration, input circuit impedance and load current. Distortion will increase if voltages are not balanced and if there is pre-existing voltage distortion on the power system. Percent current distortion also increases at lighter load.

18-pulse Converters: This converter typically uses three 6-pulse bridge rectifiers (for a total of eighteen diode rectifiers) connected either in series or in parallel. Each of the bridge rectifiers is supplied from a voltage source that is 20 degrees phase shifted from the other bridge rectifiers. For each cycle of AC input voltage, there are eighteen pulses of ripple voltage on the DC bus. This configuration cancels out certain harmonics such as 5^{th}, 7^{th}, 11^{th} and 13^{th}. Total harmonic distortion for 18-pulse converters is typically in the range of about 5% to 8% THD-i, depending on circuit configuration, input circuit impedance and load current. Distortion will increase if voltages are not balanced and if there is pre-existing voltage distortion on the power system. Percent current distortion also increases at lighter load.

Simulation Results

Circuit used for simulation:



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SIMULATION RESULTS (continued)

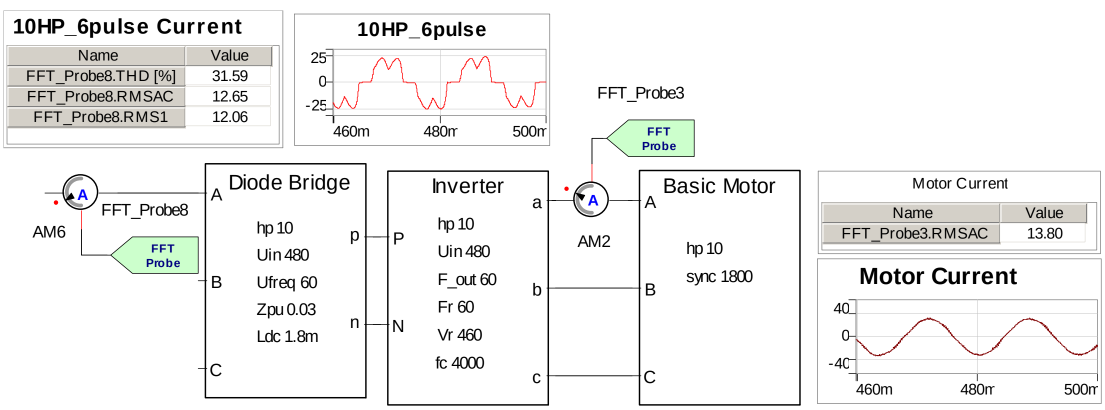
The results of simulations are shown on the following pages for individual loads, including the rms current and the THD-i at the input terminals of each load. Motors will draw a small amount of harmonic current if the voltage source supplying them is distorted.

When measuring current distortion on a common conductor (bus) upstream of several non-linear loads, the distortion may be lower than the sum of the THD-i for each individual load. This is caused by partial cancellation of some harmonics due to the phase angles of each individual harmonic component being different for various loads.

When capacitor based harmonic filters are used (5% & 8% harmonic filters), they can also offer improved displacement (and total) power factor upstream from their point of connection.

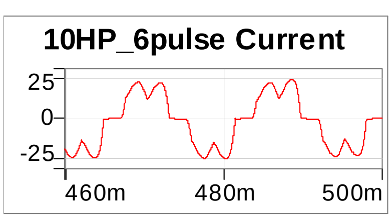
Generally speaking there will be both technical advantages and cost advantages when using multiple technologies of harmonic mitigation equipment on a common power system.

Equipment: 10HP drive; 10HP motor; 3% Line reactor, DC choke



Load: 100% motor current (13.80 amps)

VFD Input Current: 12.65 Arms; 31.59 %THD-i



10HP_6pulse Current

Name	Value
FFT_Probe8.THD [%]	31.59
FFT_Probe8.RMSAC	12.65
FFT_Probe8.RMS1	12.06

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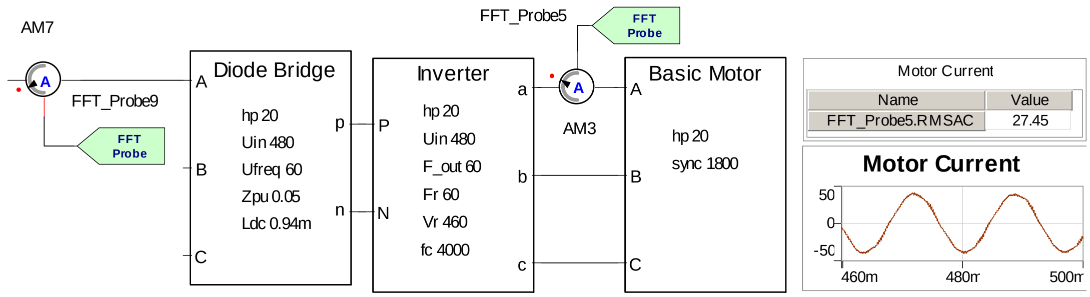
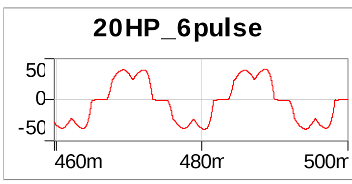
SIMULATION RESULTS (continued)

Equipment: 20HP drive; 20HP motor; 5% Line reactor, DC choke



Load: 100% motor current (27.45 amps)

VFD Input Current: 25.33 Arms; 24.45 %THD-i

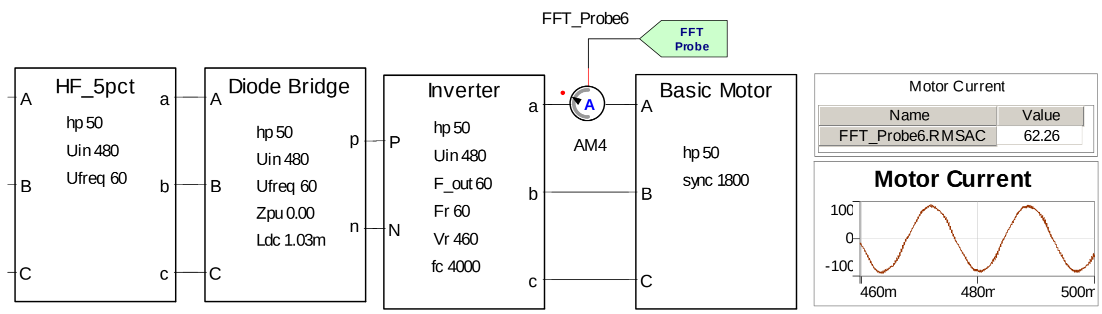


20HP_6pulse Current

Name	Value
FFT_Probe9.THD [%]	27.09
FFT_Probe9.RMSAC	25.33
FFT_Probe9.RMS1	24.45

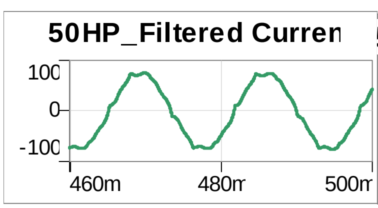
SIMULATION RESULTS (continued)

Equipment: 50HP drive; 50HP motor; ~5% THD-i Filter, DC choke



Load: 100% motor current (62.26 amps)

Input Current: **53.33 Arms;** **5.29 %THD-i**



50HP_Filtered Current

Name	Value
FFT_Probe10.THD [%]	5.29
FFT_Probe10.RMSAC	53.41
FFT_Probe10.RMS1	53.33

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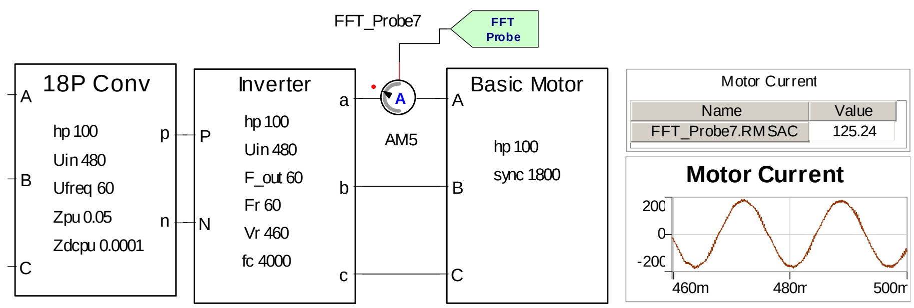
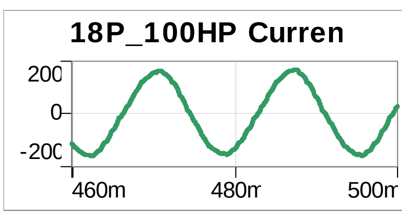
SIMULATION RESULTS (continued)

Equipment: 100HP drive; 100HP motor; 18-pulse drive, 5% line reactance



Load: 100% motor current (125.24 amps)

Input Current: 111.52 Arms; 4.09 %THD-i



18P_100HP Current

Name	Value
FFT_Probe11.THD [%]	4.09
FFT_Probe11.RMSAC	111.61
FFT_Probe11.RMS1	111.52

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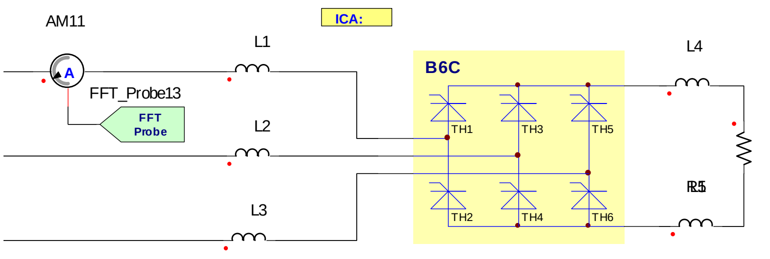
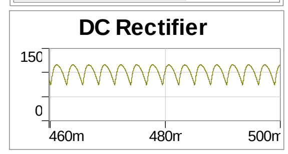
SIMULATION RESULTS (continued)

Equipment: 75 KVA DC Rectifier; 3% Line reactor.



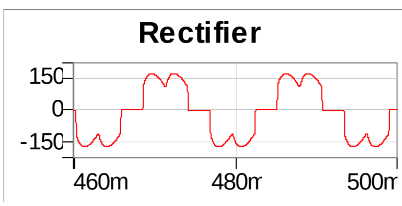
DC Rectifier

Name	Value
L4.I [A]	116.00



Load: 100% load current (116 ADC amps)

Input Current: 83.43 Arms;   31.56 %THD-i



Rectifier Current

Name	Value
FFT_Probe13.THD [%]	31.56
FFT_Probe13.RMSAC	83.43
FFT_Probe13.RMS1	79.56

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SIMULATION RESULTS (continued)

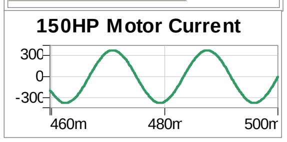
Equipment: Linear Loads (150HP + 50HP motors)

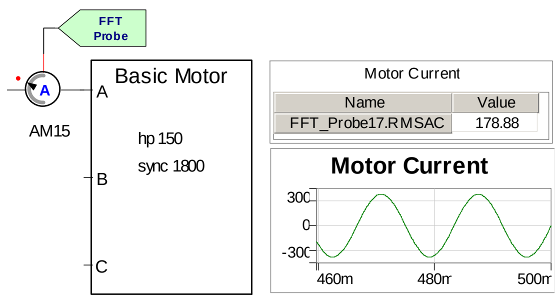
Load: 100% motor current (78.88 amps)

Input Current: 178.88 Arms; 0.68 %THD-i

150HP Motor Current

Name	Value
FFT_Probe17.THD [%]	679.70m
FFT_Probe17.RMSAC	178.88
FFT_Probe17.RMS1	178.88



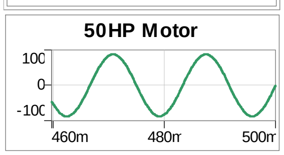


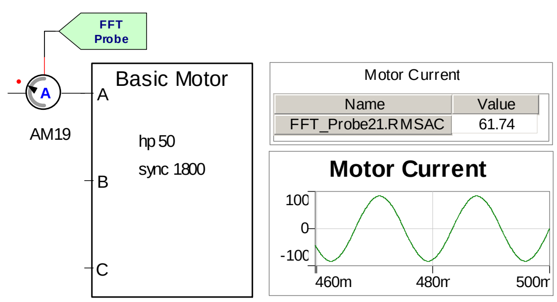
Load: 100% motor current (61.74 amps)

Input Current: 61.74 Arms; 0.67 %THD-i

50HP Motor Current

Name	Value
FFT_Probe21.THD [%]	669.25m
FFT_Probe21.RMSAC	61.74
FFT_Probe21.RMS1	61.74

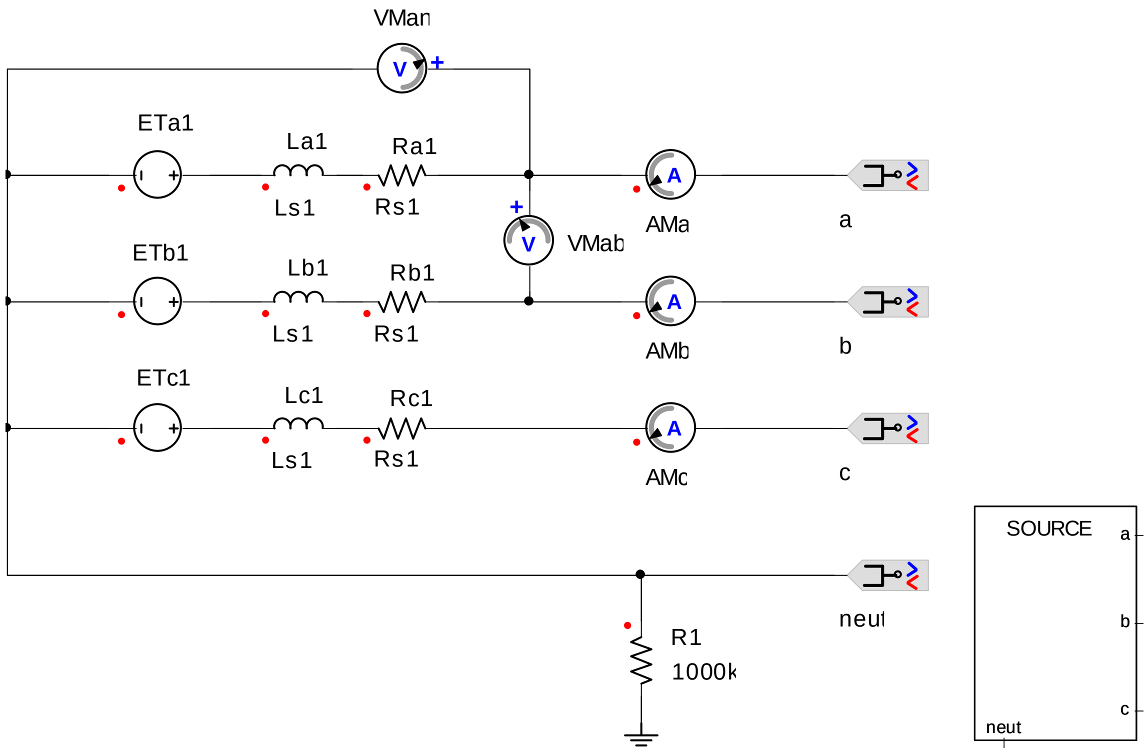




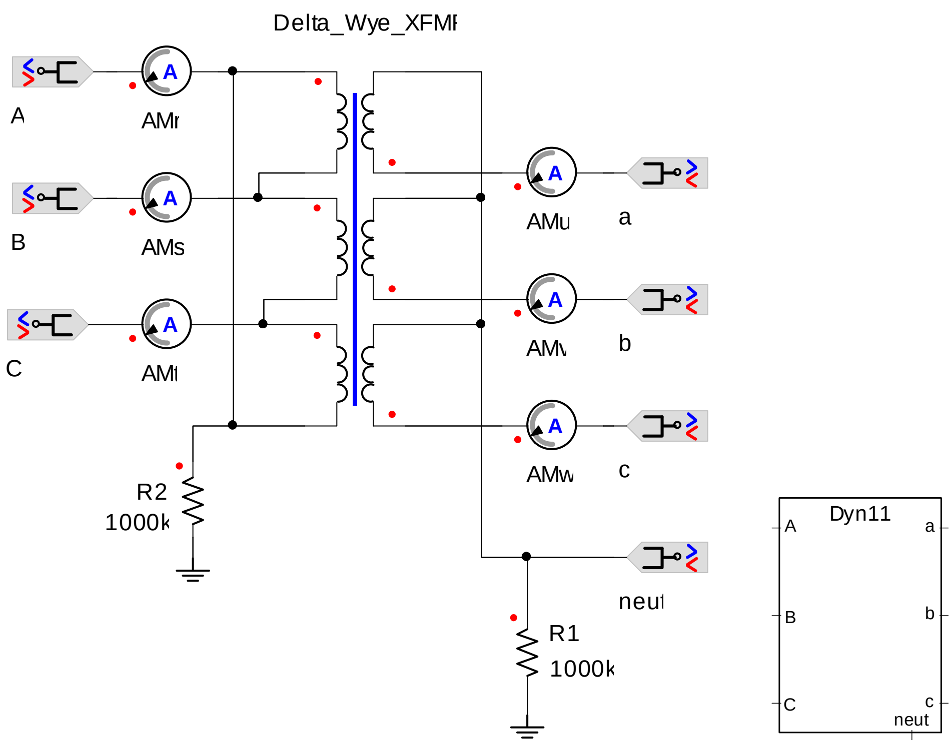
NOTE: These motors are linear loads which normally do not draw harmonic current. However, due to the voltage distortion on the power system (caused by other non-linear loads), these motors (and other linear or non-linear loads) will also draw a small amount of harmonic current.

Models used for Simulation

Power Source:



Transformer:



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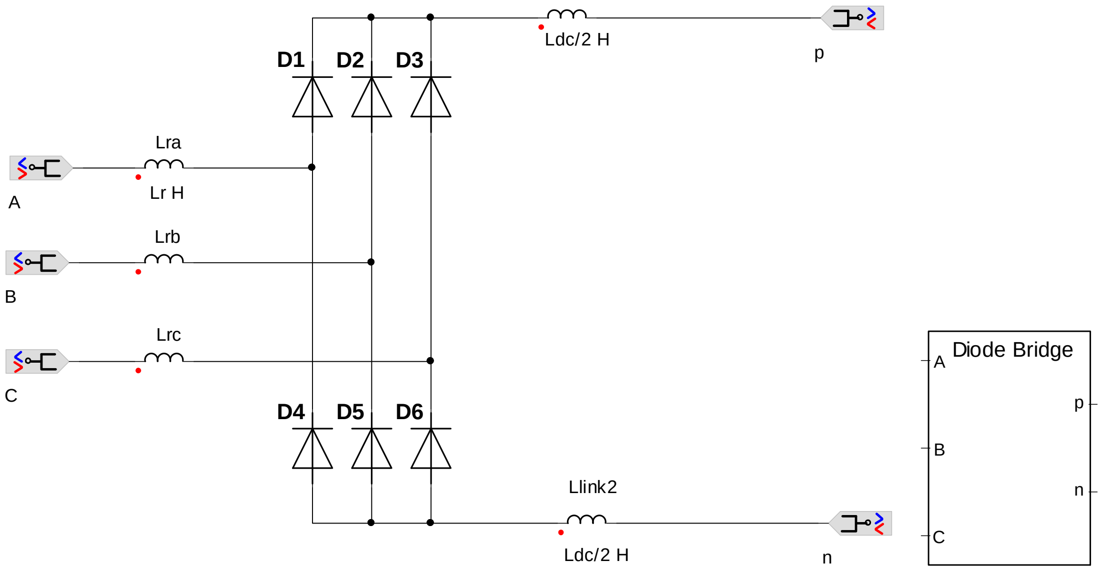
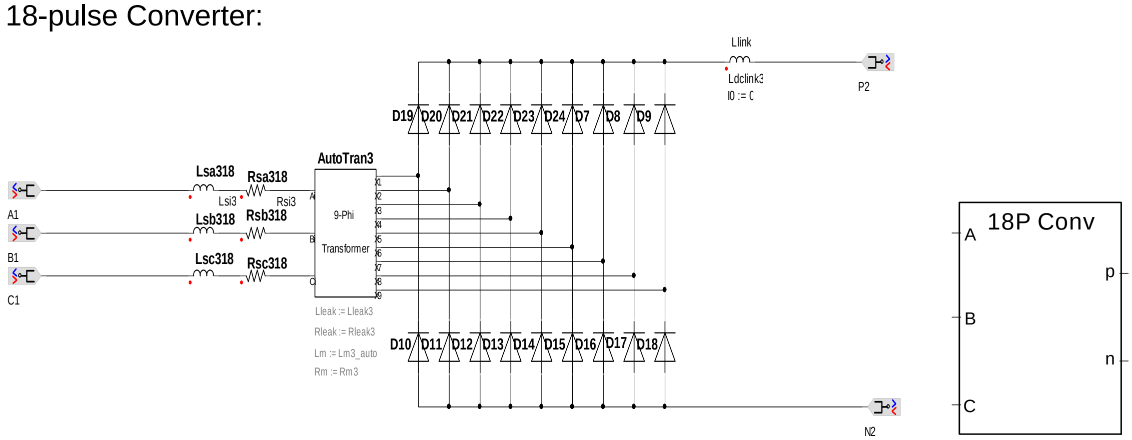
Models used for Simulation

6-pulse Converter:

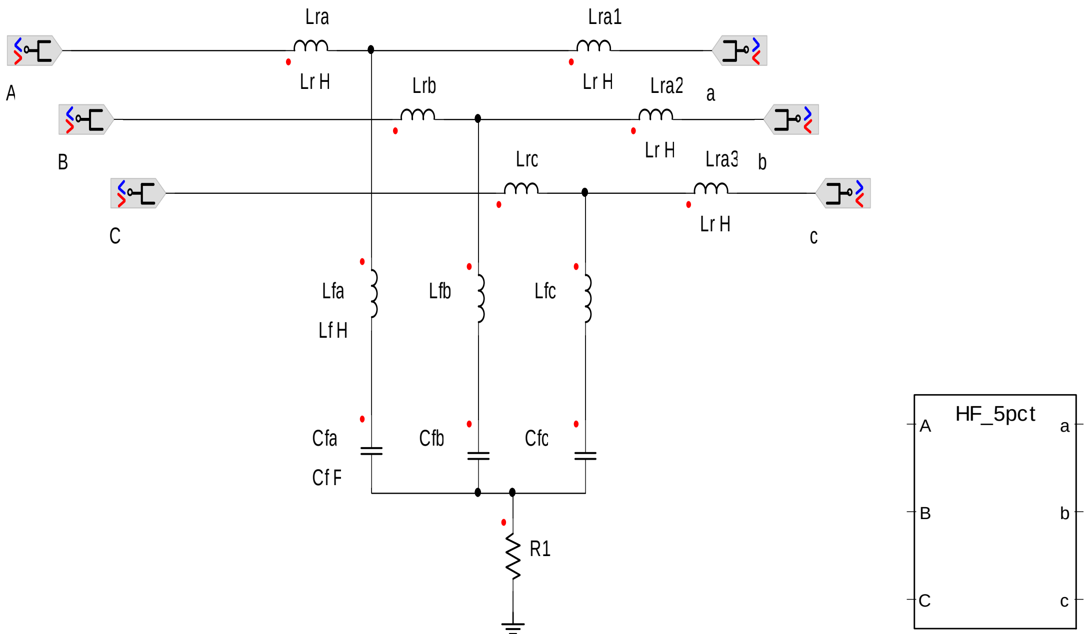


18-pulse Converter:

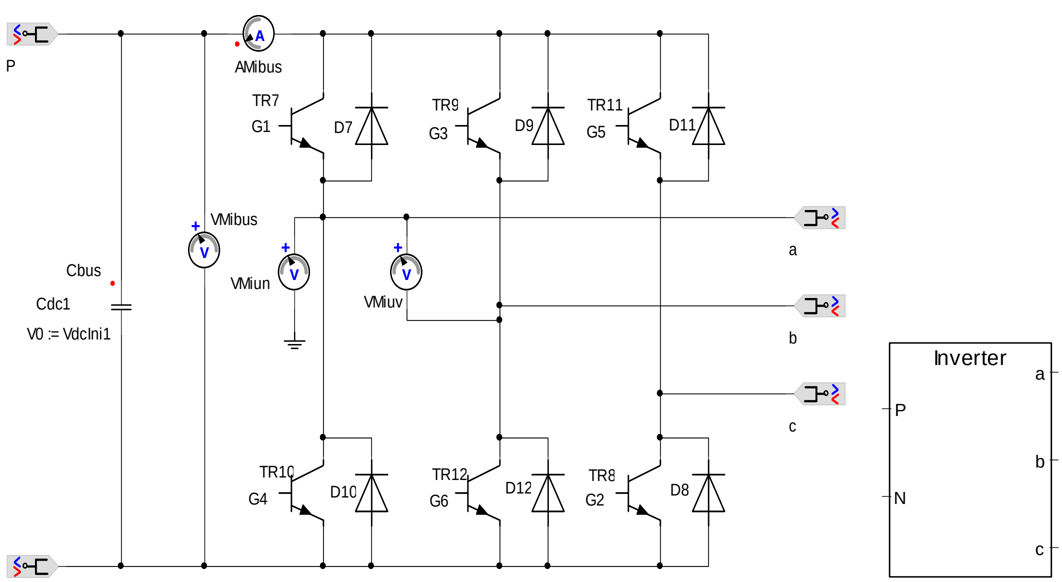


Models used for Simulation

5% THD-I Harmonic Filter:

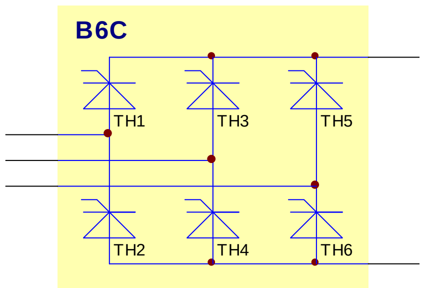


PWM IGBT Inverter:

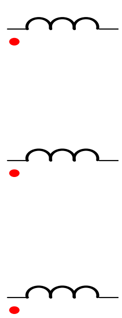


Models used for Simulation

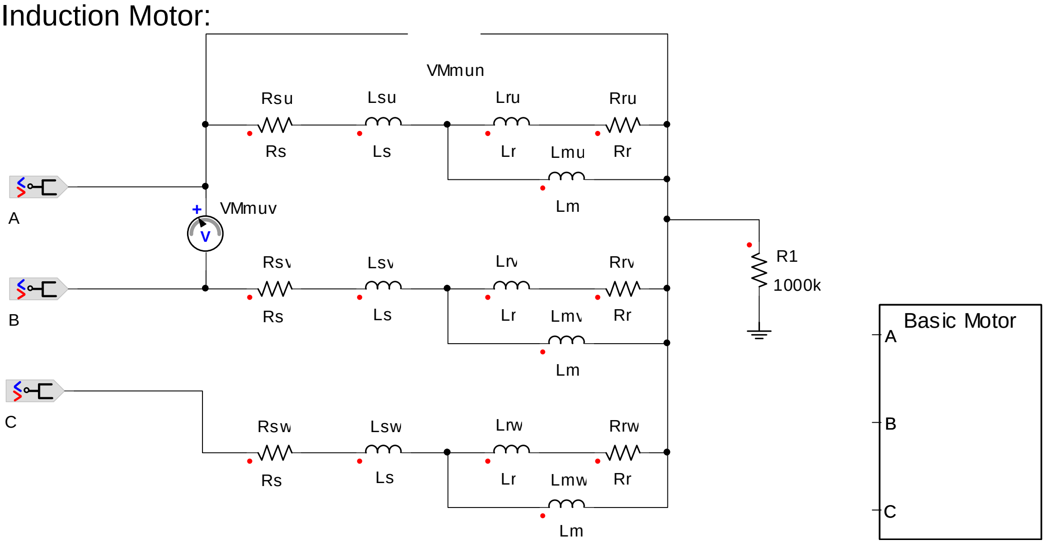
6-pulse SCR Rectifier:



3-phase Line reactor:



Induction Motor:



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APPENDIX – I

Motor Full Load Current - U.S. standard and high efficiency Motors

NEMA Designs B, C & D

Standard Efficiency Motors							High Efficiency Motors			
HP	208V	230V	460V	575V	2300V	4160V	HP	230V	460V	575V
0.5	2.4	2.2	1.1	0.9	-	-	0.5	1.6	0.9	0.8
0.75	3.5	3.2	1.6	1.3	-	-	0.75	2.8	1.4	1.2
1	4.6	4.2	2.1	1.7	-	-	1	3.2	1.6	1.9
1.5	6.6	6.0	3.0	2.4	-	-	1.5	4.8	2.4	2.7
2	7.5	6.8	3.4	2.7	-	-	2	5.8	2.9	3.1
3	10.6	9.6	4.8	3.9	-	-	3	7.8	3.9	3.6
5	16.7	15.2	7.6	6.1	-	-	5	12.8	6.4	5.6
7.5	24.2	22	11	9	-	-	7.5	19.8	9.9	8.2
10	30.8	28	14	11	-	-	10	25.6	12.8	10
15	46.2	42	21	17	-	-	15	37	18.5	16
20	59.4	54	27	22	-	-	20	51	25.5	20
25	74.8	68	34	27	-	-	25	60	30	25
30	88	80	40	32	-	-	30	72	36	29
40	114	104	52	41	-	-	40	92	46	37
50	143	130	65	52	-	-	50	118	59	47
60	169	154	77	62	16	9	60	138	69	56
75	211	192	96	77	20	11	75	172	86	70
100	273	248	124	99	26	15	100	226	113	90
125	343	312	156	125	31	18	125	276	138	113
150	396	360	180	144	37	21	150	326	163	131
200	528	480	240	192	49	27	200	434	217	174
250	-	-	302	242	60	34	250	-	-	-
300	-	-	361	289	72	40	300	-	-	-
350	-	-	414	336	83	46	350	-	-	-
400	-	-	477	382	95	53	400	-	-	-
450	-	-	515	412	103	57	450	-	-	-
500	-	-	590	472	118	66	500	-	-	-
600	-	-	720	576	142	80	600	-	-	-
700	-	-	840	672	166	93	700	-	-	-
750	-	-	900	720	177	99	750	-	-	-
800	-	-	960	768	189	106	800	-	-	-
850	-	-	1020	816	201	113	850	-	-	-
900	-	-	1080	864	213	119	900	-	-	-
1000	-	-	1200	960	236	132	1000	-	-	-
1200	-	-	1440	1152	284	159	1200	-	-	-

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APPENDIX – II

Motor Full Load Current - International Motors

International Motors					
HP	KW	230V	380V	415V	690V
0.5	**0.37**	1.7	1.03	0.92	0.6
0.75	**0.55**	2.7	1.6	1.5	0.9
1	**0.75**	3.3	2	1.9	1.1
1.5	**1.1**	4.3	2.6	2.4	1.5
2	**1.5**	5.8	3.5	3.2	2.0
3	**2.2**	8.3	5	4.6	2.8
5	**3.7**	12.8	7.7	7.1	4.3
7.5	**5.5**	19	11.5	10.6	6.4
10	**7.5**	26	15.5	14.2	8.6
15	**11**	37	22	20	13
20	**15**	50	30	28	17
25	**18.5**	62	37	34	21
30	**22**	73	44	41	25
40	**30**	99	60	55	33
50	**37**	119	72	66	40
60	**45**	141	85	78	47
75	**55**	174	105	96	58
100	**75**	228	138	127	76
125	**90**	281	170	156	94
150	**110**	345	209	192	115
200	**150**	471	285	261	157
250	**185**	582	352	323	194
300	**220**	691	418	383	230
350	**260**	817	494	453	272
400	**300**	942	570	522	314
450	**335**	1053	637	584	351
500	**375**	1178	713	653	393
600	**450**	1413	855	783	471
700	**525**	1649	998	914	550
750	**560**	1760	1065	976	587
800	**600**	1886	1141	1045	629
850	**635**	1996	1208	1107	666
900	**675**	2122	1284	1176	707
1000	**750**	2356	1426	1306	786
1200	**900**	2827	1711	1567	943

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APPENDIX – III

Motor Locked Rotor Current - U.S. standard and high efficiency Motors

Standard Efficiency Motors						
HP	**208V**	**230V**	**460V**	**575V**	**2300V**	**4160V**
0.5	23	20	10	8		
0.75	29	25	12	10		
1	34	30	1	12		
1.5	46	40	20	16		
2	57	50	25	20		
3	74	64	32	26		
5	106	92	46	37		
7.5	146	127	63	51		
10	186	162	81	65		
15	267	232	116	93		
20	333	290	145	116		
25	420	365	182	146		
30	500	435	217	174		
40	667	580	290	232		
50	834	725	362	290		
60	1000	870	435	348	87	50
75	1250	1085	542	434	108	62
100	1665	1450	725	580	145	83
125	2085	1815	907	726	181	104
150	2500	2170	1085	868	217	125
200	3335	2900	1450	1160	290	167
250	4200	3650	1825	1460	365	210
300	5060	4400	2200	1760	440	253
350	5860	5100	2550	2040	510	293
400	6670	5800	2900	2320	580	333
450	7470	6500	3250	2600	650	374
500	8340	7250	3625	2900	725	417
600						
700						
750						
800						
850						
900						
1000						
1200						

APPENDIX - IV

Harmonic Distortion Limits – IEEE std. 519

Voltage Distortion:

We use IEEE-519 Table 10.2 (For systems < 69kV).

IEEE-519 Limit	General Systems	Special Systems	Dedicated Systems
THD (voltage)	**5% THD-v**	**3% THD-v**	**10% THD-v**

We assume General System (5% THD-v) unless the project involves an airport or hospital or when a different voltage distortion limit is specified.

Current Distortion:

We use IEEE-519 Table 10.3

I_{sc} / I_{Load}	<11	11 $\le$ h < 17	17 $\le$ h < 23	23 $\le$ h < 35	35 $\le$ h	TDD
< 20	4.0	2.0	1.5	0.6	0.3	**5.0%**
20 < 50	7.0	3.5	2.5	1.0	0.5	**8.0%**
50 < 100	10.0	4.5	4.0	1.5	0.7	**12.0%**
100 < 1000	12.0	5.5	5.0	2.0	1.0	**15.0%**
1000 +	15.0	7.0	6.0	2.5	1.4	**20.0%**

We determine the TDD limit by calculating the ratio I_{sc} / I_{Load}. When available short circuit is not provided, we calculate based on transformer KVA and % impedance ratings.

NOTES:

NOTES: