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Power Factor Correction Techniques Used for Fluorescent Lamp Ballast

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Ballast for growing

1. Horticulture in conjunction with hydroponics
2. F96T12 HO lamps 0.8 amps
3. Rapid Start operation
4. AC Power Sources
   a. 120 volts 60 Hz
   b. 230 volts 60 Hz
   c. 277 volts 60 Hz
   d. 208 3ø 60 Hz
   e. 230 3ø 60 Hz
5. Single phase must be power factored to 90 percent plus third order harmonics

Harmonic Specifications

IEC 555-2 HARMONIC	CLASS C SPECIFICATIONS LIMITS
2	2 %
3	30 % X P.F.
5	10 %
7	7 %
9	5 %
11	3 %
11< N < 39	1 %

DESIGN GOAL

1. POWER FACTOR GREATER THAN 90 %
2. THIRD ORDER HAMONIC LESS THAN 27 %
3. TOTAL HARMONIC DISTORTION LESS THAN 27 %

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THD CALCULATIONS

$$\text{T.H. D.} = \frac{\sqrt{I^2_{\text{rms total}} - I^2_{\text{fundamental}}}}{I_{\text{fundamental}}}$$

Values are in rms
read from any true rms meter and a spectrum analyzer

$$\text{T.H. D.} = \sqrt{I^2_{2\text{ nd.}} + I^2_{3\text{ rd}} + I^2_{4\text{ th}} + I^2_{5\text{ th}} + \ldots + I^2_{n\text{ th}}}$$

Values are given in percents
Voltech gives percent read out

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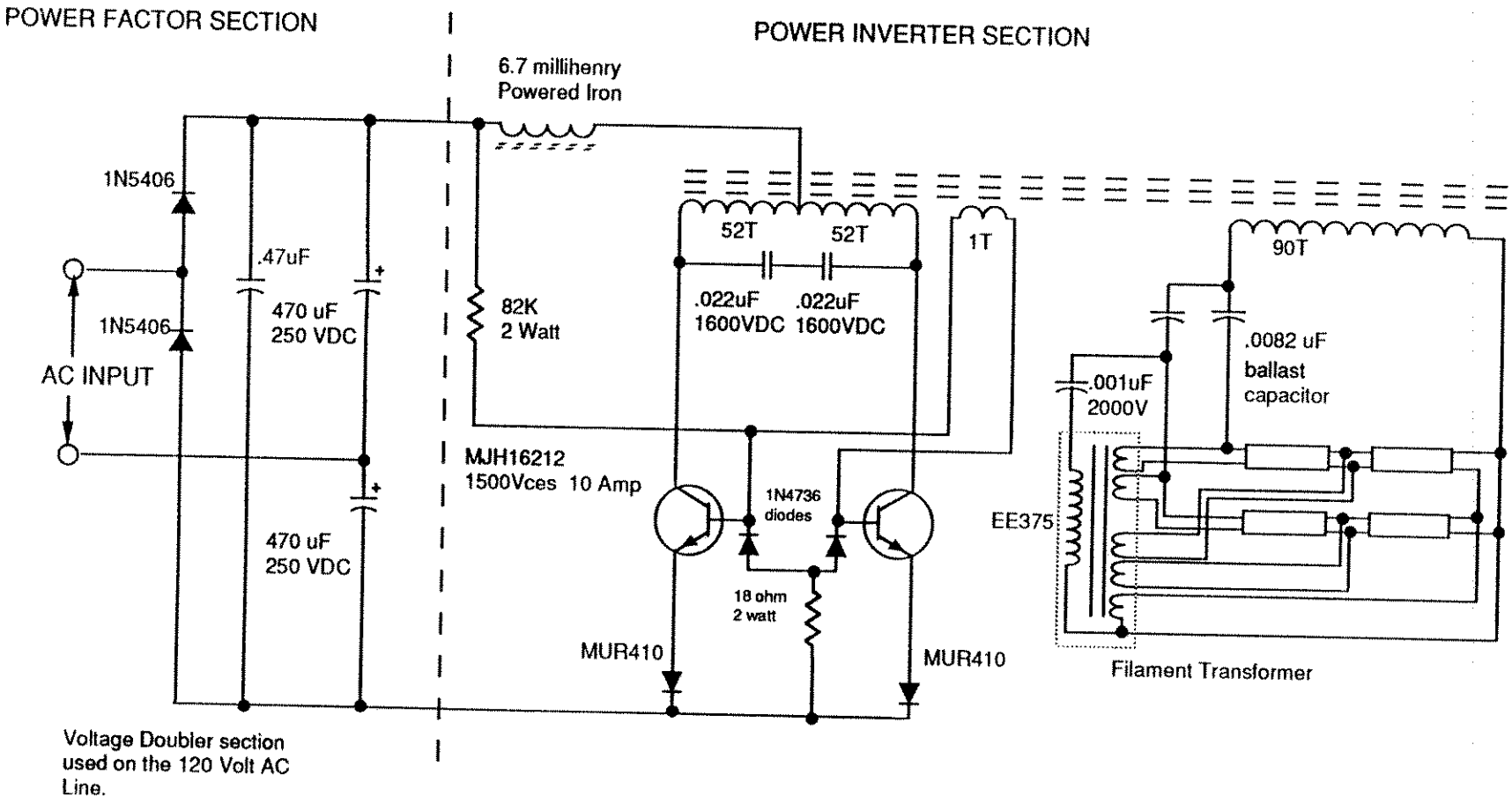
Figure 1



Current Fed Push Pull Sine Wave Converter

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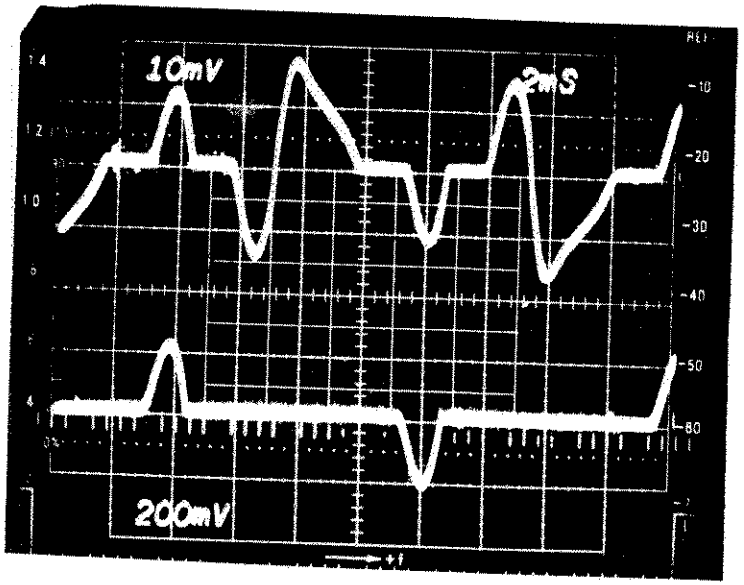
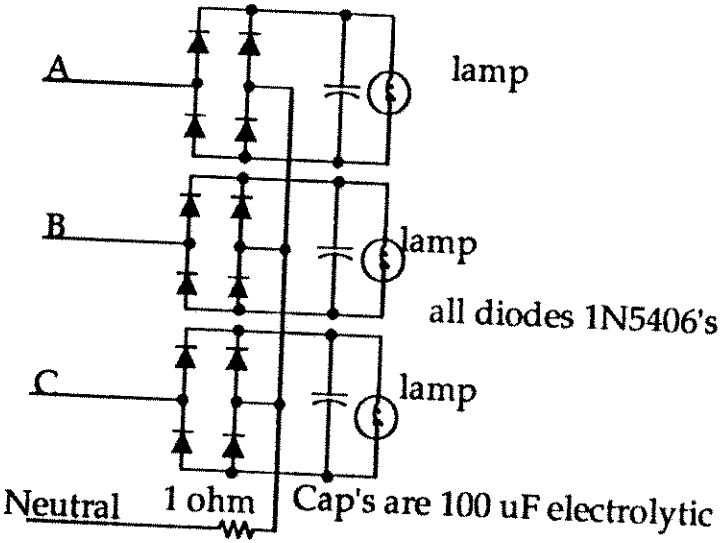
Figure 2





Three Phase Wye Test Circuit with Photo

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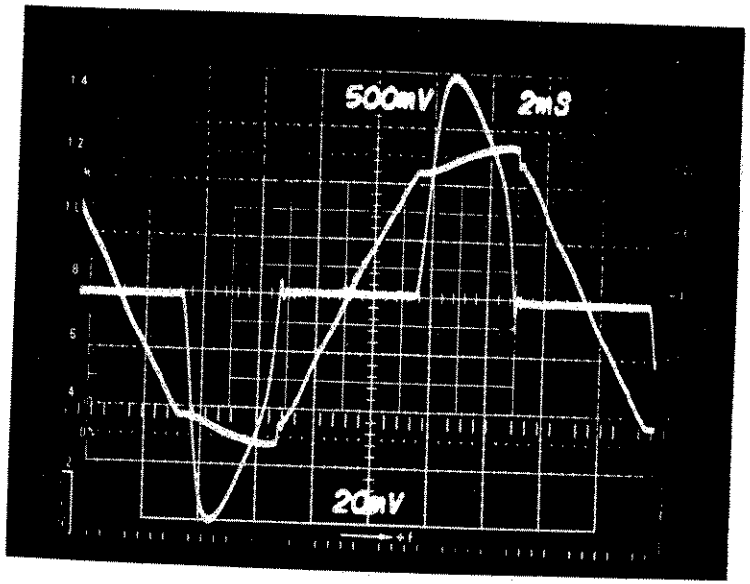

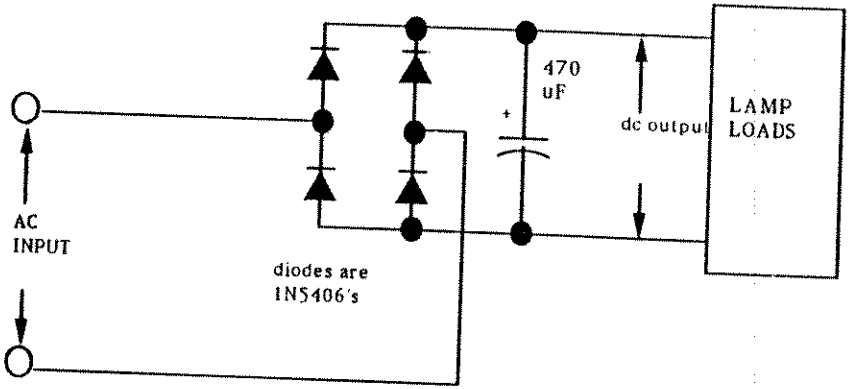

TABLE 1

Diode Bridge No Filter

volts	amps	watts	pwr factor	fund	these are in per cent 2 nd	3rd	5th	7th	9th	11th	13th	T.H.D.	
249.7	2.385	418.4	-0.701	1.7613	0.30	77.44	42.95	11.37	7.93	11.01	5.47	91.30	90.47
267.3	2.367	443.8	-0.703	1.7516	0.40	77.20	42.49	11.75	8.11	10.40	4.91	90.89	90.01
282.6	2.3318	462.9	-0.708	1.7267	0.31	76.64	41.66	11.74	8.56	9.50	4.04	90.76	89.03
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00	3.00	3.00		32.28

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Stiff Line Test Circuit

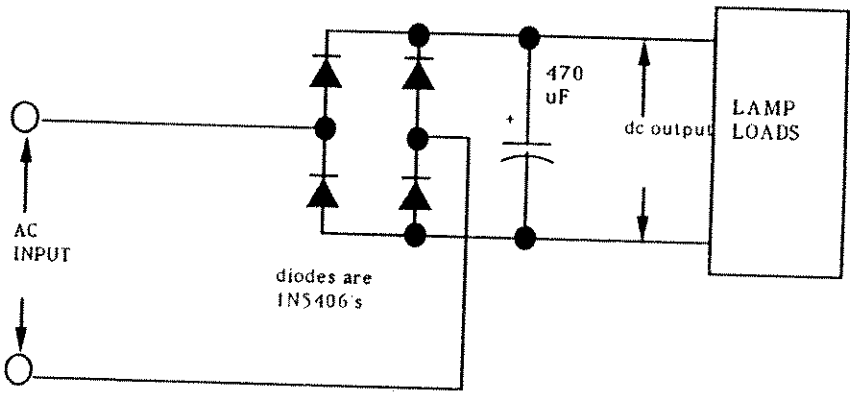
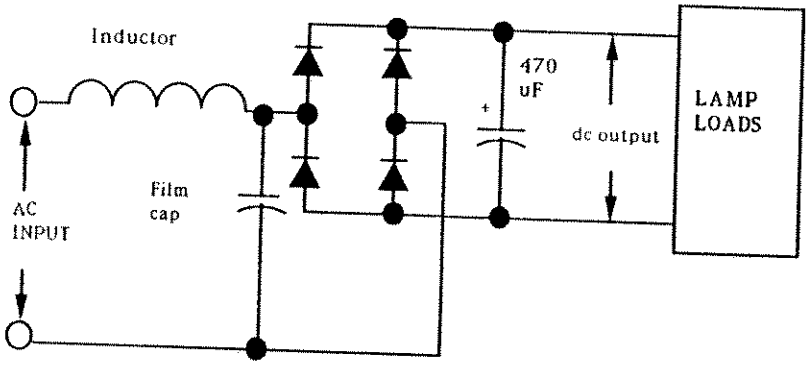


TABLE 2

Stiff Line Power Factor and Harmonic Data

volts	amps	watts	pwr factor	fund	these are in per cent 2 nd	3rd	5th	7th	9th	11th	13th	T.H.D.	T.H.D. sum of sq
122.48	1.803	127.7	-0.578	1.070	0.84	91.10	74.71	54.36	33.05	14.37	2.85	135.62	134.70
122.28	1.943	138.5	-0.583	1.170	0.58	90.43	72.92	51.38	29.52	11.28	3.75	132.58	130.95
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00	3.00	3.00		32.28



LC FILTER BEFORE THE BRIDGE DIODE

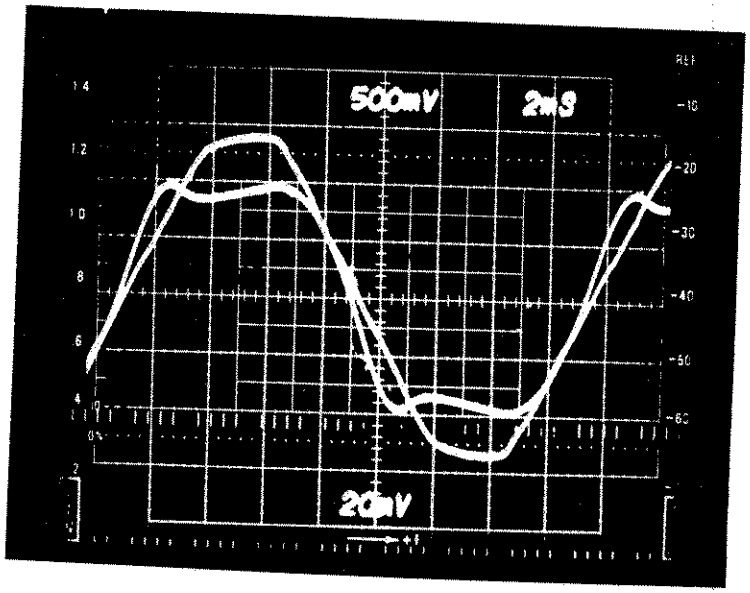


TABLE 3

L C Filter in front of Diode Bridge: Voltage Doubler 40 mH & 20.4uF

volts	amps	watts	pwr factor	fund	these are in per cent 2 nd	3rd	5th	7th	9th	11th	13th	T.H.D.	T.H.D. sum of sq
108.06	3.117	315.7	0.945	3.034	0.09	21.32	4.31	1.48	0.56	0.21	0.22	23.55	21.81
120.18	3.360	377.7	0.938	3.276	0.11	21.94	4.40	1.63	0.41	0.17	0.25	22.79	22.44
132.40	3.540	436.6	0.924	3.437	0.10	23.37	4.51	1.56	0.37	0.20	0.22	24.66	23.86
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00	3.00	3.00		32.28

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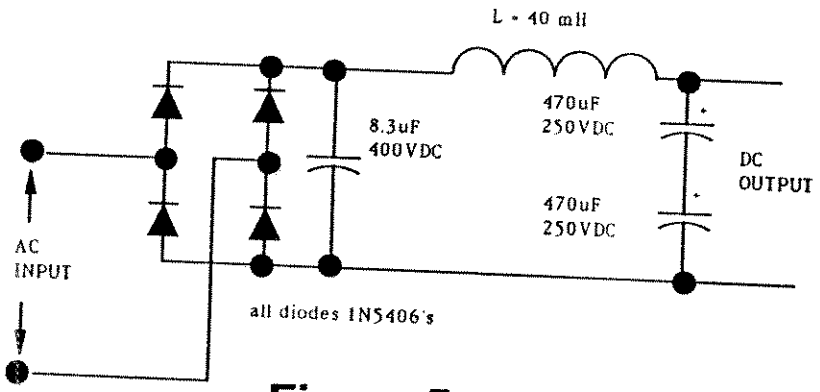

Figure 5

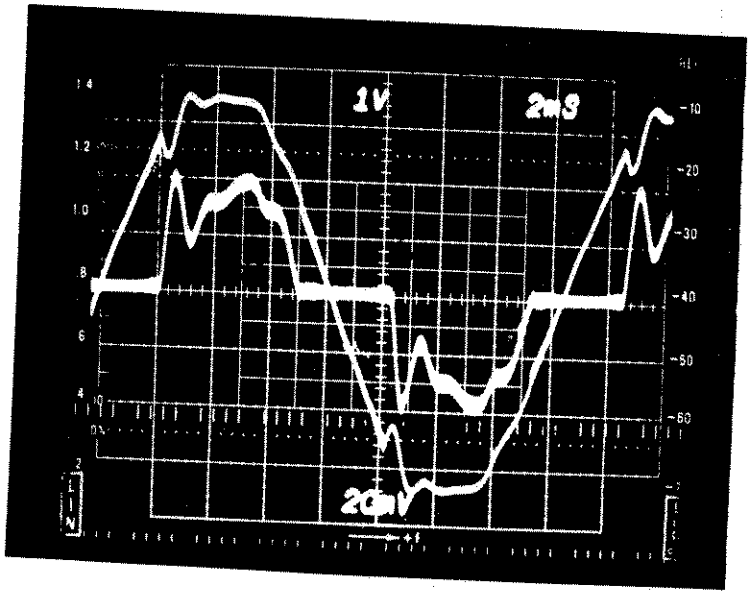

TABLE 4
L C Filter After Diode Bridge

volts	amps	watts	pwr factor	fund	these are in per cent 2 nd	3rd	5th	7th	9th	11th	13th	T.H.D.	T.H.D. sum of sq
251.2	1.594	365.6	-0.910	1.467	0.33	27.42	21.72	6.03	11.81	5.01	9.17	42.48	38.84
267.6	1.641	399.2	-0.909	1.504	0.34	27.69	22.18	6.80	12.26	5.40	10.03	43.61	39.81
284.1	1.688	434.5	-0.906	1.542	0.27	28.23	22.65	7.80	13.10	6.07	11.75	44.50	41.44
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00	3.00	3.00		32.28

RIPPLED OR VALLEY FILL PASSIVE POWER FACTOR CIRCUIT

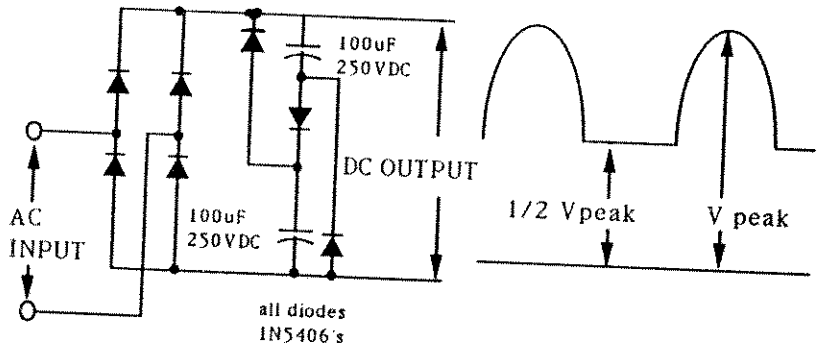

Figure 6

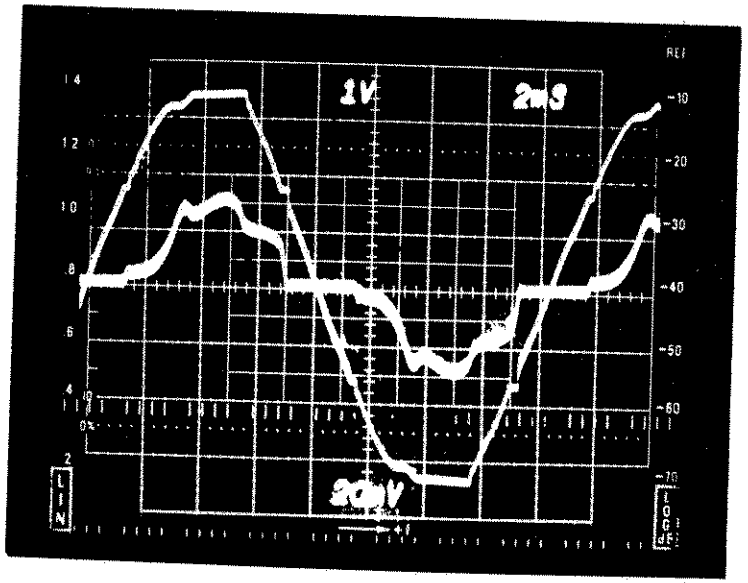

TABLE 5

Valley Fill No Inductor to Limit Current

these are in per cent

volts	amps	watts	pwr factor	fund	2nd	3rd	5th	7th	9th	11th	13th	T.H.D.	T.H.D. sum of sq
250.3	1.218	285.6	-0.936	1.155	0.33	29.25	4.36	6.41	11.78	7.75	2.49	33.54	33.48
268.7	1.313	336.6	-0.953	1.255	0.33	22.45	9.90	10.48	9.19	8.66	1.40	30.75	29.55
285.6	1.378	377.1	-0.955	1.331	0.21	20.57	12.96	11.04	8.87	9.84	2.50	26.61	29.91
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00	3.00	3.00		30.41

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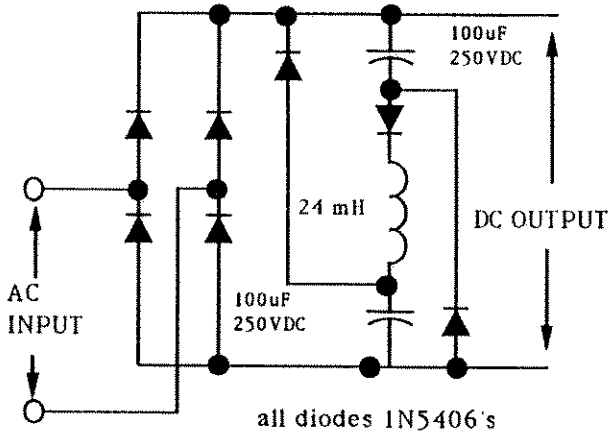
RIPPLED POWER FACTOR WITH INDUCTOR IN CHARGING LEG



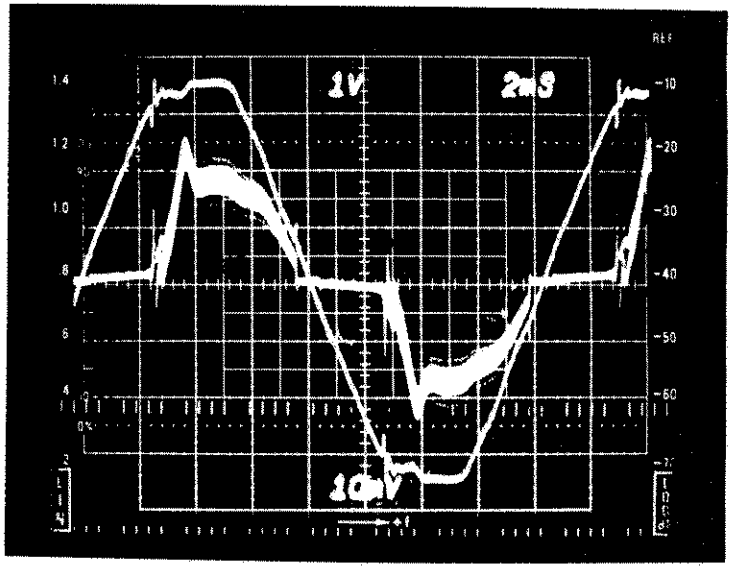


FIGURE 7

TABLE 6

Power Choke in the Charging Path

volts	amps	watts	pwr factor	fund	these are in per cent 2nd	3rd	5th	7th	9th	11th	13th	T.H.D.	T.H.D. sum of sq
253.0	1.195	283.3	-0.939	1.135	0.15	28.88	7.54	1.02	8.25	4.62	6.17	32.94	31.93
265.5	1.254	315.7	-0.950	1.199	0.19	24.46	10.61	1.51	7.59	3.86	6.35	30.40	28.74
282.0	1.303	354.1	-0.958	1.267	0.18	20.40	14.31	3.55	5.97	4.46	5.54	23.98	26.83
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00	3.00	3.00		32.28

RIPPLED POWER FACTOR WITH INDUCTOR IN SERIES WITH THE LINE

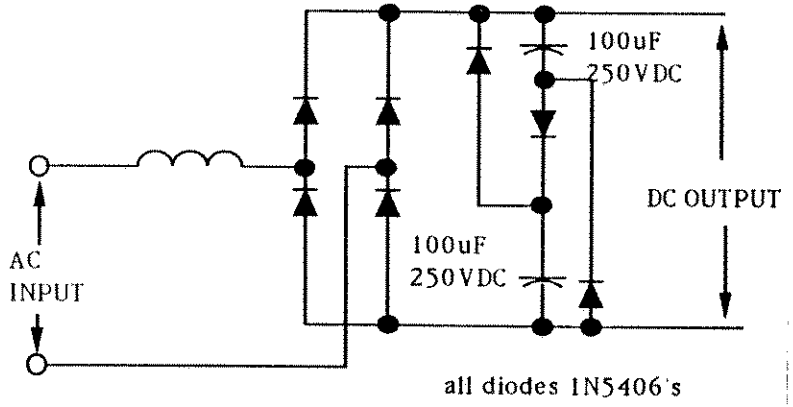


FIGURE 8

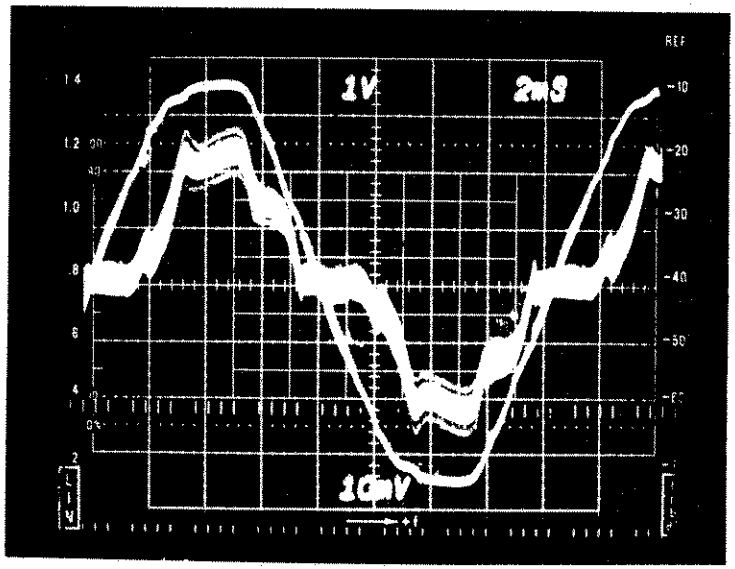


TABLE 7

Power choke in front of valley fill

volts	amps	watts	pwr factor	fund	these are in per cent 2 nd	3rd	5th	7th	9th	11th	13th	T.H.D.	T.H.D. sum of sq
257.5	1.2681	296.4	-0.925	1.206	0.19	29.98	1.48	5.14	8.31	5.60	1.77	32.50	32.11
268.4	1.3621	345.3	-0.946	1.311	0.27	24.27	4.90	5.36	8.90	4.91	3.13	28.19	27.48
282.7	1.4263	383.8	-0.953	1.377	0.20	21.91	8.37	7.74	8.22	4.96	3.88	27.00	26.78
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00	3.00	3.00		32.28

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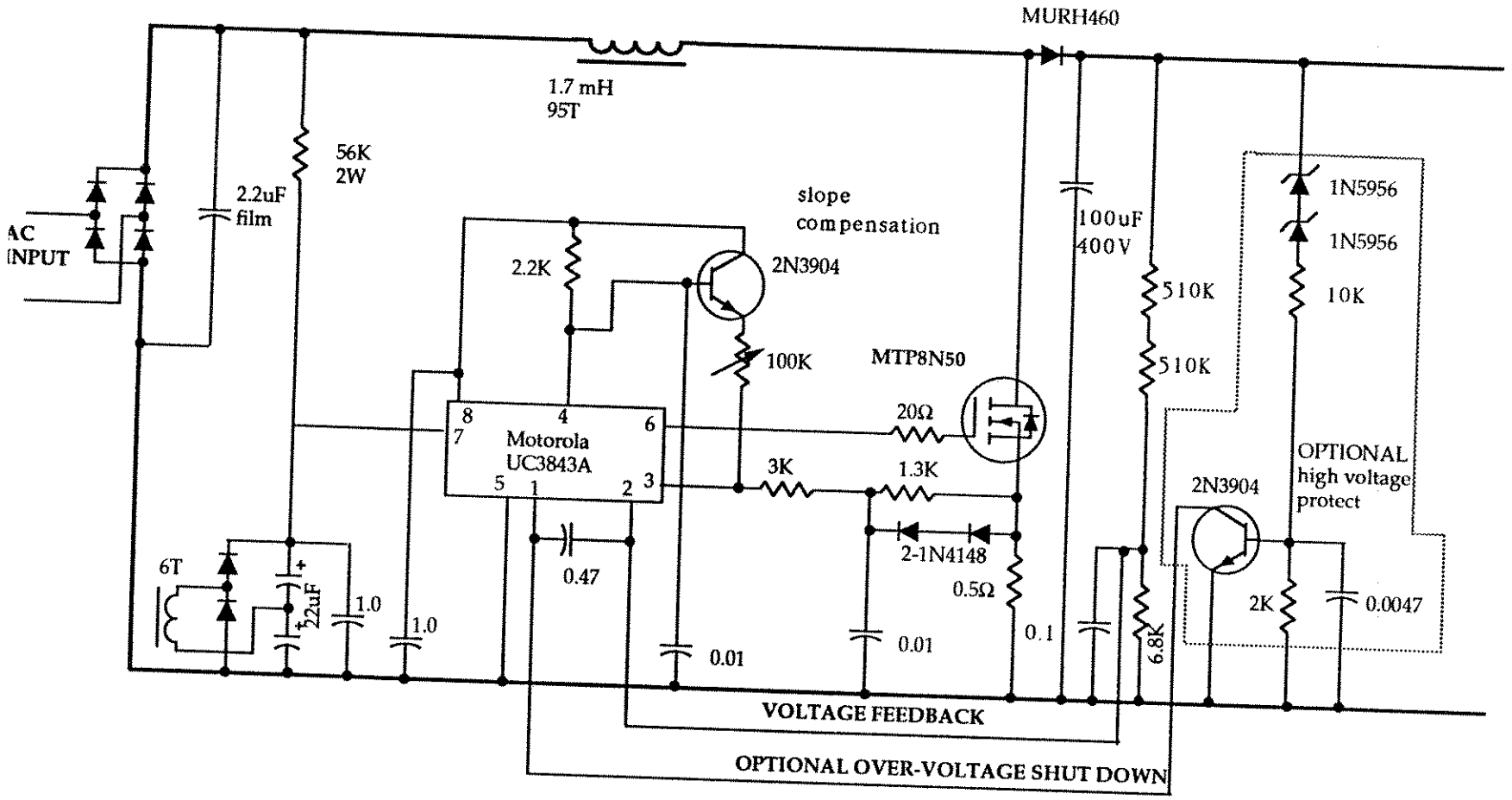

CONSTANT FREQUENCY VERSION
FIGURE 9

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TABLE 8 BOOST CONVERTER

340 VOLT BUS

volts	amps	watts	pwr fact	fund	these are in percent 2nd	3rd	5th	7th	9th	V out dc bus	T.H.D. %	T.H.D. sum of sq.	W lamps1	W lamps2
181.1	2.410	422.0	0.970	2.356	0.12	17.23	10.00	5.72	2.96	322.0	21.53	20.94	197.5	165.8
190.6	2.419	445.3	0.970	2.364	0.02	17.61	9.93	5.86	3.25	328.8	21.70	21.30	204.0	181.5
199.6	2.417	469.1	0.968	2.360	0.09	18.14	9.80	6.03	3.49	338.8	22.11	21.76	213.2	195.5
210.0	2.267	466.0	0.971	2.223	0.09	17.09	9.09	6.00	3.80	338.9	19.99	20.62	213.3	195.6
220.3	2.156	463.0	0.974	2.109	0.06	15.86	8.33	5.73	3.83	338.9	21.23	19.19	213.3	195.3
230.9	2.038	460.5	0.978	2.005	0.10	14.05	7.08	5.32	3.61	338.9	18.22	17.00	213.1	195.6
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00			32.00		

385 VOLT BUS

volts	amps	watts	pwr fact	fund	these are in percent 2nd	3rd	5th	7th	9th	V out dc bus	T.H.D. %	T.H.D. sum of sq.	W lamps1	W lamps2
182.3	1.950	348.0	0.972	1.907	0.05	16.19	10.19	5.85	2.96	384.3	21.36	20.22	163.7	137.3
190.0	1.897	350.9	0.973	1.864	0.06	15.63	10.00	5.81	3.18	384.1	18.90	19.70	163.1	138.0
199.4	1.795	349.8	0.976	1.769	0.08	14.00	9.27	5.80	3.35	384.0	17.21	18.08	163.1	139.5
211.1	1.684	348.8	0.980	1.663	0.03	11.53	8.27	5.40	3.36	384.0	15.94	15.55	162.8	140.0
220.2	1.603	348.1	0.982	1.583	0.16	9.26	7.28	4.83	3.00	383.8	16.03	13.08	162.6	140.0
231.0	1.530	347.2	0.985	1.515	0.17	6.94	6.25	4.28	2.74	383.7	13.91	10.63	162.6	140.4
240.6	1.463	347.1	0.986	1.459	0.19	4.58	5.22	3.65	2.26	383.6	7.41	8.17	162.3	140.2
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00			32.00		

400 VOLT BUS

volts	amps	watts	pwr fact	fund	these are in percent 2nd	3rd	5th	7th	9th	V out dc bus	T.H.D. %	T.H.D. sum of sq.	W lamps1	W lamps2
180.0	2.163	377.8	0.966	2.119	0.16	18.67	10.88	5.61	2.45	397.8	20.48	22.46	172.0	151.0
190.0	2.049	376.6	0.969	2.001	0.13	17.57	10.62	5.90	2.93	397.5	22.03	21.56	171.0	151.0
200.6	1.915	374.1	0.973	1.874	0.06	15.95	9.95	6.02	3.38	397.5	21.03	20.03	171.0	151.0
210.8	1.810	372.2	0.976	1.780	0.02	14.40	9.18	5.82	3.57	397.4	18.44	18.39	171.0	151.0
221.1	1.710	371.2	0.978	1.689	0.09	12.18	8.24	5.38	3.53	397.3	15.82	16.05	171.0	151.0
229.6	1.637	370.1	0.981	1.622	0.07	10.64	7.45	5.01	3.46	397.3	13.63	14.35	171.0	151.0
239.6	1.563	369.0	0.983	1.553	0.19	8.47	6.40	4.47	3.00	397.4	11.37	11.90	171.0	151.0
250.0	1.500	369.00	0.984	1.490	0.24	6.43	5.36	3.82	2.64	397.4	11.61	9.58	171.0	151.0
		IEC SPECIFICATIONS			2.00	27.00	10.00	7.00	5.00			32.00		

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ANALYSIS

$$P_{ower} = V_{rms} I_{rms} \text{Cos } \varnothing$$

$$P_{ower} = V_{rms} I_{rms} \frac{I_{1rms}}{I_{rms}} \text{Cos } \varnothing_1$$

$$P_{ower} = S\, k_d\, k_{\varnothing}$$

$$S = V_{rms}\, I_{rms}$$

$$k_d = \frac{I_{1rms}}{I_{rms\ total}}$$

$$k_{\varnothing} = \text{Cos } \varnothing_1$$

$$P_{ower} = \frac{1}{T}\int_{0}^{T} v_{(t)}\, i_{(t)}\, dt$$

$$v_{(t)} = \sum_{n=0}^{\infty} V_n \text{ Sin } (n\,wt + \emptyset)$$

$$v = \sqrt{v_{DC}^2 + v_{1vrms}^2 + v_{2rms}^2 + v_{3rms}^2 \bullet\bullet\bullet\bullet}$$

$$i = \sqrt{i_{DC}^2 + i_{1rms}^2 + i_{2rms}^2 + i_{3rms}^2 \bullet\bullet\bullet\bullet}$$

using only odd harmonics

$$P_{ower} = V_{dc}\, I_{dc} + v_{1rms} i_{rms} \operatorname{Cos} \phi_1 + v_{3rms} i_{3rms} \operatorname{Cos} \phi_3$$

$$P_{ower} = V_{dc} I_{dc} + \sum_{n=1}^{\infty} v_{nrms}\, i_{nrms} \operatorname{Cos} \phi_n$$

$$\phi_1 = \angle V_{1rms} - \angle I_{1rms}$$

$$\phi_n = \angle V_{nrms} - \angle I_{nrms}$$

Test Conditions

1. Isolation transformer and variacs offer resistance to the flow of current. They improve the power factor over a stiff line.

2. Voltage delivered from the Utility is not always pure. Please check the distortion of the voltage waveform.

3. EMI is also affected by the input resistance. A stiff line offers less resistance than a LISN . Using a Current probe or Current Transducer showed higher EMI than that measured using a LISN.

CONCLUSION

1. Passive LC filter is easy and simple. The size of the choke is large and hums. The hum can be overcome by good manufacturing (varnish).

2. Valley fill is cost effective. The DC bus voltage has a 50% ripple at twice the live frequency. The ripple produces a lamp flicker which may be objectionable.

3. Valley fill with chokes help meet the IEC specs. The iron choke can help reduce EMI. This technique can meet IEC specs.

4. Boost converter meets the IEC specs andgive good output. The Bus voltage is high about 50 volts higher than the Vpeak of the AC line which can be a problem with electrolytic caps.

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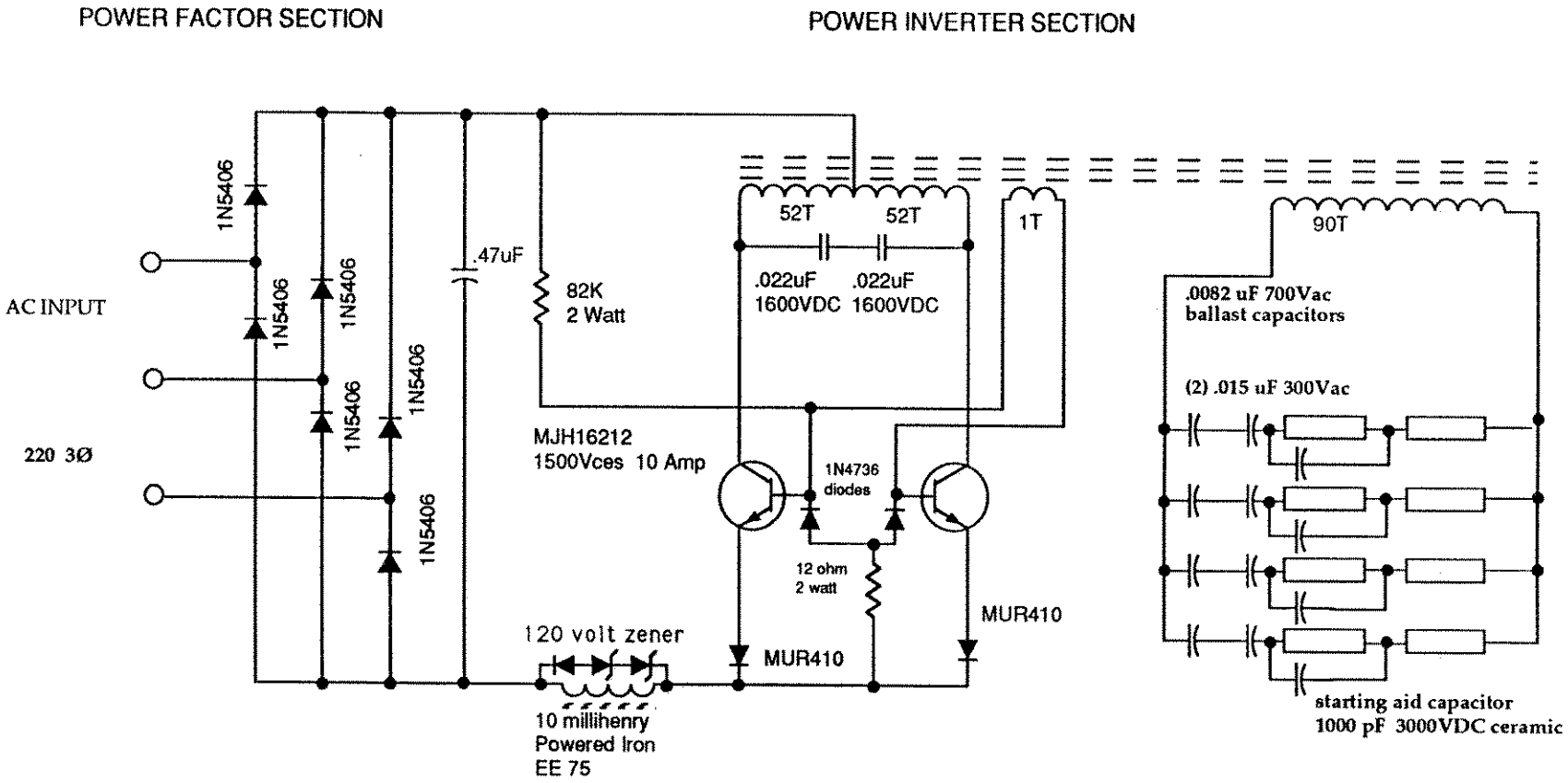
new solution



CURRENT FED SINE WAVE CONVERTER
800 watt 3 phase 220 input
INSTANT START F96T12 HO LAMPS

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