POWER FACTOR CORRECTION AT THE MIT-BATES LINEAR ACCELERATOR CENTER WITH PULSED LOADS OF UP TO 180 MW PEAK (2.7 MW AVERAGE)

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I INTRODUCTION

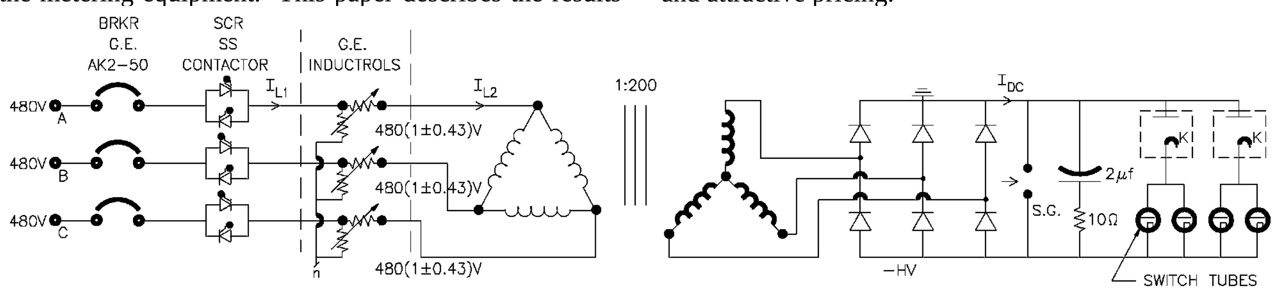
Power demand charges to MIT-Bates are based on a fixed rate times the greater of kWatt or 0.9 (kVolt A) called for in a 15 minute period within a billing cycle. There have been a number of months in a year when the power factor (PF) was less than 0.9 lagging, resulting in the increase in the demand charges to MIT by the Middleton Municipal Electric Department (MMED). A study resulted in a decision to correct the PF to >0.9 in order to minimize the demand charges. This action would save about $3500 per month in demand charges. Other benefits would also be realized by MIT-Bates and MMED, depending on the installation location. Information obtained on operational AC power requirements for the pulsed loads was obtained by measuring current and voltages at the 480V inputs to the pulsed loads and at the incoming 22,900V line input to the facility. A review of the harmonics generated in the voltage and current waveforms at both voltage levels for several operating levels allowed completion of an engineering analysis, which resulted in the selection of a 1200 kVAR switchable capacitor bank to be installed in a wye connection at the 22,900V incoming line point just after the metering equipment. This paper describes the results of the harmonic studies of the AC power, the pulsed loads required as measured at 480V, and the resultant overall harmonics generated at the 22,999V level by the pulsed loads when combined with the other normal AC loads at the Laboratory.

II 480 VOLT TRANSMITTER STUDIES

Jomitek, Inc. made a series of measurements on the five 480V substation distribution system. The information (Ref. 1) obtained was very useful to the MIT-Bates technical staff due to a lack of instrumentation which prevented observation of the normal operating loads for these substations. A report submitted to MIT-Bates by Jomitek focused on a power monitoring system proposal and additionally discussed the correction of the PF at the 480V or at the 22,900V level.

Current and voltage measurements were taken for a single transmitter operating at several different levels and repetition rates (PPS).

This information showed the harmonic levels to be maximum at the highest operating conditions. Various commercial companies have been offering power monitoring systems with increased measurement capabilities and attractive pricing.



TYPICAL OPERATING CONDITION
600 pps, 23μS

MODE	2 KLYSTRONS		HVDCPS		INDUCTROL OUT		480V IN	P + jQ	KVA
	I_{PK}(A)	E_{PK}(kV)	E_{DC}(kV)	I_{DC}(A)	E_L(V)	I_L(A)	I_L(A)	(kw) K_{VAR}	
LOW	70	107	120	1.93	473	381	467	319 + j 221	388
NORMAL	76	113	130	2.09	493	397	521	360 + j 240	433
MAX	95	131	153	2.62	610	500	664	500 + j 333	600

GENERAL SCHEMATIC FOR ONE OF SIX TRANSMITTERS

NOTE: TX6 HAS VVT, NOT INDUCTROL

Fig. 1. The schematic for a typical transmitter.

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One transmitter was instrumented with current and voltage measurements on the primary and secondary of a G.E. Inductrol unit and the input AC requirements for the HVDCPS transformer rectifier was determined for the present operating levels, which are lower than the original design specifications. The nominal pulsed parameters for an operating transmitter are: 23• S pulse width, 600 pps, and peak currents of 76A for each of the two paralleled klystrons being driven. Figure 1 shows the schematic for a typical transmitter.

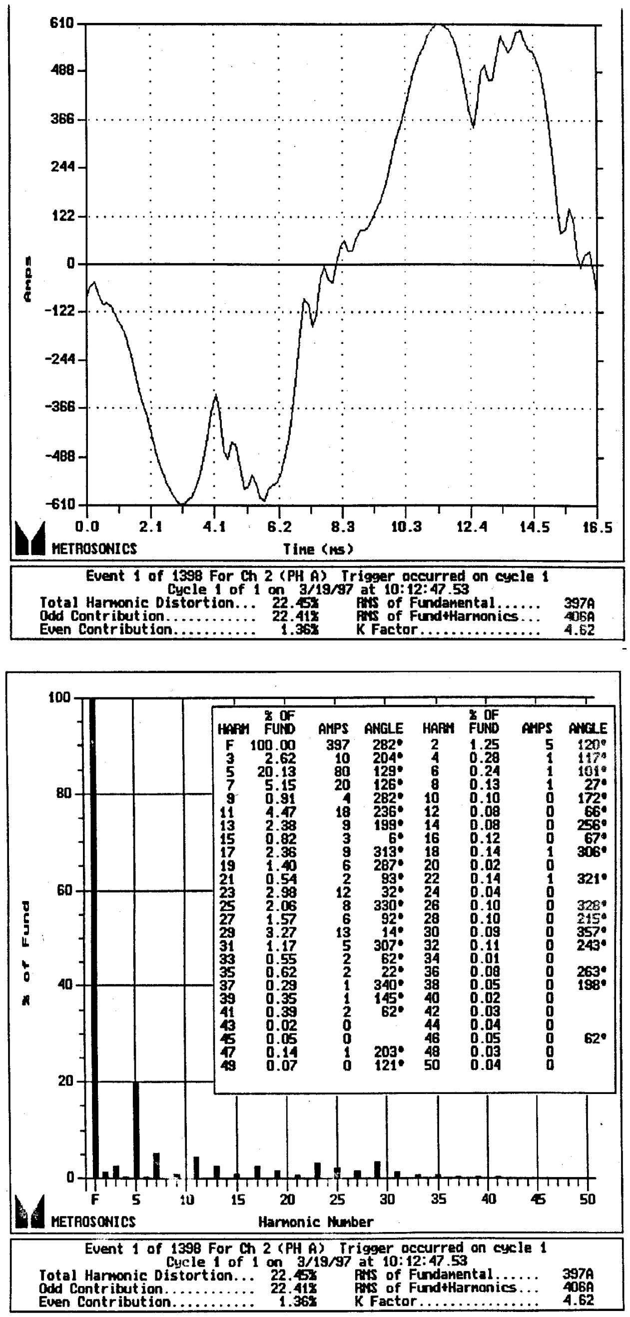
Additional transmitter harmonic measurements were taken using a METROSONICS commercial package on a single transmitter operating at the nominal operating conditions. Waveform and harmonic spectrum for the pulsed load typical 480V line current can be seen in Figure 2. The voltage waveforms are not very distorted and are not shown to save space. The voltage waveforms have a total harmonic distortion expressed as a percent of the fundamental (THD%) of 3.5%, while the current waveforms were measured to have a THD of 22.5%.

III 22,900 VOLT LINE MEASUREMENTS

PLM, Inc. an engineering firm specializing in providing service to the utility firms in New England, and in particular to MMED over the past several years on an as-needed-basis, was hired to determine if it was possible to implement a PF correction system at the MIT-Bates Laboratory, and if so where would be the best place on the power distribution system to install the equipment. PLM was given the earlier data and used some of this data to review the case for installation of the PF correction at the 480V level.

It was determined that the harmonic levels generated at the 480V level by the transmitters would require more analysis and there would be more risk, but with more benefits within the MIT-Bates distribution system. Certain filters would need to be determined and installed to prevent unwanted resonances peculiar to the variable harmonics generated by the nearby pulsed loads.

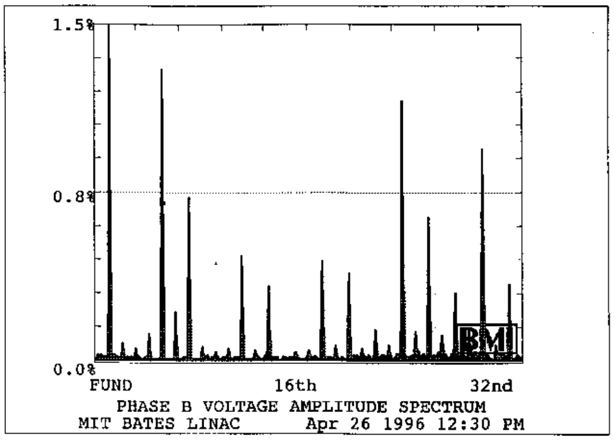
In order to study the voltage and current harmonics at the 22,900V level, measurements of the harmonics generated at the incoming metering point were necessary. PLM then could evaluate the extent of these harmonics and the effects of a capacitor bank installed on MMED's transmission line. The typical harmonic spectrum for line voltages and currents is shown in Figure 3 at the 22,900V level. PLM engineers then performed an analysis (Ref.3) of the system under several scenarios. A one-line diagram of the approximately 5 mile long transmission line is shown in Figure 4 with all impedances shown referenced to the 22,900V level. The system resonance frequencies for a 1200kVAR and 1800kVAR banks were determined with a worst case operating voltage level 5% above nominal (under normal system impedance) and under a 20% increased system impedance. The installation of a 1200kVAR capacitor bank and the resulting harmonic currents flowing through the capacitors would not exceed



HARM	% OF FUND	AMPS	ANGLE	HARM	% OF FUND	AMPS	ANGLE
F	100.00	397	282°	2	1.25	5	120°
3	2.62	10	204°	4	0.28	1	117°
5	20.13	80	129°	6	0.24	1	101°
7	5.15	20	126°	8	0.13	1	27°
9	0.91	4	282°	10	0.10	0	172°
11	4.47	18	236°	12	0.08	0	66°
13	2.38	9	199°	14	0.08	0	256°
15	0.82	3	6°	16	0.12	0	67°
17	2.36	9	313°	18	0.14	1	306°
19	1.40	6	287°	20	0.02	0	
21	0.54	2	93°	22	0.14	1	321°
23	2.98	12	32°	24	0.04	0	
25	2.06	8	330°	26	0.10	0	328°
27	1.57	6	92°	28	0.10	0	215°
29	3.27	13	14°	30	0.09	0	357°
31	1.17	5	307°	32	0.11	0	243°
33	0.55	2	62°	34	0.01	0	
35	0.62	2	22°	36	0.08	0	263°
37	0.29	1	340°	38	0.05	0	198°
39	0.35	1	145°	40	0.02	0	
41	0.39	2	62°	42	0.03	0	
43	0.02	0		44	0.04	0	
45	0.05	0		46	0.05	0	62°
47	0.14	1	203°	48	0.03	0	
49	0.07	0	121°	50	0.04	0	

Fig. 2. Typical transmitter line currents at 480V-3Ph-60Hz.

the manufacturer's ratings of the capacitor units. For this proposed installation at the nominal system impedance, the system resonance frequency was calculated to be 604.25 Hz. The bank would operate at 95.52% of the RMS capacitor voltage rating with a 3.52% THD. The capacitor RMS current was calculated to be 61.5% of the manufacturer's capacitor current rating. PLM, Inc. then proposed and MIT-Bates agreed to install a 1200kVAR PF correction system at the incoming 22,900V level as being the simplest most economical and least risk approach to solve the main goal of increasing the load PF to >0.9 and avoid the demand charges associated with PF <0.9.



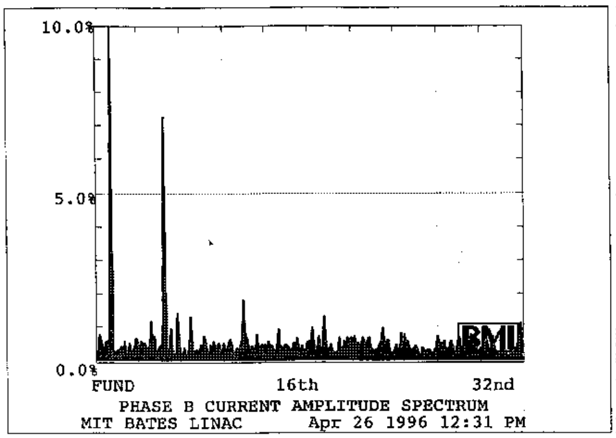


Fig. 3. Typical harmonics for line voltages and currents at 22,900V and 4.0 MVA, 0.8 PF with 6 transmitters operating

PLM then was charged to specify the PF correction equipment (Ref. 4) and to review the bids obtained. An order was placed with the low bidder for a Cooper Industries rack mounted switchable capacitor bank to be pole mounted after the incoming line metering point. The system was delivered in January 1997 and awaits an installation window of time for which the Laboratory power must be interrupted for about 4 hours to install and connect the equipment. MMED personnel have been given an installation contract including the pole, mounting the capacitor/switch assembly and connecting the capacitors to the 22,900V line.

IV CONCLUSION

The project to correct the MIT-Bates PF to > 0.9 is almost complete. Remaining work is to mount the capacitor switch assembly on the already installed pole, connect the units to the 22,900V lines and make a final checkout of the installation. Excellent cooperation between MIT-Bates technical staff, PLM, Inc. engineer and the MMED technical staff was an important part of the solution selected for implementation. The authors would like to thank the following persons for their contributions to the project: John J. Marczewski, Principal Engineer, PLM, Inc. and Paul Kilroy, Facility Coordinator, MMED.

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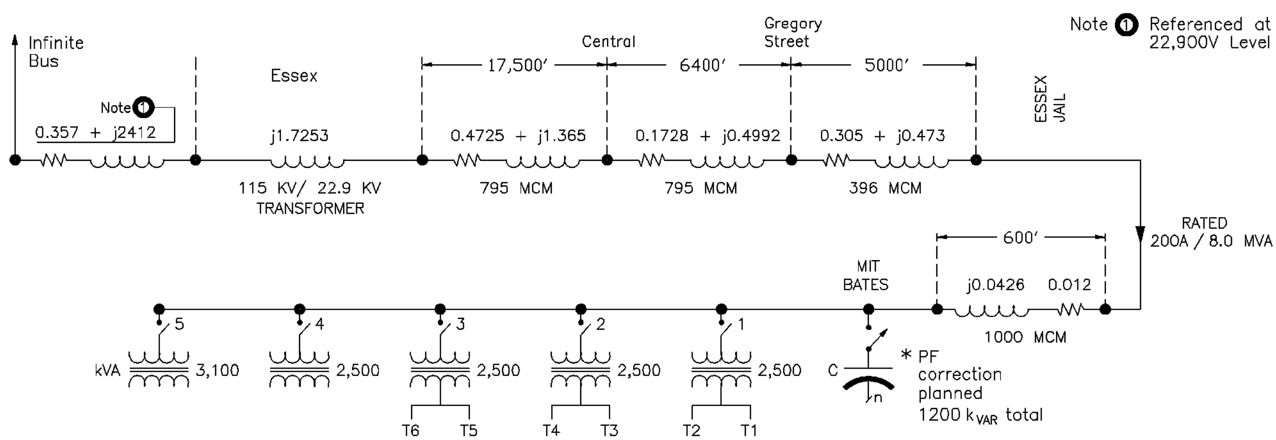

Fig. 4. Diagram of transmission line.