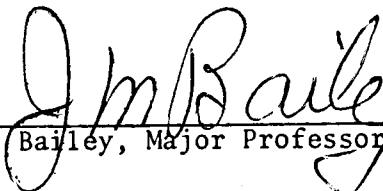
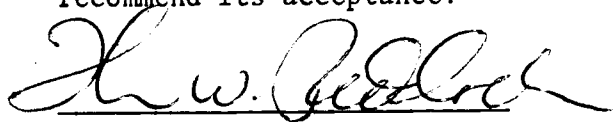
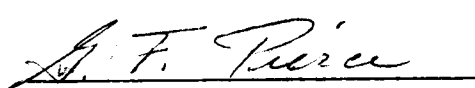


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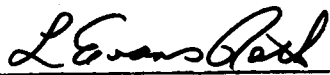
I am submitting herewith a thesis written by Wallace F. Carden, Jr., entitled "Pulsed Load Effects on Electrical Power Distribution Systems." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Electrical Engineering.


J. M. Bailey, Major Professor

We have read this thesis and
recommend its acceptance:

Accepted for the Council:


Vice Chancellor
Graduate Studies and Research

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PULSED LOAD EFFECTS ON ELECTRICAL POWER
DISTRIBUTION SYSTEMS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee; Knoxville

Wallace F. Carden, Jr.

June 1980

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ABSTRACT

The Oak Ridge National Laboratory's Elmo Bumpy Torus nuclear fusion device has been selected by the U.S. Department of Energy to be developed to the proof of principle level. The proof-of-principle device has been designated EBT-P, and will be constructed at the Union Carbide Corporation, Nuclear Division's Y-12 plant in Oak Ridge, Tennessee. Due to the planned addition of the EBT-P, which operates in a steady state mode, an investigation was needed to determine the effect of a pulsed load from other experiments or facilities on the Y-12 electrical distribution system (and hence on EBT-P). The main problem posed by the pulsed loads will be their effect on the distribution system bus voltages.

The method for analyzing this problem was to obtain an approximate computer modeling of conditions in the distribution system and make recommendations, based on the computer modeling, for network modifications to minimize or isolate the impact of these experiments on the EBT-P experiment through the Y-12 plant electrical distribution system.

A load flow program developed by The University of Tennessee, Knoxville, personnel (under Union Carbide Corporation, Nuclear Division Subcontract No. 7259) was used to model the system during steady state conditions.

A computer program entitled "Electromagnetic Transients Program" or "EMTP" for short was used to model the system during the application of the pulse loads. The EMTP program was developed by Dr. Herman Dommel and Dr. Scott Meyer of the Bonneville Power Authority in Oregon. The

EMTP consists of simple electrical or power system components which can be connected together to model electrical systems over intervals of time.

After modeling the pulsed loads on the computer a consistent trend emerged. A power system voltage dip occurred during the peak of each pulsed load, proportional to the size of the load.

To eliminate this voltage dip from affecting the entire distribution system, a separate transmission line and transformer were added to the model to supply the pulsed load experiments. A capacitor bank was also added to the model to see if any reduction of the voltage dip occurred.

Conclusions from the computer modeling suggest that a separate transmission line and transformer would reduce the voltage drop due to the pulsed load experiments to less than 1 percent in the Y-12 distribution system. Little reduction in the voltage drop was seen when a capacitor bank was added to the model.

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CHAPTER I

INTRODUCTION

1.1 The Elmo Bumpy Torus-P Experiment

During 1978 an ad hoc committee was convened by the U.S. Department of Energy (DOE) to examine the fusion effort in the United States. One of their recommendations was to broaden the research effort to include alternatives to the leading concepts. Two of the leading concepts are tokamaks and mirror machines. The Oak Ridge National Laboratory's (ORNL's) ELMO Bumpy Torus (EBT) was selected by the committee as one of the alternative concepts to be pursued to proof-of-principle level [1].

The proof-of-principle device has been designated EBT-P. In contrast to a tokamak, which is pulsed, an EBT is a steady state device containing a series of torodial magnetic traps, each consisting of a set of linked magnetic mirrors. The EBT-P device will be constructed at Union Carbide Corporation Nuclear Division's (UCCND's) Y-12 Plant in building 9201-2. Building 9201-2 is operated by ORNL, which is also operated by UCCND.

1.2 Existing Research Experiments

There are also several other research experiments being carried on at UCCND's Y-12 plant by ORNL. These experiments consist mainly of pulsed loads.

1.2.1 Impurity Study Experiment-B

The Impurity Study Experiment-B (ISX-B) is a moderate size, shell-less tokamak with an iron core [2, pp. 34, 35]. The pulsed loads associated with the ISX-B experiment are the ISX-B shaping coil power supply, the ISX-B diverter coil power supply, the toroidal field power supply, vertical field power supply and the ISX-B neutral beam power supply. All of the power supplies are 12 phase rectifiers used to supply dc power to the ISX-B tokamak magnetic fields, with the exception of the ISX-B neutral beam power supply which supplies dc power for neutral particle beams used to heat the plasma inside the tokamak. The ISX-B is used to study the equilibrium and stability limits of various plasmas.

1.2.2 Medium Energy Test Facility

The Medium Energy Test Facility (METF) is used to test several medium energy neutral beam systems which are used to heat plasma in various fusion experiments [2, p. 138]. The pulsed load associated with the METF is the METF power supply which is a 12 phase rectifier used to supply dc power for testing of medium energy neutral beam systems.

1.2.3 High Energy Test Facility

The High Energy Test Facility (HETF) is used for two stage beam optics study, two stage beam steering and high energy neutral beam development [2, p. 138]. The pulsed load associated with the HETF is the HETF power supply which is a 12 phase rectifier supplying dc power for the high energy neutral beam systems being tested.

1.3 Method of Analysis

Due to the planned addition of the Elmo Bumpy Torus-P experiment, an investigation is needed to determine the effect that pulsed loads will have on the electrical distribution system and hence on EBT-P. No comprehensive study has been done to date that analyzes the effect of a pulsed load on the Y-12 electrical distribution system. The pulsed loads are the operation of dc power supplies in the previously mentioned experiments or facilities. The pulsed loads have a magnitude of several megawatts each and have a duration of approximately one second. The main problem posed by the pulsed loads will be their effect on the distribution system bus voltages and power factors, and how to predict the effect of future pulsed loads.

The method for analyzing this problem is to obtain an approximate computer modeling of conditions in the distribution system and make recommendations, based on the computer modeling, for network modifications to minimize or isolate the impact of these experiments on the EBT-P experiment and the Y-12 plant electrical distribution system.

A load flow program developed by The University of Tennessee, Knoxville, personnel under Union Carbide Corporation, Nuclear Division Subcontract No. 7259, was used to model the system during steady state conditions.

A computer program entitled "Electromagnetic Transients Program" or "EMTP" for short was used to model the system during the application of the pulsed load. The EMTP program was developed by Dr. Herman Dommel and Dr. Scott Meyer of the Bonneville Power Authority in Oregon. The

EMTP consists of simple electrical or power system components which can be connected together to model electrical systems over intervals of time.

This thesis will describe the analysis of the Y-12 electrical distribution system during steady state conditions by use of the static load flow equations and during the pulse loading of the system by use of the EMTP computer program.

Results of the study are presented along with graphs of the voltage and current waveforms of the power supply bus during the pulse loading of the power system.

CHAPTER II

Y-12 ELECTRICAL DISTRIBUTION SYSTEM MODEL

2.1 Impedance Diagram

The impedance diagram of the Y-12 electrical distribution system was obtained from the Y-12 Plant electrical engineering records. Only the 161 KV and 13.8 KV distribution levels were used. This was to greater simplify the model, since electrical power usage is only recorded on these voltage levels and the power supplies of interest are supplied by 13.8 KV distribution transformers. The Y-12 Plant electrical distribution system is a simple radial system consisting of two 161 KV lines which supply 161/13.8 KV building transformers. These lines originate from a bus which has several interconnections with TVA power generating stations. Since all the experiments occur on line No. 1, line No. 2 was shown as an equivalent load. The impedance diagram is shown in Figure 1.

2.2 Basic Load History

The monthly power usage reports for the past five years were researched to determine the average loads and peak demands of the system. From the monthly reports, August was discovered to be the month of greatest usage and highest demand. On the 161 KV system real and reactive power usage was recorded by the Elza Substation and Elza lines No. 1 and No. 2 along with the peak real power demand of the Y-12 substation for that month (see Figure 1). The total kilowatt-hours used

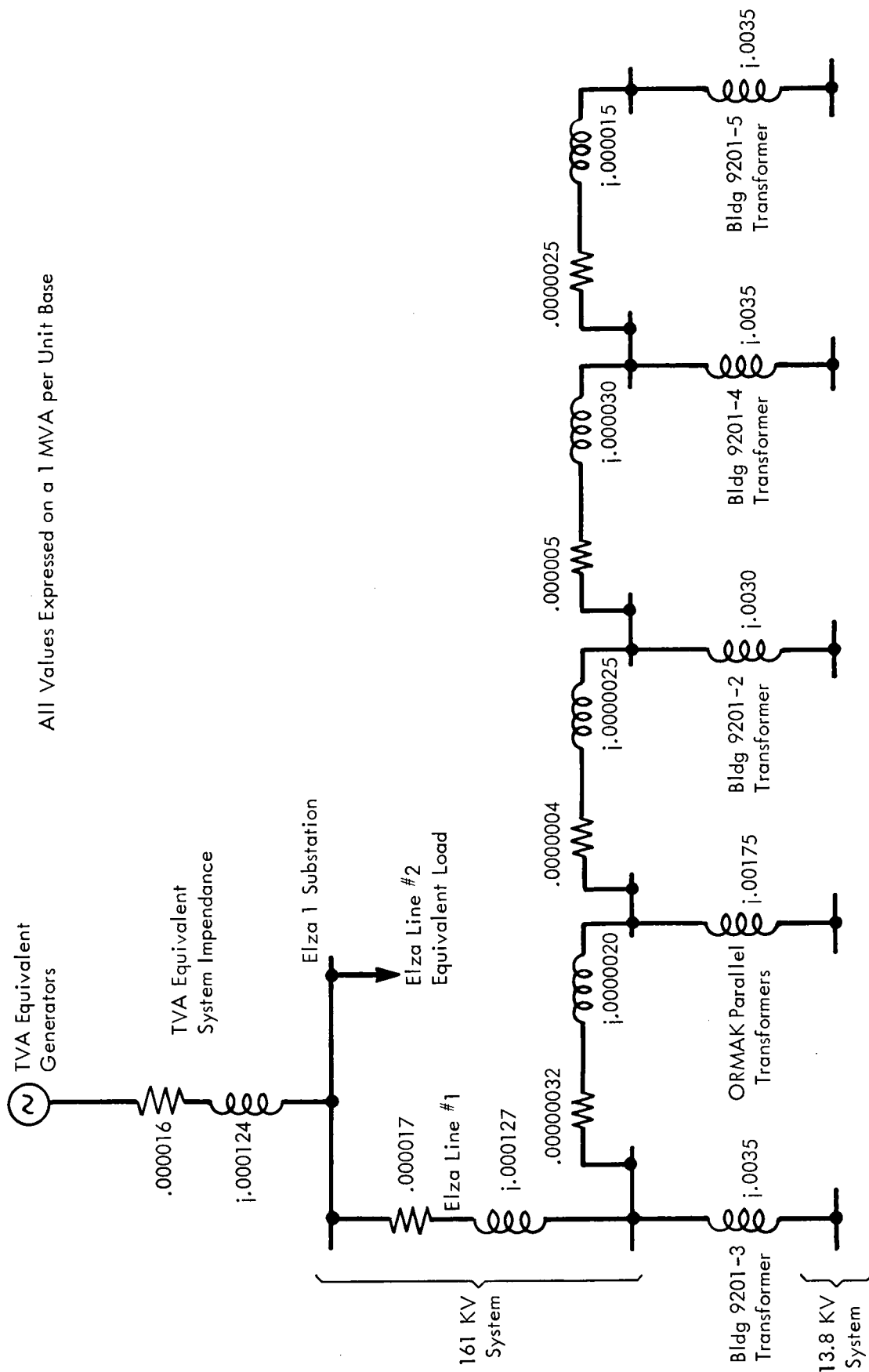


Figure 1. Y-12 electrical distribution system impedance diagram.

for the month were divided by the hours in the month to give an average load. Then all the real loads were multiplied by the ratio of the peak real power demand over the average real power demand to give the peak real power demand for the Elza substation and Elza lines 1 and 2. Knowing the peak real power demand (P), and assuming the power factor of the system remains constant (θ), the reactive power demand (Q) can be calculated using the following formulas [3, p. 32]:

$$\bar{S} = |S| \angle \theta = P + jQ \quad (1)$$

$$P = |S| \cos \theta \quad (2)$$

$$Q = |S| \sin \theta \quad (3)$$

Using equation 2 and knowing P and θ renders S which can be used in equation 3 to find Q.

On the 13.8 KV system kilowatt-hour usage was the only data recorded for each building transformer. Again the kilowatt-hours for the month were divided by the hours in the month to yield an average load. Then the average load was multiplied by the ratio of the peak real demand over the average real demand to yield the peak load for each building. Resistance in the system was ignored so that the sum of the building peak real power loads would equal the Elza substation peak real power load.

2.3 Load Flow Study

A load flow study is a computer solution of a particular power system's static load flow equations. Static load flow equations are

algebraic nonlinear equations relating a network's voltages and powers. All voltage and powers are expressed in per unit notation. In the computer, these equations are solved in vector form for the network in question. The complete solution of the static load flow equations gives the voltage profile, power generation and demand, and line power flows of the power system being analyzed.

The load flow program used in this study was developed by personnel of The University of Tennessee, Knoxville, under Union Carbide Corporation, Nuclear Division Subcontract No. 7259. This program utilizes the Gauss-Seidel method of numerical integration to solve the static load flow equations. The buses or nodes of the power system have six variables. These variables are real power demand (P_D), imaginary power demand (Q_D), real power generation (P_G), imaginary power generation (Q_G), bus voltage magnitude ($|V|$) and bus voltage phase angle (δ). Of these six variables, four must be either known or specified for solution of the static load flow equations. Depending on the variables known at each bus or node of a power system, buses can be classified into three categories for this program; type 1, type 2 and type 3. For type 1 buses both the real and imaginary power demand is known. The real and imaginary power generation is specified. The solution of the static load flow equations will render the voltage magnitude and phase angle. Type 1 buses are referred to as load buses. For type 2 buses again both the real and imaginary power demand is known. The bus voltage magnitude and real power generation are specified. The solution will render the imaginary or reactive power and the voltage phase angle. A type 2 bus is

referred to as a voltage control bus. For type 3 buses the real and imaginary power demand is known. The voltage magnitude and phase angle are specified. The solution of the equations will render the real and imaginary power generated. A type 3 bus is referred to as a reference bus or slack bus. There can be only one reference bus in a network load flow study.

With the basic load history, a load flow study was performed to determine the steady state parameters of the Y-12 distribution system. The Tennessee Valley Authority's (TVA's) electrical system was used as the reference bus. The TVA system impedance was used to connect the reference bus to the Elza bus, because of its ties to several TVA power generating plants.

The generator per unit voltage for the reference bus was assumed to be 1.05 per unit. This is the normal value used in load flow studies. All system resistances were neglected. All building transformer voltages on the 13.8 KV system were assumed to be 1.0 p.u. Each 13.8 KV building bus was specified a voltage control bus with the real load specified. Then the load flow program calculated the generated reactive power at that bus. A negative reactive power would indicate a reactive load. The results of the study are shown in Figure 2.

2.4 Calculation of the D.C. Power Supply Pulsed Loads

For this study there were seven major power supplies to model. These power supplies are the five power supplies associated with the ISX-B experiment, the Medium Energy Test Facility and the High Energy

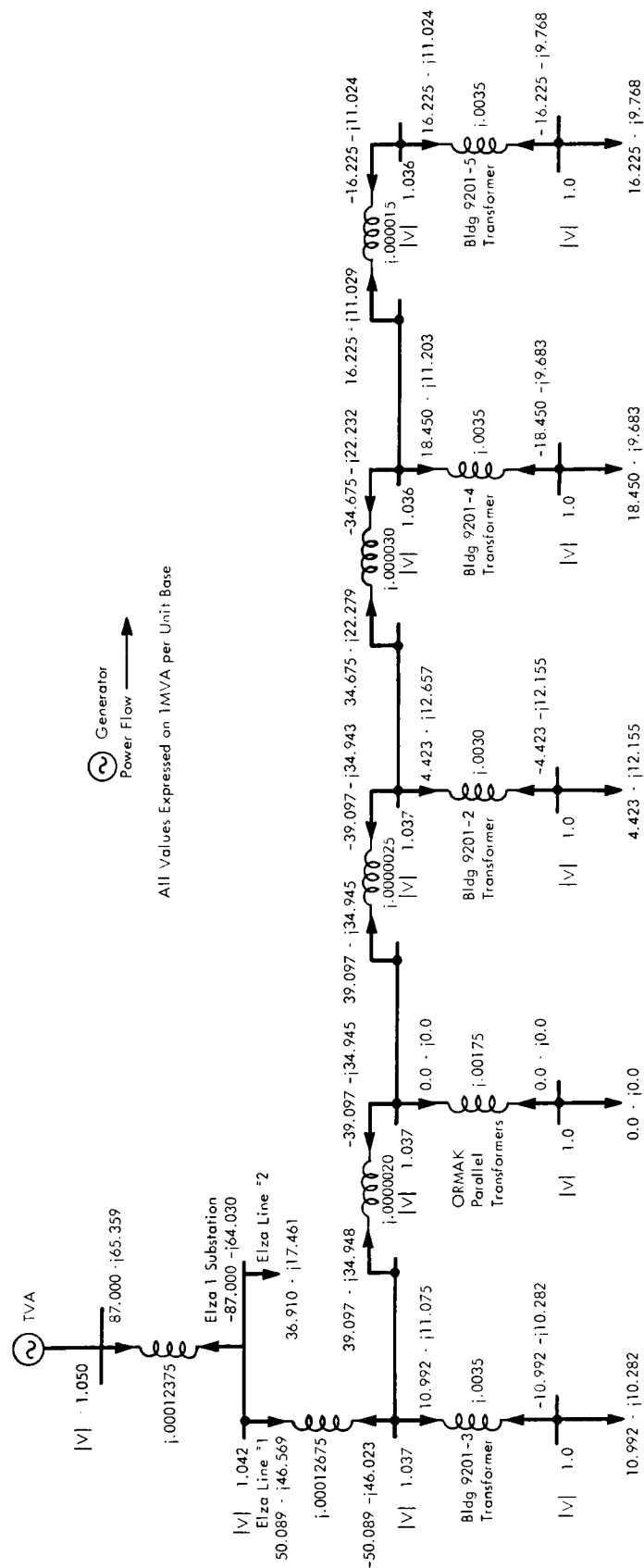


Figure 2. Report of load flow calculations.

Test Facility — which are discussed in Chapter I. To determine the effect of these dc power supplies on the ac system their equivalent ac loads needed to be calculated from their dc ratings. All dc power supplies are 12 phase ac rectification.

Let:

- E_{ϕ} = ac line to neutral voltage
- E_{1-1} = ac line to line voltage
- I_d = dc average line current
- I_1 = ac line current
- E_d = dc average voltage
- γ = phase shift angle for transformer and diode connection ($\gamma = 15^\circ$ for 12 phase rectifier)

The ac and dc power ratings are calculated as follows [4]:

$$I_1 = \frac{\sqrt{2} E_d}{3 E_{\phi}} I_d \cos(\gamma)$$

$$I_1 = \frac{\sqrt{2} E_d I_d}{\sqrt{3} E_{1-1}} \cos(\gamma)$$

Assume: $E_d \approx E_{1-1}$; $\cos(\gamma) = \cos(15^\circ) \approx 1$

$$I_1 = \sqrt{2/3} I_d$$

$$VA_{ac} = \sqrt{3} I_1 E_{1-1}$$

$$VA_{dc} = I_d E_d$$

$$S_{ac} = VA_{ac} \angle \theta^\circ$$

$$\theta^\circ = \cos^{-1} \frac{VA_{dc}}{VA_{ac}}$$

Table 1 shows the results of these calculations for each power supply.

Table 1
Power Supply Calculations

Power Supply	E _D	I _D	E _{L-L}	I _L	V _{AC}	V _{DC}	S _{AC}	θ
ISX-B Shaping Coil	400 V	7,500 A	480 V	6,130 A	10.2 MVA	3.0 MVA	10.2 MVA	73°
ISX-B Diverter Coil	746 V	25,000 A	480 V	20,430 A	34.0 MVA	18.7 MVA	34.0 MVA	57°
Toroidal Field	480 V	60,000 A	374 V	49,000 A	63.5 MVA	29.0 MVA	63.5 MVA	63°
Vertical Field	2,000 V	2,500 A	1,700 V	2,040 A	12.0 MVA	5.0 MVA	12.0 MVA	65°
Medium Energy Test Stand	60,000 V	60 A	2,450 V	49 A	4.1 MVA	3.6 MVA	4.1 MVA	60°
High Energy Test Stand	56,000 V	50 A	22,200 V	41 A	4.7 MVA	2.8 MVA	4.7 MVA	53°
ISX-B Neutral Beam	60,000 V	60 A	24,150 V	49 A	4.1 MVA	3.6 MVA	4.1 MVA	29°

CHAPTER III

COMPUTER MODELING USING THE ELECTROMAGNETIC TRANSIENTS PROGRAM (EMTP)

3.1 The EMTP Code

The EMTP program is used to solve ordinary differential and algebraic equations associated with an arbitrary interconnection of the following elements [5, pp. vi-a-vi-b]:

- a. Lumped resistance:  $v = Ri$
- b. Lumped inductance:  $v = L di/dt$
- c. Lumped capacitance:  $i = C dv/dt$
- d. Multiphase Pi-equivalents where the preceding scalars R , L , C , become symmetrical matrices $[R]$, $[L]$, and $[C]$.
- e. Multiphase distributed-parameter transmission lines.
- f. Nonlinear inductors.
- g. Time varying resistance.
- h. Switches, used to simulate circuit breakers, lightning arrestors, diodes or any other network connection change.
- i. Voltage or current sources.
- j. Transformers.
- k. Dynamic three phase synchronous machines.
- l. Control system dynamics, as normally represented on analog computers.

The EMTP program uses the trapezoidal rule of integration to solve the network equations.

The program user assembles a data card deck containing the network elements, problem constraints and desired information output. Each data deck is composed of the following parts, in the order listed [5, p. 1]:

- a. Cards to begin a data case, containing special requests and miscellaneous data cards.
- b. Extensions to the miscellaneous data cards (optional).
- c. Cards which define any control system representation (optional).
- d. Cards for linear and nonlinear branches, transformers and transmission lines.
- e. Cards for switches.
- f. Cards for voltage or current sources.
- g. Cards for overriding initial conditions (optional).
- h. Cards for node voltage output.
- i. Cards for user defined source functions (optional).
- j. Cards for computer plotting.

Each nonground node is given a 6-character alphanumeric name. All elements are identified by their node name and their data. All network parameters are specified in real units as opposed to per unit values used in the load flow program. The voltage values used are peak-to-peak values to allow time solution of the network equations. The EMTP program can also solve the network equations to render the network steady state solution in rms values.

3.2 Basic Components of the Model

Each portion of the EMTP computer model of the Y-12 electrical distribution system and power supply models will be explained along with reasons given why these methods were chosen.

3.2.1 Y-12 Electrical Distribution System

The basic information used in the load flow study was converted to the EMTP model. This model is shown in Figure 3. The TVA reference bus was replaced by an ideal voltage source in series with an R-L branch representing the TVA system impedance (see Figure 3). In the EMTP single phase model real peak values were used instead of per unit values. All voltages used were the line-to-line values so that powers would be calculated in three phase quantities. A single phase model was used which assumes symmetry in the three phase system. All transmission lines were assumed short enough to neglect shunt capacitance and were represented by R-L branches. All steady state loads were represented as R-L branches to ground. All transformers were modeled using the EMTP single phase transformer model (see Figure 4). The EMTP transformer model consisted of an ideal transformer with the transformer high and load side short circuit impedance in series with the transformer coils. Core losses are represented by a resistance branch in parallel with the high side coil. Magnetizing inductance can be represented by a nonlinear inductance branch in parallel with the high side coil. However, for this study magnetizing inductance was neglected.

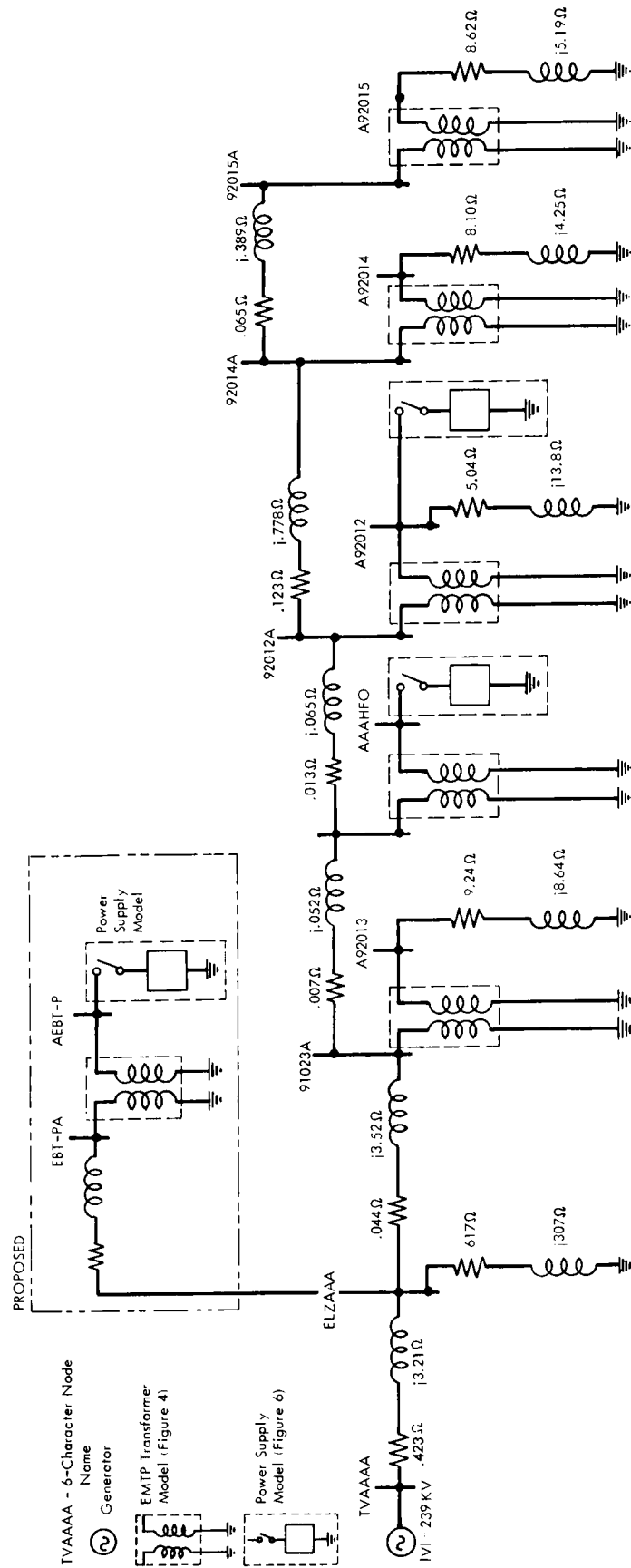
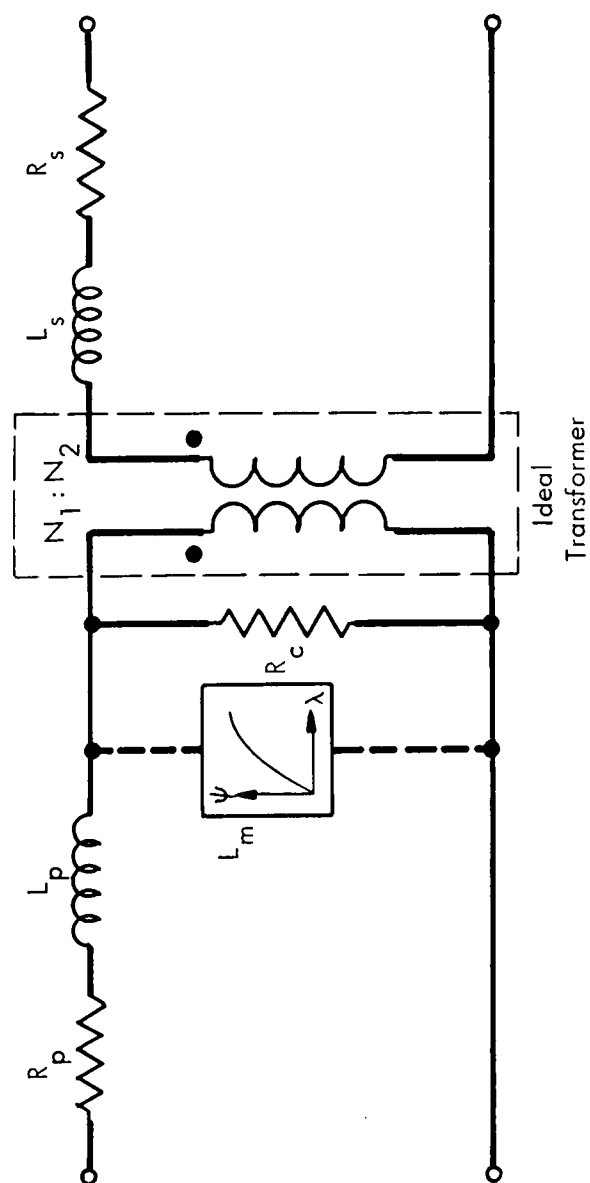


Figure 3. EMTP model of the Y-12 electrical distribution system.



- R_c - Core Resistance
- R_p - Primary Short Circuit Resistance
- R_s - Secondary Short Circuit Resistance
- L_m - Magnetizing Inductance (neglected)
- L_p - Primary Short Circuit Inductance
- L_s - Secondary Short Circuit Inductance
- N_1 - Primary Turns
- N_2 - Secondary Turns

Figure 4. EMTP transformer model.

This model gave the same steady-state results as the load flow study.

3.2.2 Power Supply Model

During a pulsed load, the dc current characteristic of the power supply is shown in Figure 5. Noting the direct relationship between ac and rectified dc current for 12 phase rectification [4],

$$I_1 = \sqrt{2/3} I_d$$

a model was needed to duplicate a ramping ac current whose magnitude resembled that in Figure 5. Using switches and R-L branches available in the EMTP program, a series of 10 parallel R-L branches were used to digitally represent the analog signal of Figure 5. The switches were used to switch in and out lower impedance branches to raise and lower the equivalent load which represents the operation of the dc power supply. This model is shown in Figure 6. The equivalent no load impedance used was 200 ohms. Using switches this impedance is lowered in steps by paralleling the high impedance branches with low impedance branches. The low impedance branches were calculated so that the full load ac current of the power supply would flow at rated voltage. Figure 7 shows the ac current waveshape of the power supply model.

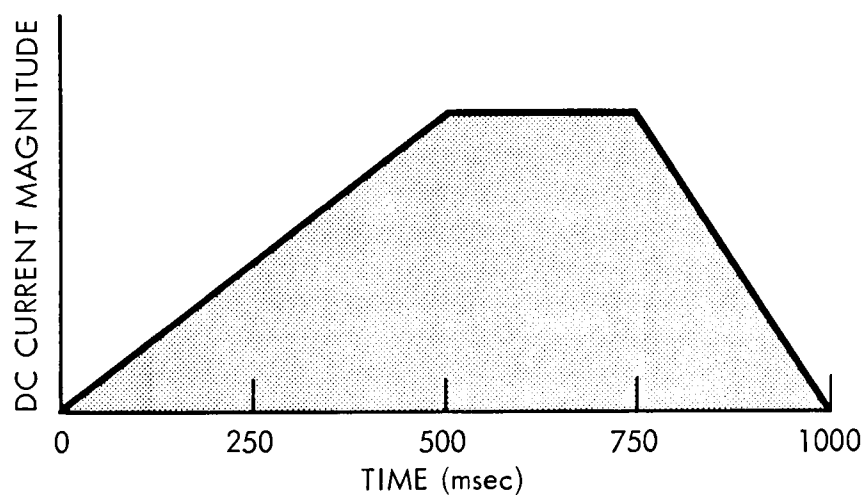


Figure 5. DC current characteristic.

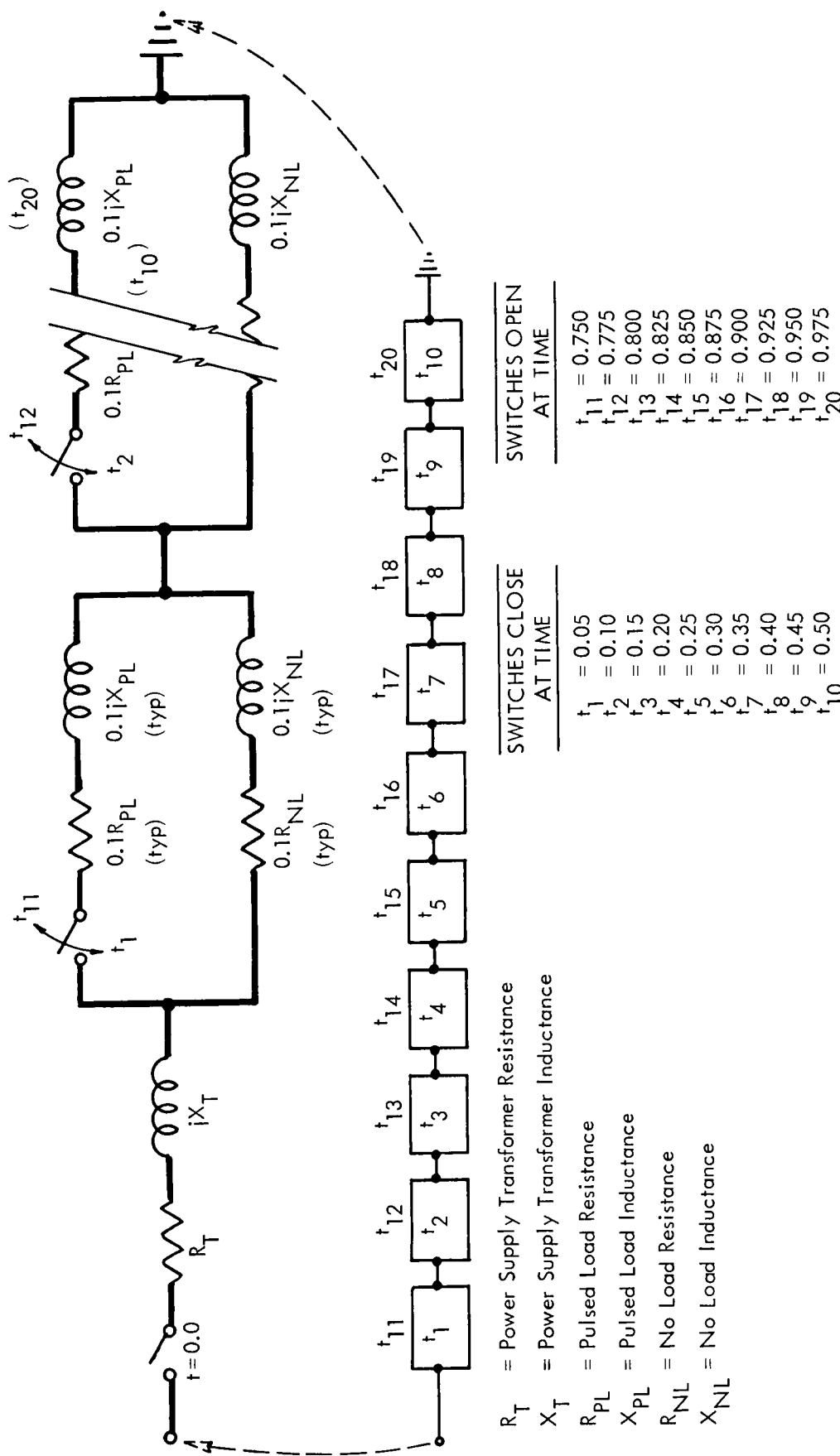


Figure 6. Power supply model.

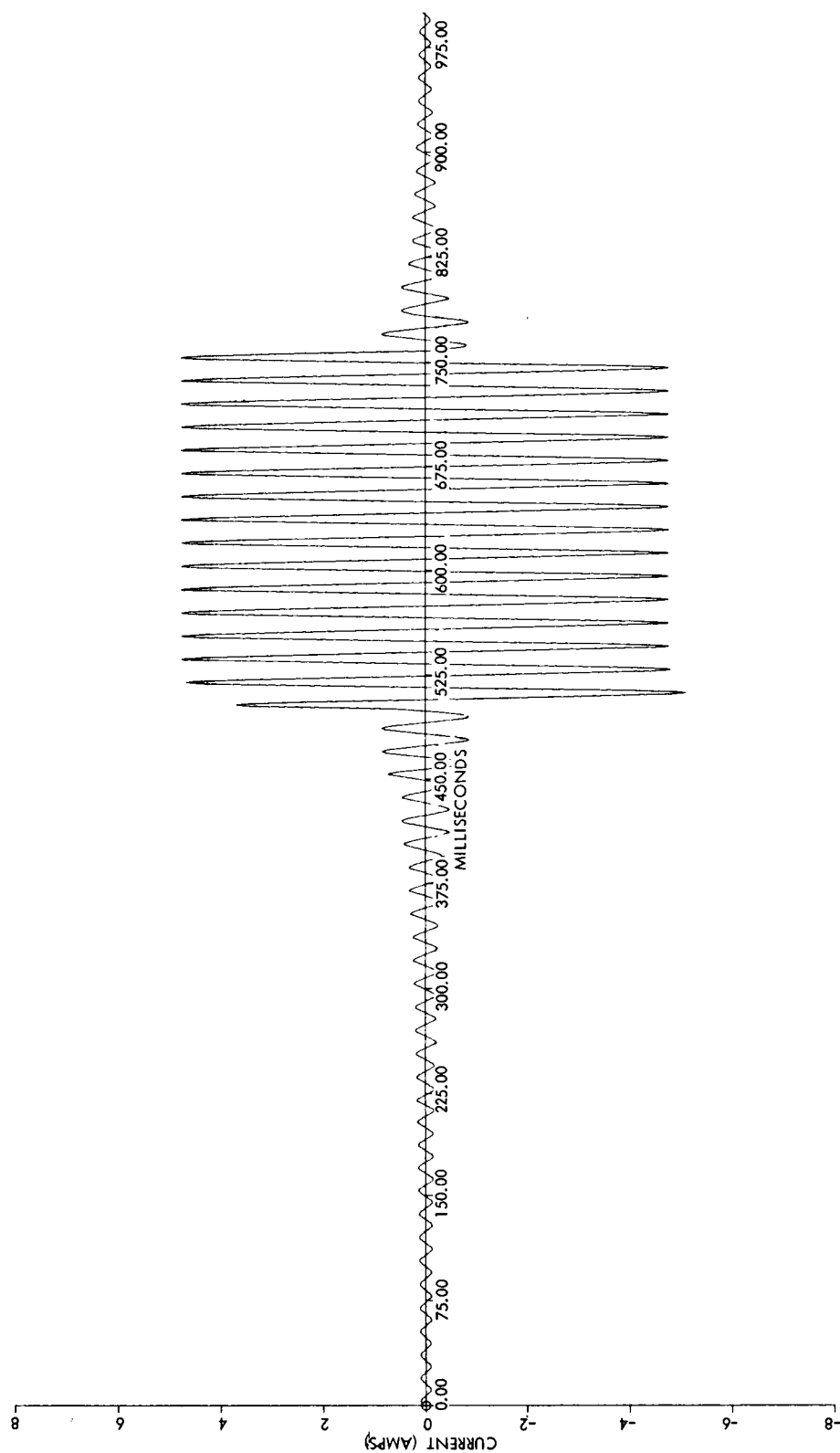


Figure 7. DC power supply AC current characteristic.

CHAPTER IV

RESULTS OF EMTP COMPUTER MODELING

4.1 Existing Power Supplies

After modeling each of the power supplies on the computer, a consistent trend emerged. A power system voltage dip occurred during the peak of each pulsed load. The voltage dip varied in magnitude according to the magnitude of the pulsed load, the larger the pulsed load the larger the voltage dip. The power system voltage returned to normal after the end of each pulsed load. Figures 8 and 9 show the voltage waveforms of the 13.8 KV and 161 KV systems as calculated by the computer. Table 2 shows the voltage dip and power supply load for each power supply modeled.

Modeling the system again with a 20 MVA capacitor bank on the 13.8 KV bus, voltage drop was decreased by about 1 percent from results obtained without the capacitor bank. A 20 MVA capacitor bank is the largest bank which can be switched by a 13.8 KV circuit breaker without experiencing capacitor restrike phenomenon. The addition of the capacitor bank would reduce the harmonic currents generated by the dc rectifiers, however, it would not reduce the voltage drop enough to justify its installation.

4.2 EBT-P Experiment

A voltage dip of up to 20 percent will occur during the operation of a dc power supply which produces a pulsed load. This great a

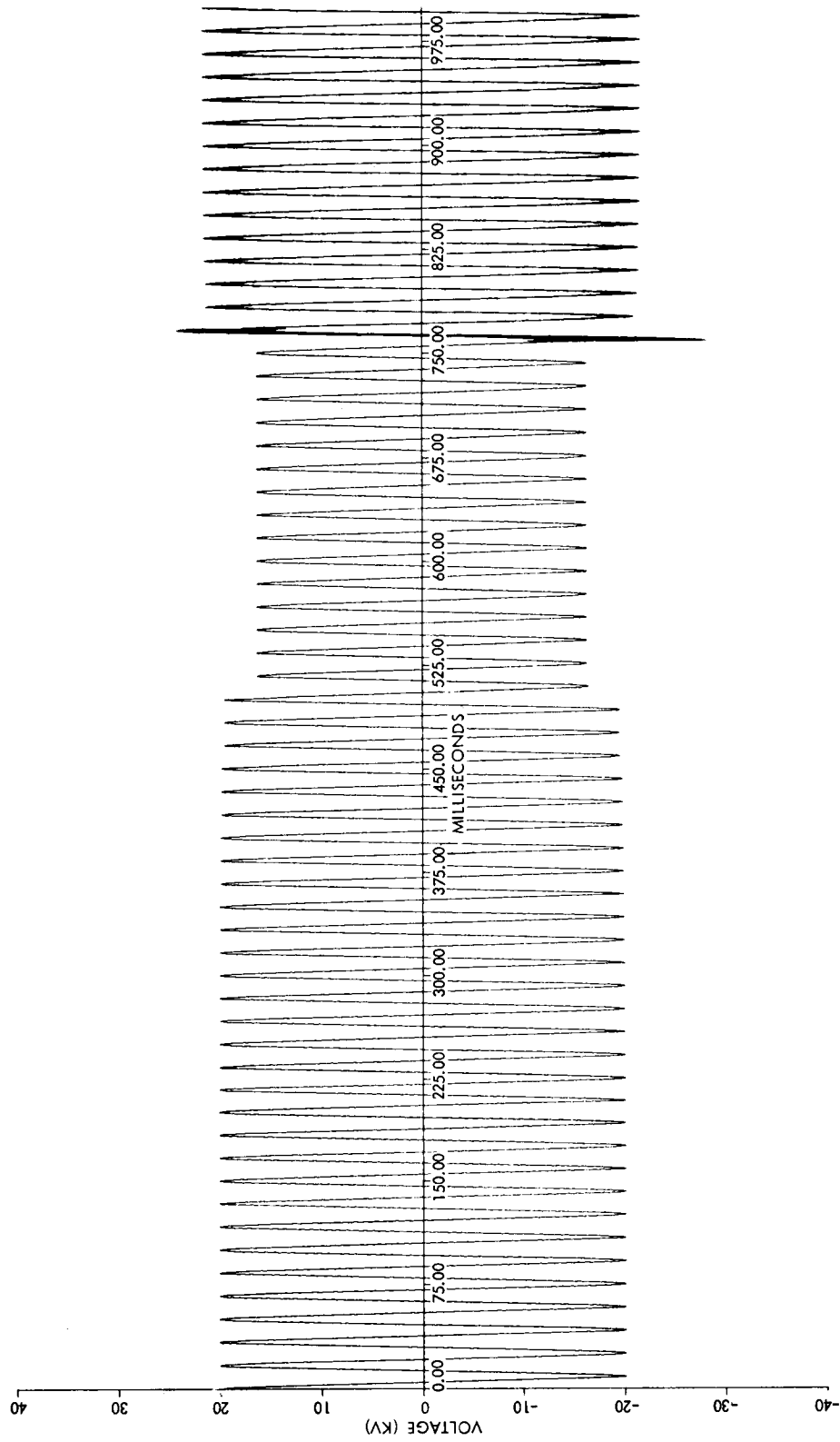


Figure 8. 13.8 KV voltage waveform.

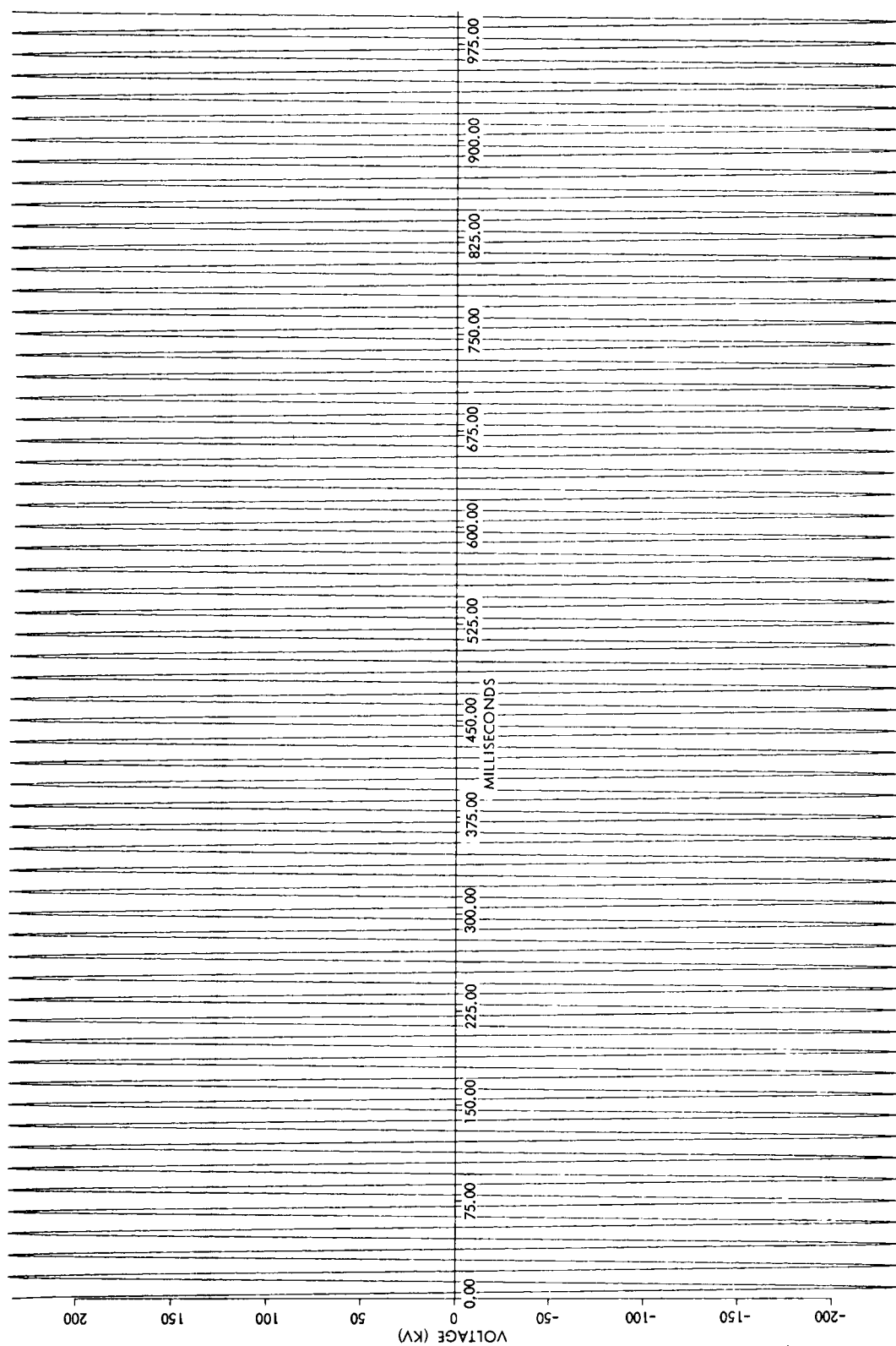


Figure 9. 161 KV voltage waveform.

Table 2
Power Supply Voltage Dip and Load

DC Power Supply	Change in 13.8 KV System Voltage (%)	MVA Load
ISX-B Shaping Coil	3.0	10.2
ISX-B Diverter Coil	9.2	28.4
Toroidal Field	19.4	63.5
Vertical Field	4.0	10.9
Medium Energy Test Stand	1.6	8.2
High Energy Test Stand	1.1	3.8
ISX-B Neutral Beam	1.0	3.7

voltage dip could adversely affect the EBT-P experiment. Design plans call for a 161 KV transmission line and power transformer to serve solely as the power supply for pulsed load experiments (see Figure 3, page 16). Modeling this arrangement with the 161 KV transmission line originating on the Elza substation bus ahead of the regulating transformers showed a voltage dip of 9.6 percent during a 30 MVA pulsed load at the power supply 13.8 KV bus. However, the voltage drop on the building transformers in the plant was approximately 0.2-0.4 percent. This arrangement clearly has significantly reduced the effect of the pulsed load on the EBT-P experiment and the rest of the Y-12 Plant distribution system. The addition of a 20 MVA capacitor bank at the 13.8 KV power supply bus showed little reduction in the voltage drop. An additional model of the experiment was done with the 161 KV transmission line originating on the load side of the regulating transformer. This model showed a voltage drop of 9.8 percent on the 13.8 KV power supply bus and 0.3-0.6 percent on the 13.8 KV building transformer buses.

CHAPTER V

CONCLUSIONS

5.1 Power System Recommendations

It is evident that operation of a dc power supply which produces a pulsed load results in a voltage drop in the electrical distribution system. The severity of the drop depends on the size of the pulsed load. Therefore, it is recommended that only one power supply be operated at a time to avoid compounding the effects of the pulsed loads. The addition of static capacitor banks could benefit the electrical distribution system in three ways: (1) improve the plant power factor, (2) reduce the voltage drop associated with the pulse loading of the dc power supplies, and (3) filter the ac harmonic currents generated by the dc power supplies. However, the reduction of the voltage drop by the addition of the static capacitors is too slight when compared to the size and cost of the capacitors to warrant their installation. The other factors are not a consideration at hand.

5.2 EBT-P Recommendations

For the EBT-P experiment in particular, it is recommended that a 161 KV transmission line and distribution transformer should be installed to effectively isolate the voltage drop during the operation of a dc power supply from the rest of the Y-12 Plant distribution system. The 161 KV transmission line should originate on the line side of the 161 KV regulating transformers. This would simplify protective relaying schemes and would not subject the line regulating transformers to the pulsed loads.

LIST OF REFERENCES

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1. "EBT-P Proposed Reference Design Report," ORNL/TM-7191, Fusion Energy Division, Oak Ridge National Laboratory, p. 5, Oak Ridge, Tenn., January 1980.
2. "Fusion Energy Division Annual Progress Report, Period Ending December 31, 1977," ORNL-5405, Fusion Energy Division, Oak Ridge National Laboratory, pp. 34, 35, 138, Oak Ridge, Tenn., August 1978.
3. O. I. Elgerd, "Electric Energy Systems Theory: An Introduction," pp. 32, McGraw-Hill, New York, 1971.
4. J. M. Schaefer, "Rectifier Circuits: Theory and Design," p. 274, Wiley, New York, 1965.
5. Electromagnetic Transients Program, Methods Analysis Unit, pp. vi-a through vi-b, 1-2, Route EOGA, Branch of System Engineering, Bonneville Power Administration, P. O. Box 3621, Portland, Oregon, November 1977.

VITA

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