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OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Athens Automation and Control Experiment

Project Review Meeting

Dallas, Texas
December 5–6, 1984

J. S. Detwiler
P. S. Hu
J. S. Lawler
L. C. Markel
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POWER SYSTEMS TECHNOLOGY PROGRAM

OPERATED BY
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R. L. Sullivan§§
G. R. Wetherington†

*BBC Brown Boveri, Inc.
†Oak Ridge National Laboratory.
‡The University of Tennessee.
§Consultant to the Office of Energy Storage and Distribution, Electric Energy Systems Program, U.S. Department of Energy.
¶Consultant to Oak Ridge National Laboratory.
**Baltimore Gas & Electric Company.
††Athens Utilities Board.
‡‡Minimax.
§§The University of Florida.

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
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FOREWORD

A review meeting of the Athens Automation and Control Experiment (AACE) was held at the Registry Hotel in Dallas, Texas, on December 5–6, 1984. Invitations to attend were extended to numerous people associated with the electric utility industry. Representatives from various electric utilities attended the Dallas meeting. Also in attendance were individuals from manufacturing companies, universities, consultants in the electric utility industry, and several support personnel from Oak Ridge National Laboratory (ORNL) who are involved with the AACE. One of the principal objectives of the AACE is to transfer the results of the project to the electric utility industry. The review meeting was held to facilitate such a transfer in a timely fashion. Because the major portions of the project are not expected to be completed until 1987, it was felt that waiting until the conclusion of the project to disseminate information would result in less timely communication of information. The meeting reviewed the progress of the AACE and communicated the objectives and experimental plans to those in attendance.

The AACE is a distribution automation project involving research and development of both hardware and software. Equipment for the project is being installed in the electric distribution system of the Athens Utilities Board (AUB), located in Athens, Tennessee. AUB is one of 160 distributors in the Tennessee Valley Authority (TVA) bulk power system. As the host utility, AUB is responsible for the installation and operation of the equipment. The U.S. Department of Energy (DOE), Office of Energy Storage and Distribution, Electric Energy Systems Program, is the sponsoring agency for the AACE; ORNL is providing project management and technical leadership.

A number of organizations are supporting DOE and ORNL in this project. The Electric Power Research Institute (EPRI) is sponsoring certain load control experiments and is providing load control expertise, experimental designs, and individual appliance instrumentation. TVA is providing bulk power coordination and technical support. Baltimore Gas & Electric Company has loaned an electric distribution engineer to ORNL to work on the AACE in Oak Ridge. A Utility Advisory Group, comprised of experienced electric distribution engineers from various utilities, is providing expertise and perspective. Thus the AACE has broad-based utility industry support.

AUB is located in McMinn County, Tennessee. Its 100-mile^2 service territory includes the city of Athens and the communities of Englewood and Niota. AUB is a nongenerating utility with TVA as its source of electric power. AUB distributes electric power to more than 9000 customers, of which 7890 are residential and 1235 are commercial. Energy sales by AUB exceed 300,000,000 kWh annually. The system peak of >77 MW occurred in 1981.

The purposes of the AACE are to develop and test load control, volt/var control, and system reconfiguration capabilities on an electric distribution system and to transfer what is learned from this project to the electric utility industry. The project has been designed to test various control techniques, quantify the associated benefits, identify the type and amount of hardware required to accomplish these benefits, and transfer the findings to the electric utility industry so that a utility can use the data to conduct its own internal studies. The thrust of the project is to provide actual installation and operating experience so that utilities considering distribution control systems can implement a system that will satisfy their needs. It is anticipated that the knowledge and experience gained during the AACE will permit the implementation of similar systems in a shorter time period and with an improved cost/benefit ratio.

The AACE will involve the implementation of a hardware system referred to as the Integrated Distribution Control System (IDCS) on the three substations—North Athens, Englewood, and South Athens—and on the 12 distribution feeders of the AUB system. The North Athens substation supplies power to six feeders at 13 kV and, via a 69-kV line, supplies power to the Englewood and South Athens substations. The Englewood and South Athens substations each supply 3 feeders at 13 kV.

IDCS is a system of hardware and software capable of detailed monitoring of the distribution system, switching various distribution devices, turning customer loads on and off, controlling real and reactive power during normal and emergency conditions, and coordinating the control of the distribution system with the operation of the bulk power system.

Three experimental areas are being designed to take place on the AUB system. These are (1) load control, (2) volt/var control, and (3) system reconfiguration. After the IDCS is installed, the experiments will take place individually during the first year and then simultaneously during the second year to determine the interaction of the three experimental areas. Evaluation and data analysis will be performed after each experiment is completed.

The Dallas review meeting was divided into five main sections: background, hardware, and the three experimental areas (load control, volt/var control, and system reconfiguration). This document follows the same format. A short summary will be found at the beginning of each set of viewgraphs. A list of attendees of the meeting is also provided.

This publication was compiled primarily for the attendees of the Dallas project review meeting. There were numerous requests for copies of the viewgraphs; hence, it was announced at the meeting that copies would be supplied to the attendees. This document serves that purpose. Of course, the viewgraphs will be more meaningful to those who attended the Dallas meeting and heard the corresponding explanations.

Anyone who would like further information concerning the AACE is directed to contact

Mr. S. L. Purucker
Oak Ridge National Laboratory
Building 5500, MS A218
Oak Ridge, TN 37831
(615) 576-5233

CONTENTS

ABSTRACT

The U.S. Department of Energy, Office of Energy Storage and Distribution, Electric Energy Systems Program, is the sponsoring agency for the Athens Automation and Control Experiment (AACE). Oak Ridge National Laboratory (ORNL) is providing project management and technical leadership. Others involved in the AACE include the Electric Power Research Institute (EPRI), Tennessee Valley Authority (TVA), Baltimore Gas & Electric (BG&E), and an advisory group comprised of experienced electric utility distribution engineers.

The AACE is an electric power distribution automation project involving research and development of both hardware and software. Equipment for the project is being installed on the electric distribution system of the Athens Utilities Board (AUB), located in Athens, Tennessee.

The purposes of the AACE are to develop and test load control, volt/var control, and system reconfiguration capabilities on an electric distribution system and to transfer what is learned to the electric utility industry. Expected benefits include deferral of costly power generation plants and increased electric service reliability.

A project review meeting was held in Dallas, Texas, on December 5–6, 1984, to review the progress of the AACE and to communicate the objectives and experimental plans to the electric utility industry, represented by those in attendance.

At the time of the meeting, the experimental test plans were being written; much of the AACE field equipment had been received by AUB, and installation had begun. A computer system, the AACE Test System (AACETS), was already operational at ORNL. AACETS will be used to develop and test applications software and experimental control strategies prior to their implementation on the AUB system. The AACE experiments are scheduled to begin in October 1985 and to continue through October 1987.

PROGRAM AGENDA

POWER SYSTEMS TECHNOLOGY PROGRAM

OAK RIDGE NATIONAL LABORATORY

Sponsored by the
Electric Energy Systems Division
U.S. Department of Energy

PROJECT REVIEW MEETING
ATHENS AUTOMATION AND CONTROL EXPERIMENT
REGISTRY HOTEL
DALLAS, TEXAS
December 5-7, 1984

PROGRAM AGENDA

December 5, 1984

BACKGROUND

8:00	Registration	
8:30	Welcome Address PSTP Overview Athens Utility Perspective EPRI Perspective	D.J. Roesler, DOE/EES P.A. Gnadt, ORNL G. Usry, AUB J.H. Chamberlin, EPRI
10:00	Break	
10:30	AACE Project Overview	S.L. Purucker, ORNL

HARDWARE

11:00	Communication & Control System AACETS/Modscan Installation Status	J.S. Detwiler, BBC G.R. Wetherington, ORNL L.D. Monteen, AUB
12:00	Luncheon (Registry Hotel)	

LOAD CONTROL EXPERIMENT

1:00	Overview Load Control Experiment Customer Selection and Recruitment Load Control Coding Scheme Customer Load Data Substation Load Model	S.L. Purucker, ORNL J.H. Reed, ORNL J.H. Reed, ORNL P.S. Hu, ORNL J.H. Reed, ORNL
2:30	Break	
3:00	Characterization Test Plans Learning Year Test Plans	B.A. Smith, Minimax J.M. McIntyre, Consultant

Program Agenda

December 5, 1984 (continued)

4:00	Question and Answer Session	
5:00	Adjournment	
6:00	Social Hour (with cash bar)	

December 6, 1984

VOLTAGE AND CAPACITOR CONTROL EXPERIMENT

8:30	Overview-Voltage and Capacitor Control Experiment	S.L. Purucker, ORNL
	Studies and Modeling	R.L. Sullivan, Consultant
	Computer Assisted Capacitor Control	R.L. Sullivan, Consultant
	Computer Assisted Voltage Control	R.L. Sullivan, Consultant
10:00	Break	
10:30	Voltage and Capacitor Control Example	R.L. Sullivan, Consultant
11:30	Distribution Automation Designs	L.D. Monteen, AUB
12:00	Luncheon (Registry Hotel)	

SYSTEM RECONFIGURATION EXPERIMENT

1:00	Overview - System Reconfiguration Experiment	S.L. Purucker, ORNL
	Fault Detection, Location Isolation, and Service Restoration	J.S. Lawler, Consultant
	Capacity Utilization	J.B. Patton, Consultant
3:30	TVA Perspective	D.W. Hilson, TVA
4:00	Question and Answer Session	

December 7, 1984

ADVISORY GROUP MEETING

8:00	Advisory Group Meeting - Closed Session	
9:30	Advisory Group Feedback to Project Team	
12:00	Adjournment	

BACKGROUND

STATUS OF DISTRIBUTION AUTOMATION

This presentation was designed to give an overview of eight distribution automation and control (DAC) projects. The eight projects are as follows:

1. Commonwealth Edison, PROBE Project.
2. Texas Electric Service Co., IDCPS.
3. American Electric Power, ALADDIN.
4. Carolina Power and Light (CPL).
5. Florida Power and Light (FPL).
6. Ontario Hydro.
7. Niagara Mohawk Power Corp. (NMPC).
8. Philadelphia Electric (PE).

To facilitate comparison with the Athens Utilities Board's Athens Automated and Control Experiment (AACE) project, a description of AACE has been added.

The presentation consists of nine major slides:

1. Project List.
2. Objectives.*
3. Monitored and Controlled Points.*
4. Communications Systems.
5. Status.
6. Functions Included.*
7. Hardware Development.
8. Applications Software for DAC Dispatch and Analysis.*
9. Summary/Issues.

The slides marked with an asterisk (*) are followed by backup information that gives more detail about each project.

The eight DAC projects indicate a high level of activity by the utility industry in the distribution monitoring and control area. The emphasis is currently on developing and testing hardware and communications systems. The utilities share a common desire to gain experience in operating DAC systems to determine what the real benefits are and to develop procedures that will make it easier for the operation and planning departments to obtain these benefits. Questions about distribution data—What data should be collected? How should the data be organized and analyzed?—are very important at this point. Applications software is being developed, but applications programs are not yet fully integrated with automated distribution systems. Indeed, the integration of distribution automation with the other functions of the utility—planning, cost/benefit assessment, and operations—is still under way. Facilitating the integration process is one of the primary objectives of the AACE project.

ATHENS AUTOMATION AND CONTROL EXPERIMENT

Project Review Meeting

Dallas, Texas
December 5-6, 1984

OVERVIEW OF SOME MAJOR UTILITY DISTRIBUTION AUTOMATION AND LOAD CONTROL PROJECTS

presented by

Lawrence C. Markel

ELECTROTEK Concepts, Inc.

2570 El Camino West, Suite 404
Mountain View, CA 94040
(415)-941-2986

SLIDE 1

MAJOR DISTRIBUTION AUTOMATION AND LOAD CONTROL PROJECTS

PROBE	Commonwealth Edison	GE	DAC
IDCPS	Texas Electric Service Co.	GE	DAC
ALADDIN	American Electric Power	GE	AMR,DAC
CPL	Carolina Power & Light	Westinghouse	DAC,AMR,LC
FPL	Florida Power & Light	CLMS	LC,AMR
OH	Ontario Hydro	Motorola Dacscan	LC,AMR,DAC
NMPC	Niagara Mohawk Power Corp.	GE	DAC,AMR
PE	Philadelphia Electric	Altran	Communications
		Robinton	AMR
		Westinghouse	AMR
AACE	Athens Utility Board	BBCSI	DAC,LC,AMR

SLIDE 2

OBJECTIVES

PROBE
Develop and test an integrated digital systems approach for substation and distribution feeder automation.

IDCPS
Field-test prototype hardware performing 18 integrated distribution monitoring and control functions.

ALADDIN
Verify the technical and economic feasibility of distribution automation (load survey, automatic meter reading, feeder control) on the AEP system.

CPL
Prepare for the system-wide implementation of distribution automation.

FPL
Implement a residential time-of-use rate and associated meter reading and load control functions.

ONTARIO HYDRO
Determine the extent to which a distribution automation and load management system can be made to work effectively.

NMPC
Demonstrate the usefulness of distribution automation and provide data to evaluate its cost-effectiveness on the NMPC system.

PE
Test a communications channel for distribution automation. Provide remote access to selected customer meters.

AACE
Provide data, control strategies, and operating experience on an integrated distribution automation and load control system.

SLIDE 3

MONITORED AND CONTROLLED POINTS

	CE	TESCO	AEP	CPL	FPL	OH	NMPC	PE	AUB
Number of Substations	1	1	4	8	-	1	2	-	3
Number of Feeders	1	2	5	3	-	2	2	-	12
Substation Breaker	C	C	C	C			C		C*
Substation Transformer	M	M	M			M	M		M*
Load Tap Changer	C								C*
Tie Switch	C	C	C	C*		C	C		C*
Sectionalizing Switch	C	C	C	C*		C	C		C*
Capacitor Bank	C	C	C	C	C*	C	C		C*
Voltage Regulator							C		C*
Fault Detector	C	M	M	M*		M	M		C*
Meter			M	M	C*	M	M	M	M*
Customer Load				C	C*	C			C*

KEY

M monitored
C controlled and monitored
* installation in near future

SLIDE 4

COMMUNICATIONS SYSTEMS

PROJECT	COMMUNICATIONS MEDIUM	OPERATION ON UNENERGIZED SECTIONS?
PROBE	Radio & Power Line Carrier	No (theoretical yes)
IDCPS	Telephone	Yes
ALADDIN	Telephone-Microwave/ Power Line Carrier	Yes
CPL	Power Line Carrier	No (upgrade planned)
FPL	Power Line Carrier (TWACS)	No
ONTARIO HYDRO	Telephone	Yes
NMPC	Power Line Carrier	Yes
PE	2-way radio Telephone Power Line Carrier	Not Implemented Yes No
AACE	Telephone & Power Line Carrier	YES

SLIDE 5

STATUS

PROBE, Commonwealth Edison

The project was completed in May, 1980. Development and implementation of distribution automation systems is continuing on the systems of the sponsoring utilities. RP1472 (TESCo) is making use of suggested design improvements in its prototype hardware and expanded set of distribution automation functions.

IDCPS, TESCo.

The system is being installed at the Handley Substation.

ALADDIN, AEP

The system has been operating for about 2 years.

CPL

A large system has been in operation to aid in the development and field testing of distribution automation equipment and procedures. An EPRI-sponsored research project is installing additional substation and feeder breakers. CPL plans to add the capability of operation on unenergized feeder sections.

FPL

FPL is negotiating with the vendor.

SLIDE 5 (continued) STATUS

ONTARIO HYDRO

The system has been operating for several years. Data collected are being evaluated and used to improve operating procedures.

NMPC

Data collection has been completed; analysis of the data has not yet begun.

PHILADELPHIA ELECTRIC

The test of the McGraw Edison-Altran communications system is EPRI-sponsored research, and is just beginning. Several industrial solid state meters have been installed in the Robinton program. The Westinghouse meter reading system has a few units in the field; the system is still in the experimental stage.

AACE, AUB

Equipment is being installed. The experiment plans are being developed. The IDCS should be operational in April, 1985. The "learning year" of operation is scheduled to be completed in October, 1986. The year of integrated operations will be completed in October, 1987.

SLIDE 6

FUNCTIONS INCLUDED

	LC	AMR	LS	VC	FD	FISR	FR	BC	Monitoring Sub	Monitoring Fdr	Comm. Link
PROBE				X	X	X	X	X	X	X	X
IDCPS				X	X	X	X	X	X	X	X
ALADDIN		X	X	X	X	X	X	X	X	X	X
CP&L	X	X	X	X			X	X	X	X	X
FP&L	X	X	X	X							X
OH	X	X		X	X	X	X		X	X	X
NMPC		X	X	X	X		X	X	X	X	X
PE		X									X
AACE	X	X	X	X	X	X	X	X	X	X	X

KEY

LC	load control
AMR	remote meter reading
LS	load survey
FD	fault detection
FISR	fault isolation and service restoration
VC	voltage/var control
FR	feeder reconfiguration, load leveling
BC	breaker/recloser control (protection)
Sub	substation monitoring and data storage
Fdr	feeder monitoring & data storage
Comm. Link	communications between dispatch center & distribution system

SLIDE 7

HARDWARE DEVELOPMENT

PROBE	Emphasis was on proving the concept, not perfecting hardware.
IDCPS	Testing prototype DAC hardware.
ALADDIN	Designing pole-mounted equipment packages.
CPL	Communications system and field equipment R&D, as well as distribution automation concepts and procedures.
FPL	Vendors will customize existing technology to the extent possible.
ONTARIO HYDRO	Emphasis on developing procedures and data base.
NMPC	See PROBE.
PE	Field testing for R&D of communications system.
AACE	Will use existing hardware & communications systems.

SLIDE 8

APPLICATIONS SOFTWARE
FOR
DAC DISPATCH AND ANALYSIS

All systems have SCADA system software and MMI

PROBE	Software being developed for FD, FISR, VC, FR Integrated data base
IDCPS	EPRI-developed software for VC, FR, sectionalizing
ALADDIN	Operator makes switching decisions
CPL	Analysis done off-line
FPL	Load control and AMR software
OH	VC, FD, FISR, FR software being developed
NMPC	See PROBE
PE	None
AACE	Software being developed on a simulator for LC, VC, FD, FISR, FR

SLIDE 9

SUMMARY/ISSUES

Distribution automation is still maturing.

Current emphasis is on hardware and communications system development.

Operating experience is necessary before distribution automation's capabilities can be fully realized.

What data should be collected, and how is it organized and analyzed?

Applications software is under development, but not yet fully integrated with distribution automation systems.

Current distribution automation systems do not include dispersed generation or storage.

AACE PROJECT OVERVIEW

This was an overview presentation designed to (1) establish the project objectives and rationale, (2) define the hardware system, and (3) identify the basic experiment structure. The AACE experiments are designed to quantify the benefits associated with automation and, through experimentation, to determine the minimal amount of hardware required to support automation functions. The development and testing of control strategies are required to generate experimental data and to demonstrate the strengths and weaknesses of an automated distribution system.

The Integrated Distribution Control System (IDCS) is the hardware system on which the experiments will be conducted. The IDCS consists of two separate types of equipment: (1) a traditional Supervisory Control and Data Acquisition (SCADA) system modified for distribution automation and (2) the interface equipment, which is that equipment required to link the SCADA system to traditional utility equipment.

Additionally, Electric Power Research Institute (EPRI) is providing a separate customer appliance monitoring system, the Electric ARM system. EPRI is also a codesigner of the load control experiments.

The experiments are divided into three areas: load control, volt/var control, and system reconfiguration. Load control deals with customer monitoring and control. Volt/var control deals with capacitor monitoring and control. System reconfiguration deals with breaker and distribution switch control. The experiments are identified as the characterization year (pre-IDCS), learning year, and integrated year experiments. The integrated operation of customer load control and capacitor and regulator control, as well as breaker and switch control, is the goal of the last year of operation and experimentation.

The current AACE project schedule calls for the IDCS to be operational in 1985 and for experimental operation to be concluded in 1987.

ATHENS AUTOMATION AND CONTROL EXPERIMENT

Electric Energy Systems Division - DOE

STEVEN L. PURUCKER
Project Manager

Oak Ridge National Laboratory
Martin Marietta Energy Systems

ORNL WSC-37061

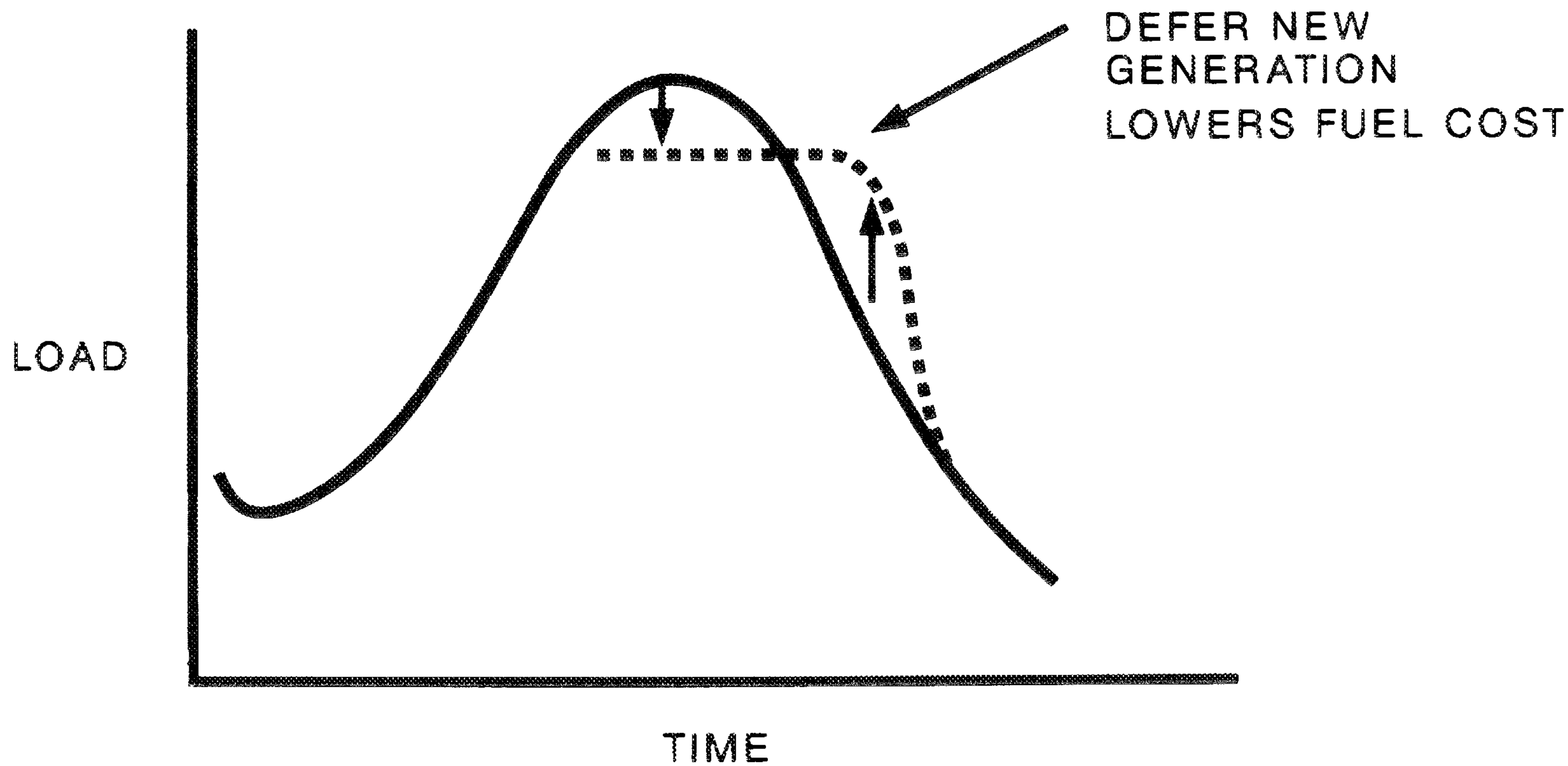
ATHENS AUTOMATION AND CONTROL EXPERIMENT

- RATIONAL AND PROJECT OBJECTIVES
- OVERVIEW ACTIVITIES AND PARTICIPANTS
- INTEGRATED DISTRIBUTION CONTROL SYSTEM
- EXPERIMENTS
- SCHEDULE

ORNL-DWG 84C-13835

SOME REASONS FOR THE ATHENS PROJECT

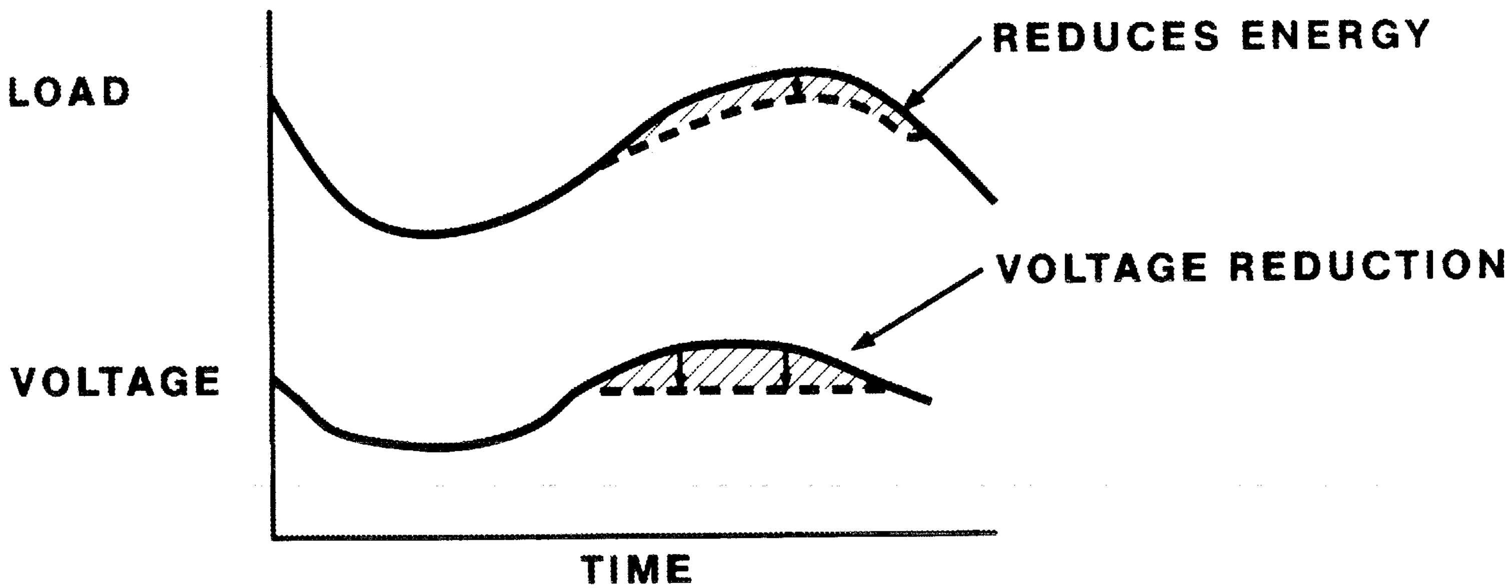
REDUCE PEAKS-LOAD CONTROL



ORNL-DWG 84C-13836

SOME REASONS FOR THE ATHENS PROJECT (cont'd)

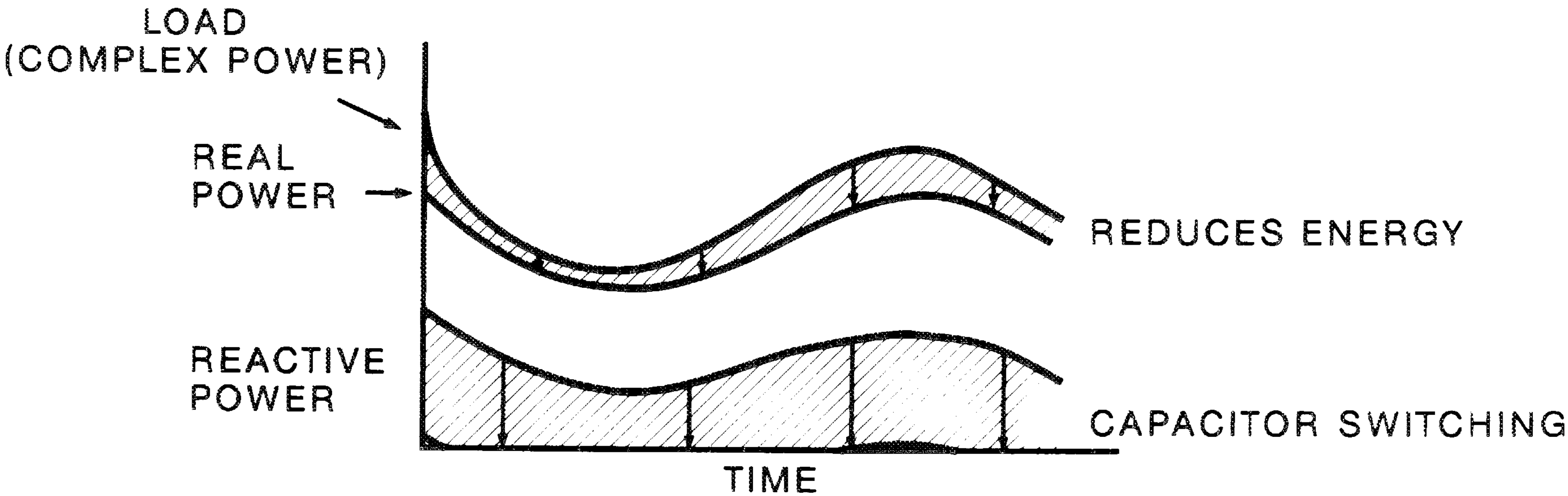
REDUCE PEAKS OR CONSERVE ENERGY - VOLTAGE CONTROL



ORNL-DWG 84C-13837

SOME REASONS FOR THE ATHENS PROJECT (cont'd)

REDUCE ELECTRICAL LOSSES-CAPACITOR CONTROL

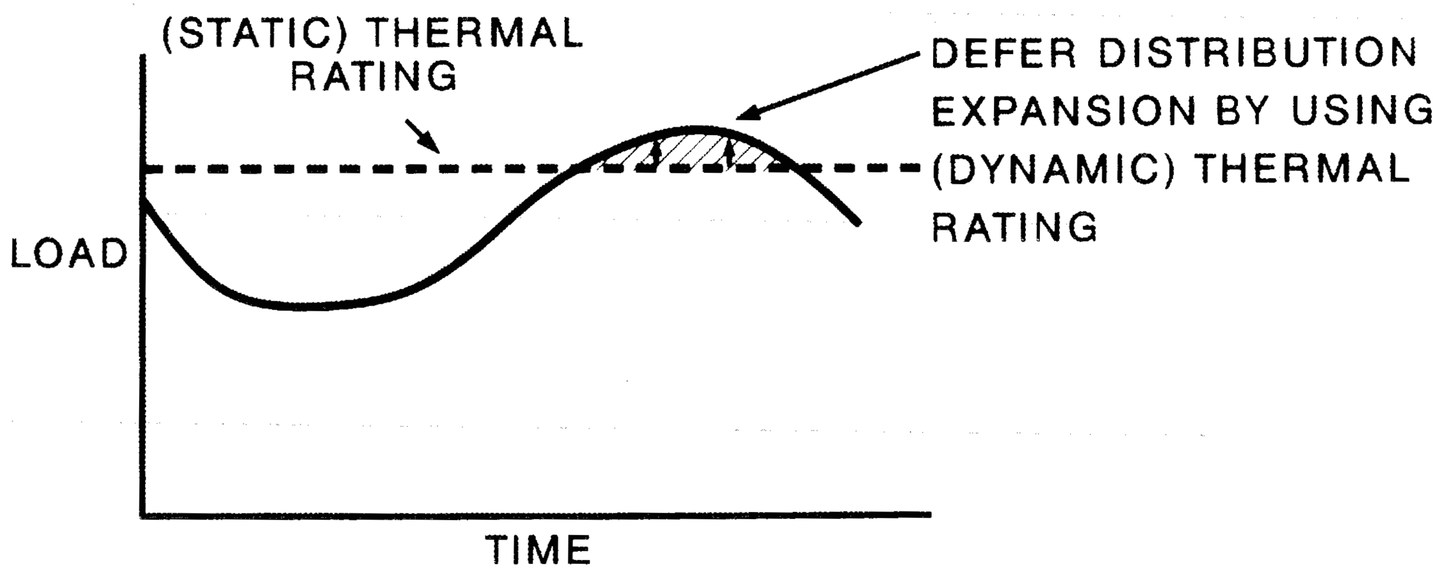


24

ORNL-DWG 84C-13838

SOME REASONS FOR THE ATHENS PROJECT (cont'd)

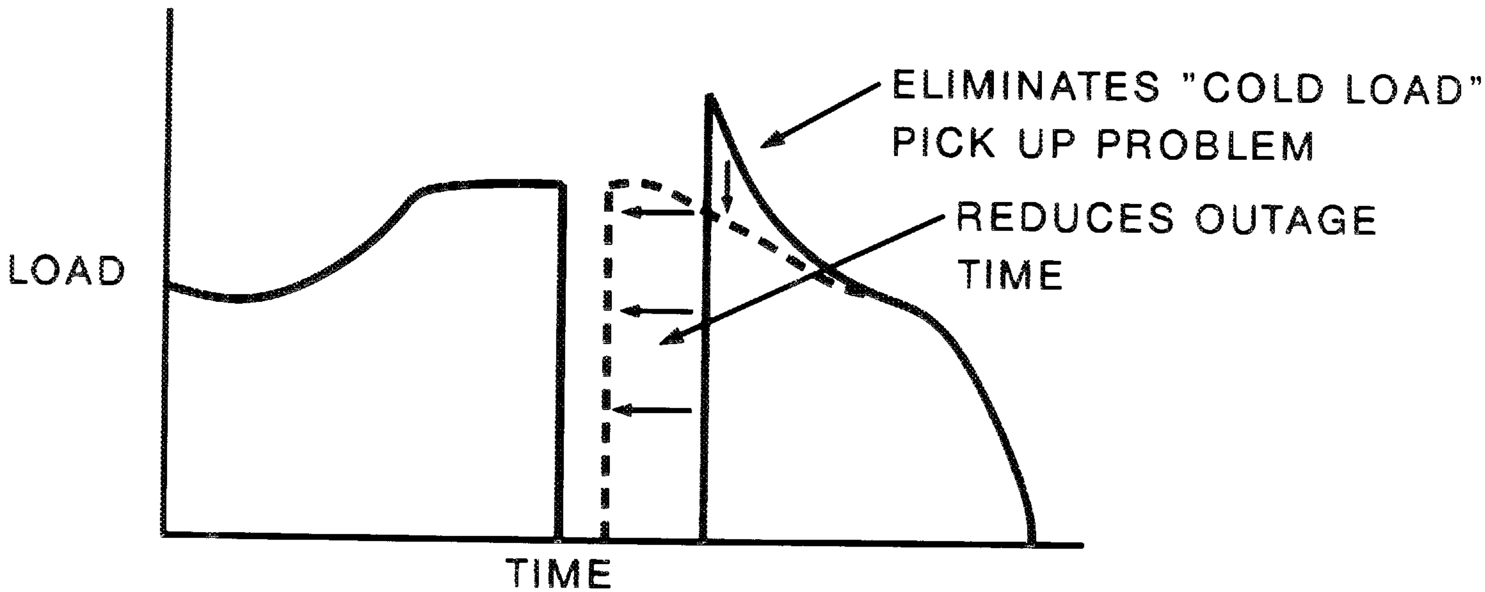
INCREASE THERMAL RATINGS OF EQUIPMENT-DISTRIBUTION AUTOMATION



ORNL-DWG 84C-13839

SOME REASONS FOR THE ATHENS PROJECT

IMPROVED RESPONSE TO OUTAGES-
DISTRIBUTION AUTOMATION

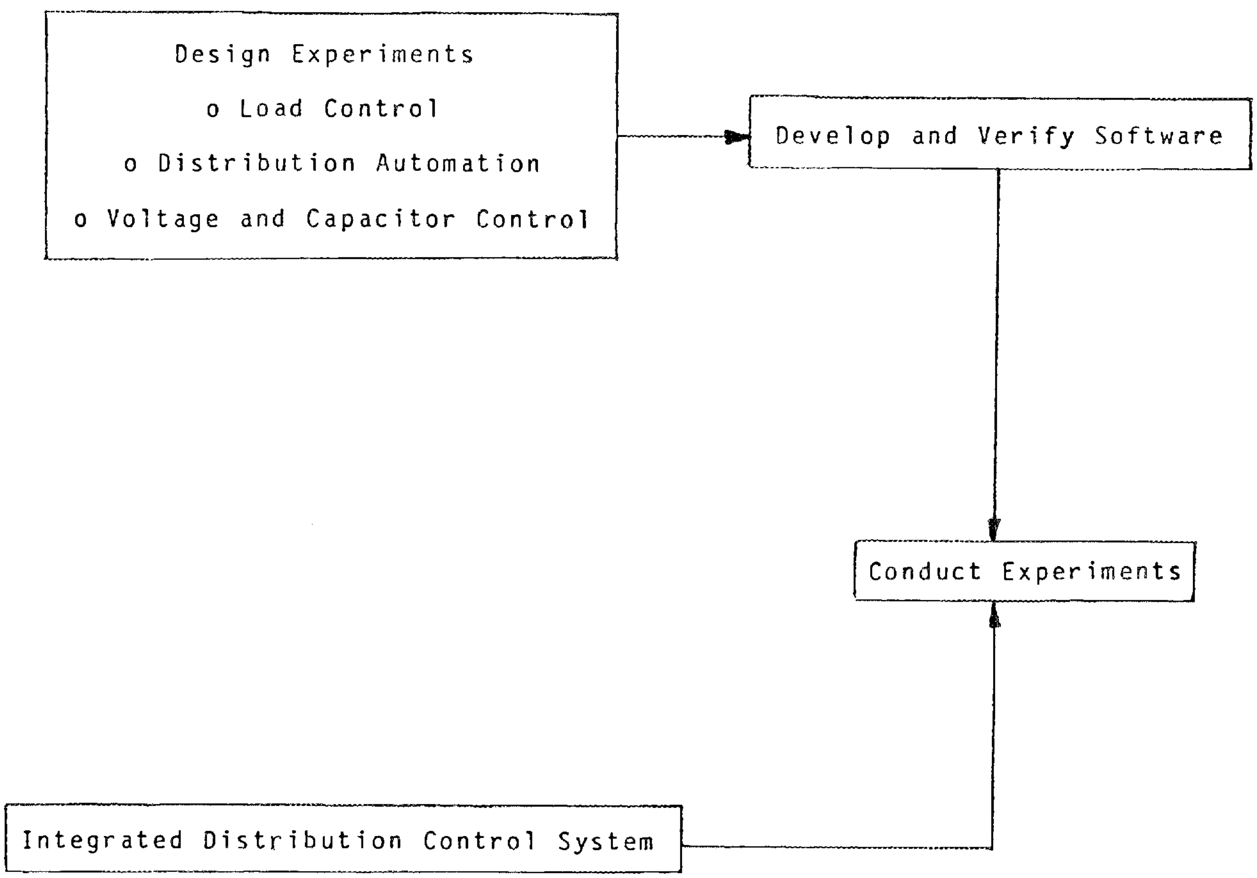


ORNL WS-34537

OBJECTIVES OF THE ATHENS AUTOMATION AND CONTROL EXPERIMENT

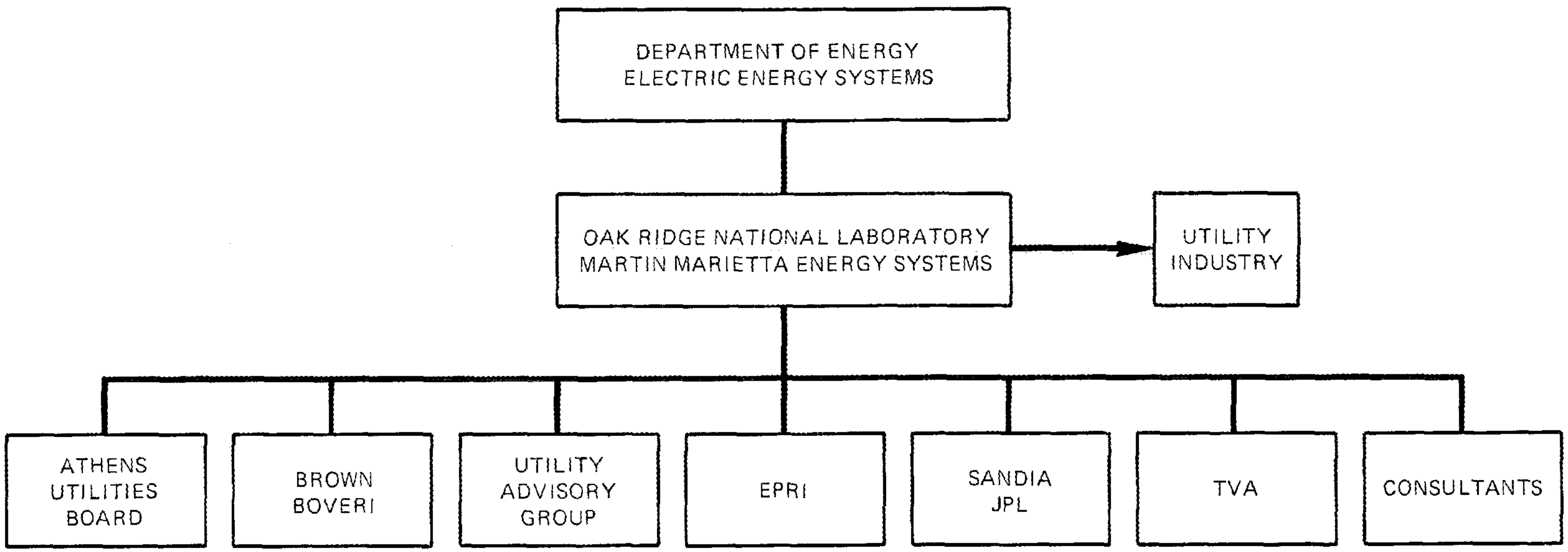
- QUANTIFY BENEFITS OF AUTOMATION
- DEVELOP AND TEST CONTROL STRATEGIES
- DETERMINE MINIMAL HARDWARE REQUIREMENTS
- DEFINE SECOND GENERATION REQUIREMENTS
- COORDINATE DISTRIBUTION, GENERATION, AND TRANSMISSION CONTROL
- QUANTIFY SOCIO-ECONOMIC ASPECTS
- TRANSFER RESULTS TO THE UTILITY INDUSTRY

Major Events of the AACE

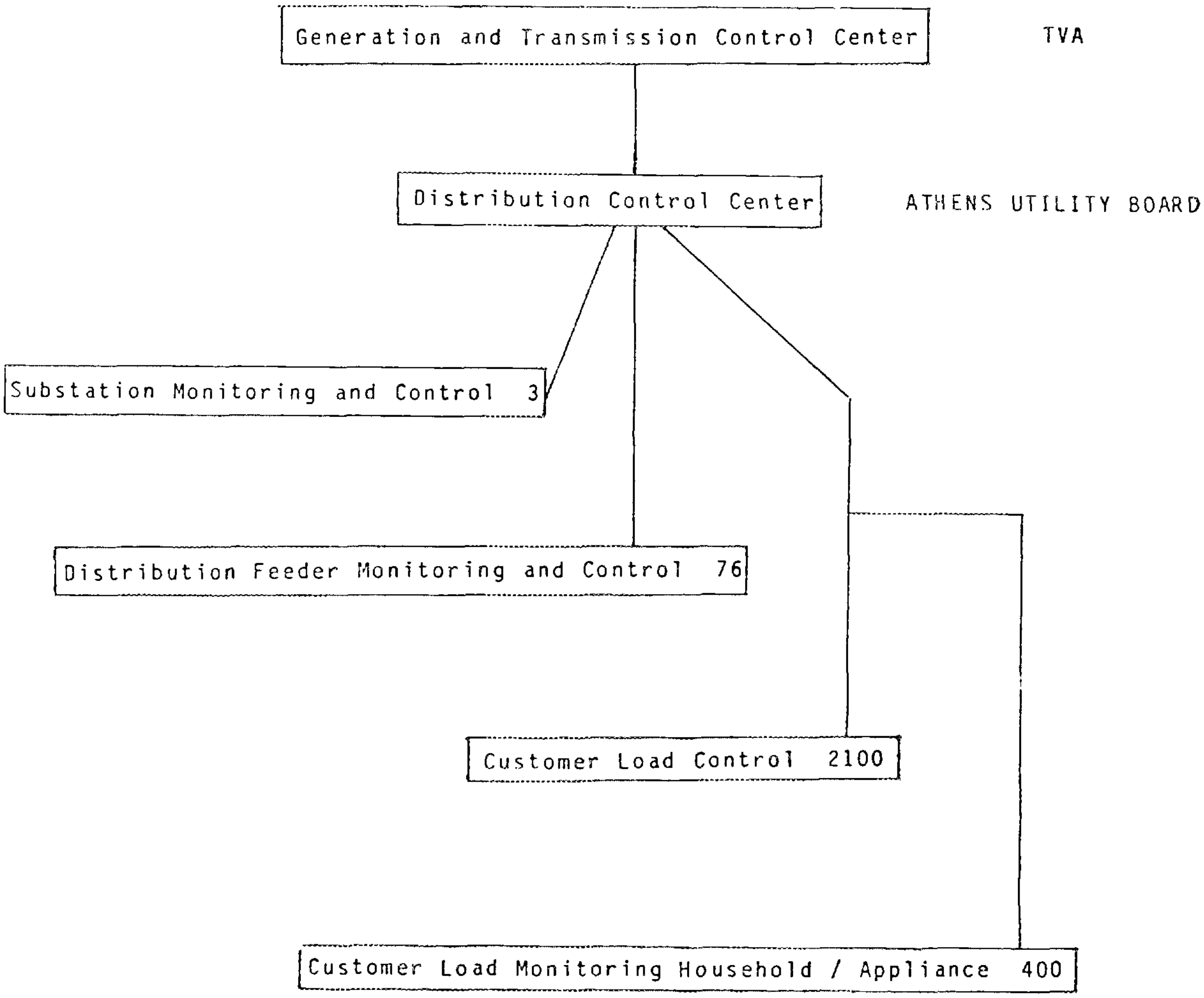


ORNL–DWG 84-12390

PARTICIPANTS IN THE ATHENS AUTOMATION AND CONTROL EXPERIMENT (AACE)

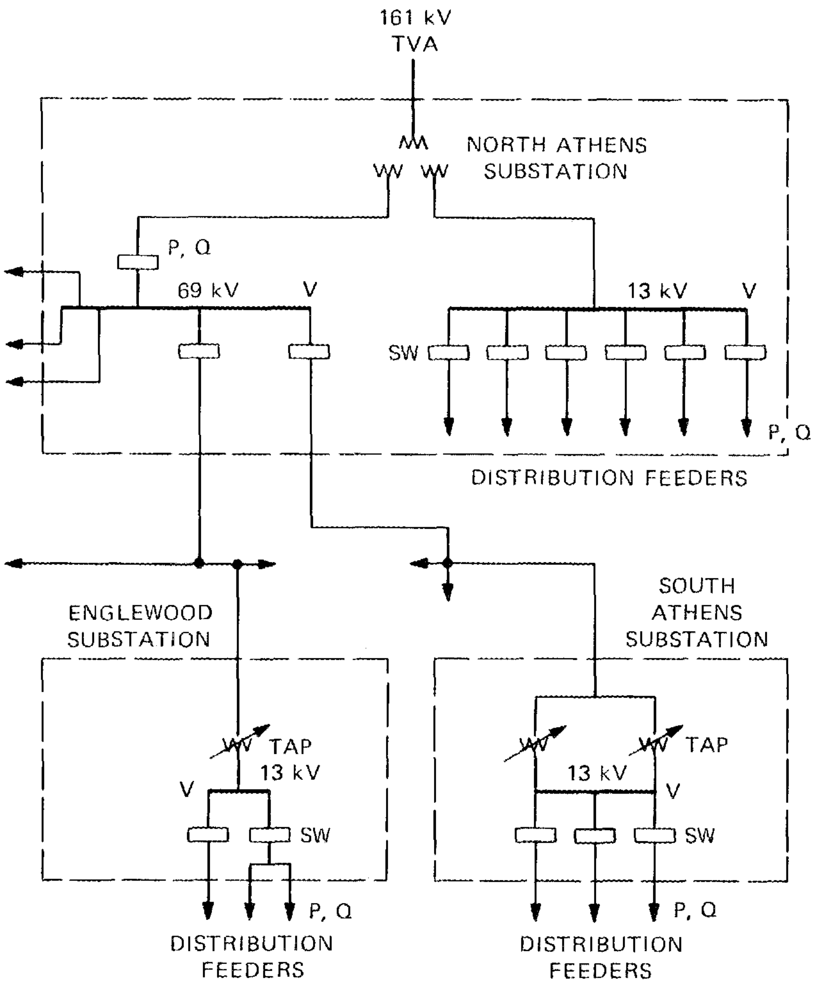


COMMUNICATION AND CONTROL HIERARCHY



ORNL-DWG 82-18666R3

SUBSTATION CONTROL AND MONITORING



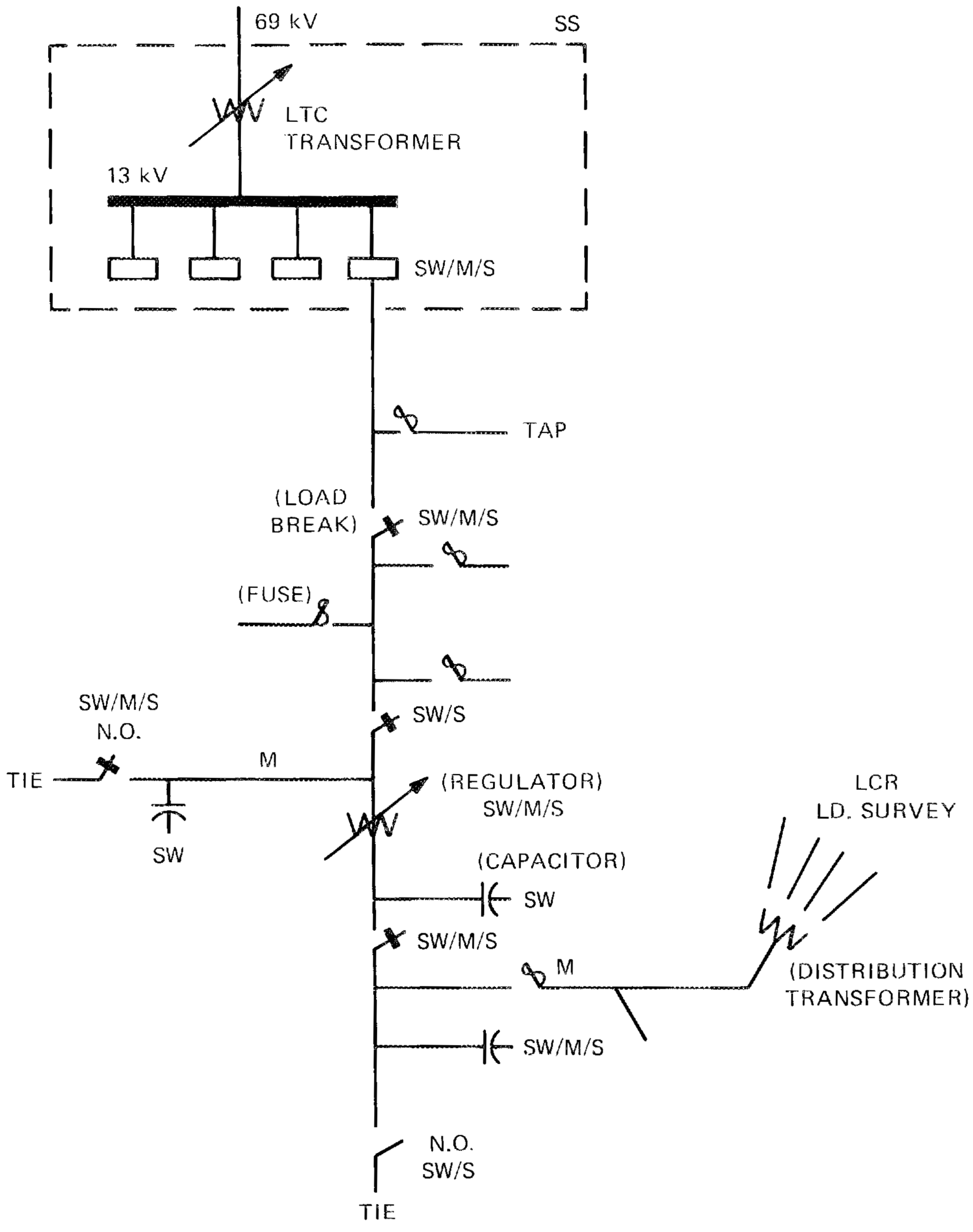
OTHER AUTOMATION AND MONITORING POINTS

STATION CAPACITORS
TEMPERATURE AND HUMIDITY
NEUTRAL BUS CURRENTS
STATION AND BREAKER RELAY STATUS

SW SWITCHABLE FROM COMPUTER
PQ 1ϕ REAL POWER AND REACTIVE MONITORED
V BUS VOLTAGE MONITORED
TAP LTC AND REGULATOR CONTROL

ORNL-DWG 82-18669R3

FEEDER CONTROL AND MONITORING



SW SWITCHING CAPABILITY

M 1ϕ OR 3ϕ MONITORING CAPABILITY

S STATUS OF SWITCH AND ASSOCIATED RELAYS

LCR LOAD CONTROL RECEIVER

ORNL WSC-37062

IDCS CUSTOMER MONITORING AND CONTROL EQUIPMENT

- SMART METERS

- LOAD CONTROL RECEIVER

ORNL WSC-37063

THE EXPERIMENTS

EXPERIMENTAL AREAS	CHARACTERIZATION YEAR	LEARNING YEAR	INTEGRATED YEAR
LOAD CONTROL			
VOLT/VAR CONTROL			
SYSTEM RECONFIGURATION			

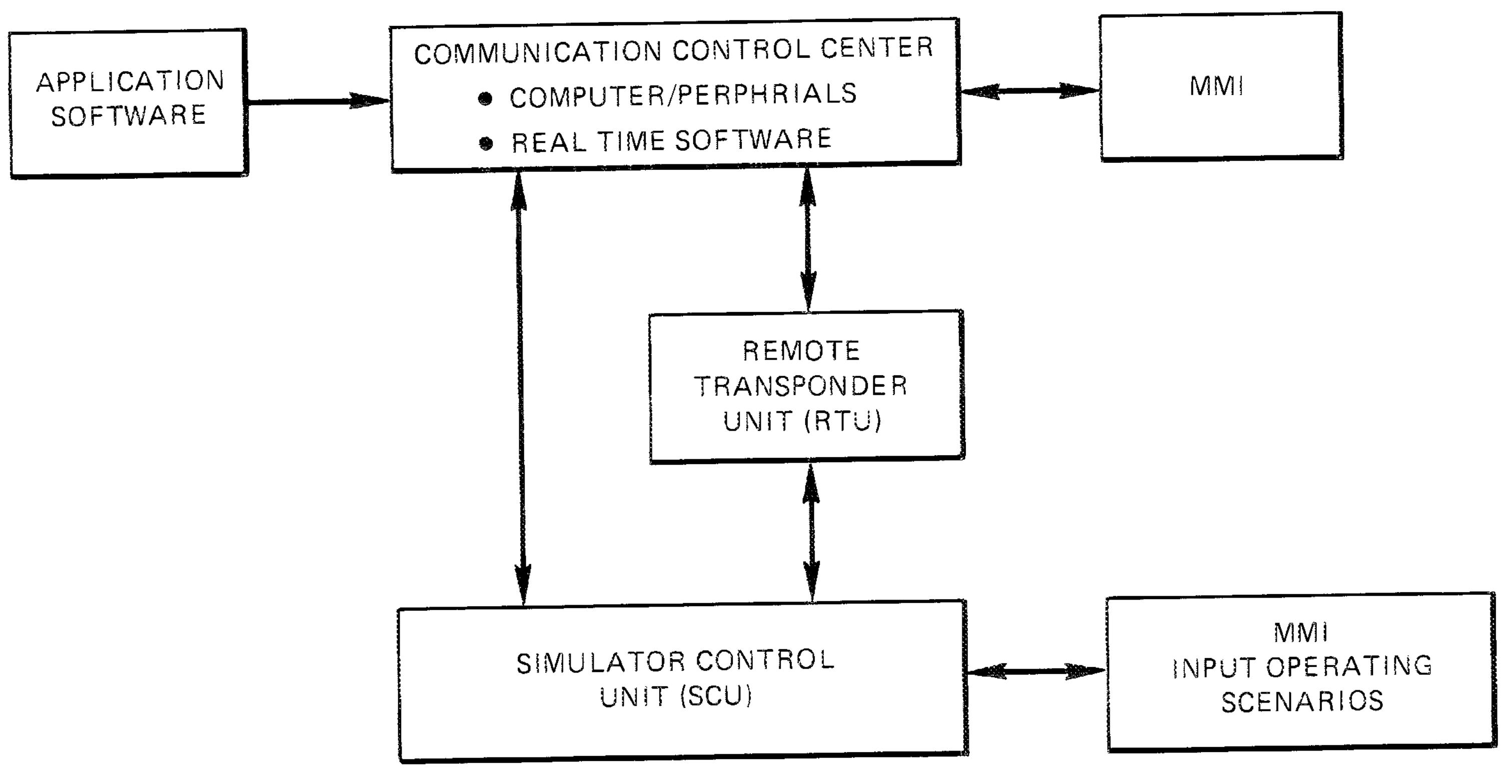
ORNL WSC-37064

THE CHARACTERIZATION YEAR EXPERIMENTS

- CHARACTERIZATION HARDWARE
  - CUSTOMER APPLIANCE MONITORING
  - CUSTOMER HOUSEHOLD MONITORING
  - CUSTOMER LOAD CONTROL
  - SUBSTATION MONITORING
- ATHENS AUTOMATION AND CONTROL EXPERIMENT TEST SYSTEM (AACETS)

ORNL–DWG 84-7919

AACE TEST SYSTEM



ORNL WSC-37065

THE CHARACTERIZATION YEAR EXPERIMENTS

- MONITOR SUBSTATION AND CUSTOMER LOADS
- CUSTOMER LOAD CONTROL
- DEVELOP MODELS
- DEVELOP CONTROL STRATEGY SOFTWARE AND DISPLAYS
- COMPLETE LEARNING YEAR TEST PLAN

ORNL WSC-37066

THE LEARNING YEAR EXPERIMENTS

- CONDUCT EXPERIMENTS SEPARATELY
- ANALYSIS
- MODIFY MODEL AND CONTROL STRATEGY SOFTWARE
- COMPLETE INTEGRATED YEAR TEST PLAN

ORNL WSC-37067

THE INTEGRATED YEAR EXPERIMENT

- CONDUCT INTEGRATED EXPERIMENTS
- ANALYSIS
- FINAL REPORT

ORNL WSC-37068

ATHENS AUTOMATION AND CONTROL EXPERIMENT SCHEDULE

AACE TEST SYSTEM OPERATIONAL	JULY 1984
AN OVERVIEW OF THE ATHENS AUTOMATION AND CONTROL EXPERIMENT	DECEMBER 1984
IDCS OPERATIONAL	OCTOBER 1985
CHARACTERIZATION DATA OBTAINED	OCTOBER 1985
LEARNING YEAR EXPERIMENTS COMPLETE	OCTOBER 1986
INTEGRATED YEAR EXPERIMENTS COMPLETE	OCTOBER 1987

HARDWARE

COMMUNICATION AND CONTROL SYSTEM

The communication and control system (CCS) forms a major part of the experimental "tools" that will be used to conduct the AACE. The CCS combines standard with nonstandard (custom) hardware and coordinates both types of hardware through a modified Supervisory Control and Data Acquisition (SCADA) software program. This presentation reviews the design goals and implementation decisions that determined the final shape of the CCS.

The CCS must allow operators to collect data from the Athens Utilities Board (AUB) network and enable them to manipulate the network with load control and distribution control commands. Both data collection and control capabilities must operate under abnormal as well as normal conditions of the AUB network. To ensure this level of reliability, proven components of SCADA hardware and software are used. Standard hardware components of the CCS include Brown Boveri Control Systems, Inc., remote terminal units (RTUs), signal injection units (SIUs), and load control receivers (LCRs). Other major components are Metretek load survey units (LSUs), Digital Equipment Corporation (DEC) computers, and Aydin display generators. The major software component is Brown Boveri's MODSCAN III SCADA software, running in the environment of DEC's RSX-11M operating system. Communication among the various hardware elements takes place over three kinds of channels: (1) dedicated (leased) telephone lines, (2) ordinary dial-up telephone lines, and (3) AUB distribution lines themselves (in the form of power line carrier messages). Data collected from the remote units (RTUs and LSUs) are displayed to system operators and recorded in "history files" for later analysis. Provisions for future expansion and adaptation of software will facilitate adding real-time control of experiments and on-line data analysis to accelerate experimentation.

ATHENS AUTOMATION AND CONTROL EXPERIMENT

Communication and Control System

PRESENTATION GOALS

1. Report on the realization of the system as previously envisioned.
2. Recap overall system concepts for orientation to experimental designs.
3. Describe any significant changes from original system design.
4. Show provisions for future applications.

ATHENS AUTOMATION AND CONTROL EXPERIMENT

Communication and Control System

PRESENTATION STRUCTURE

1. Overview of system goals and architecture
2. Identification of system elements
3. Description of communication channels
4. Introduction to database and control structures

GOALS OF COMMUNICATION AND CONTROL SYSTEM

1. Data Collection

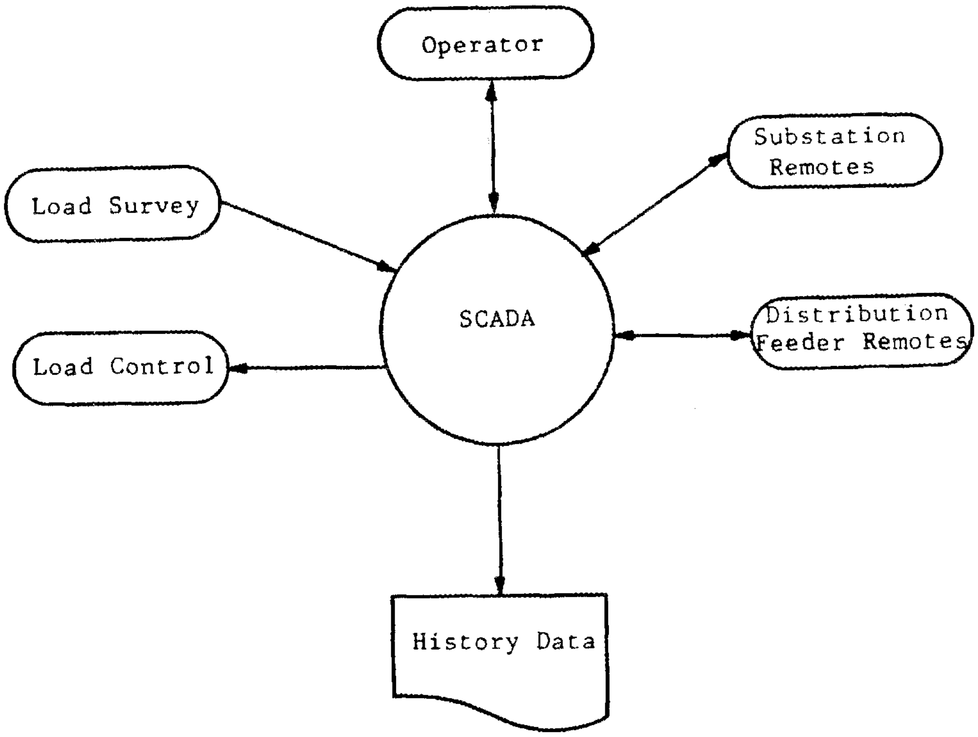
   Distribution system behavior
   Customer behavior
   Operator behavior

2. Command Functions (Load Control)

   Load sampling
   Load cycling
   Load deferral/denial

3. Command Functions (Distribution Control)

   Voltage/VAR control
   Switching and sectionalizing
   Power outage recovery


Operator
Substation Remotes
Load Survey
SCADA
Distribution Feeder Remotes
Load Control
History Data

COMMUNICATION AND CONTROL HARDWARE

1. Standard SCADA Equipment

   CCC (Central Control Computer)
   computers, display generators, CRTs, printers

   RTUs (Remote Terminal Units)
   3 substation locations
   8 distribution system locations

2. Standard, Non-SCADA Equipment

   LCRs (Load Control Receivers)
   2100 customer locations

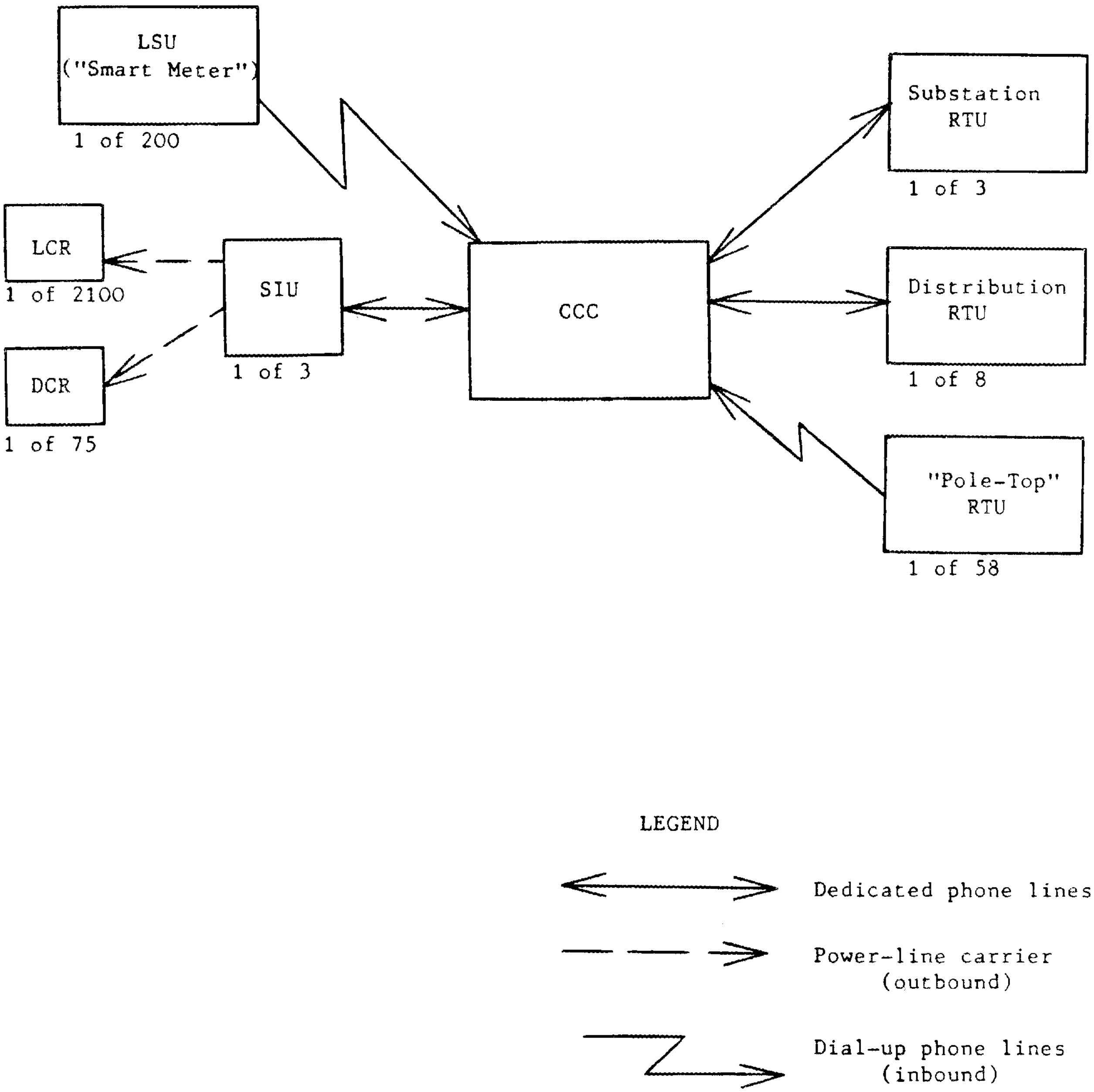
   SIUs (Signal Injection Units)
   3 substation locations

   LSUs (Load Survey Units), "Smart Meters"
   200 customer locations

3. Special Equipment

   PTUs ("Pole-top" RTUs)
   58 distribution system locations, for control and monitoring

   DCRs (Distribution Control Receivers)
   17 distribution system locations, for control only


LSU
("Smart Meter")
1 of 200
LCR
1 of 2100
SIU
1 of 3
DCR
1 of 75
CCC
Substation
RTU
1 of 3
Distribution
RTU
1 of 8
"Pole-Top"
RTU
1 of 58
LEGEND
Dedicated phone lines
Power-line carrier
(outbound)
Dial-up phone lines
(inbound)

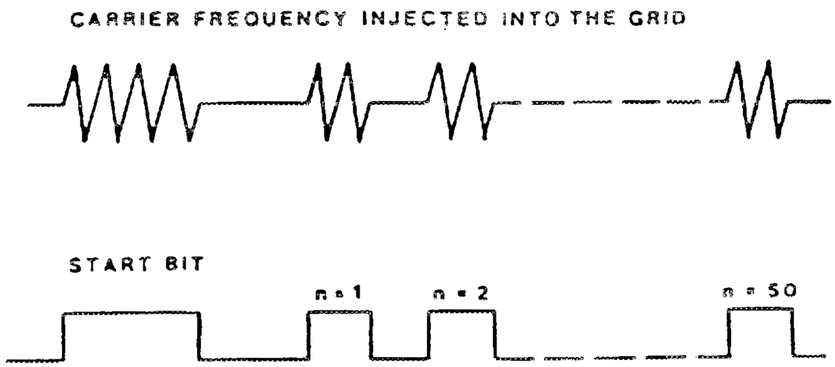


FIGURE 1

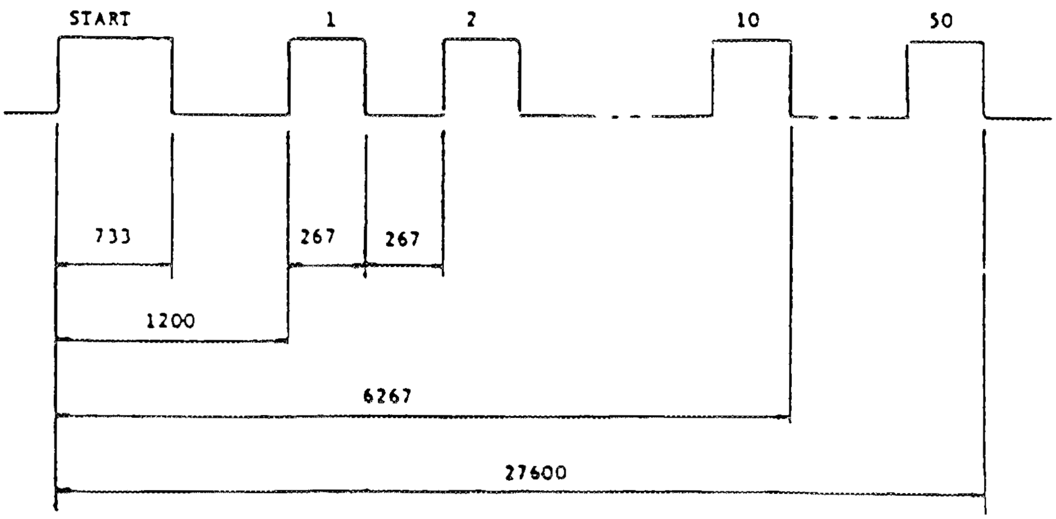


FIGURE 2

COMMUNICATION AND CONTROL DATA FLOW
(All times are typical)

1. Data sampling (at point of measurement)

   RTU
     analog (every 15 seconds)
     status (every 10 seconds)

   PTU
     analog (every 5 seconds)
     status (every 1 second)

   LSU ("Smart Meter")
     KWH (pulse per 3.6 watt-hour)

2. Data transmittal (to AUB from measurement point)

   Periodic
     LSU call back (every 15 minutes)
     RTU "Integrity" scan (every 65 minutes)
     PTU "Integrity" scan (every 120 minutes)

   Non-periodic (event-driven)
     RTU Report-by-Exception
       analog (polled every 30 seconds)
       status (polled every 20 seconds)
     PTU Report-by-Exception
       on change of analog or status
       (subject to debounce count and delay)

   Non-periodic (solicited)
     PTU "demand scan"
       from operator or application programs

3. Data accumulation

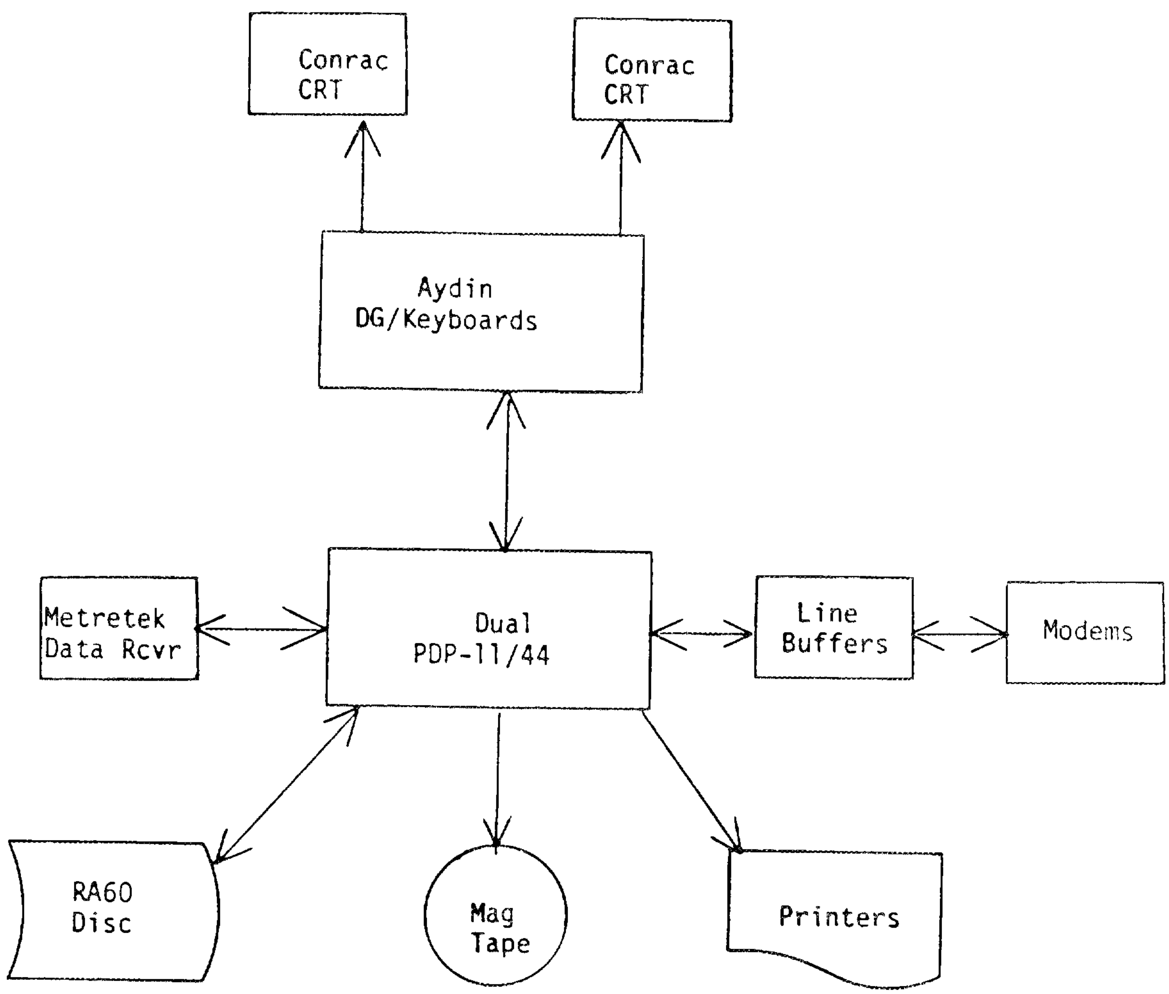
   History file collection (every 15 minutes)
   Application programs/experiments

4. Data archival

   History file rolled out to mag-tape (daily)

5. Data analysis

   Off-line processing by ORNL and others


Conrac
CRT
Conrac
CRT
Aydin
DG/Keyboards
Metretek
Data Rcvr
Dual
PDP-11/44
Line
Buffers
Modems
RA60
Disc
Mag
Tape
Printers

COMMAND AND CONTROL SOFTWARE
(computer codes and data structures)

1. Standard SCADA Software

    Operating system (RSX-11M)

    On-line SCADA functions (MODSCAN)

        Communications
        Man-machine interface
        Database management
        History files

    Line Buffer firmware

    RTU firmware

        Report-by-exception

    Off-line SCADA utilities

        Display definition (INTAC)
        Database compiler

2. Standard, Non-SCADA Software

    Load Management

        Addressing techniques
        LCU firmware
        LCR firmware

    Load Survey

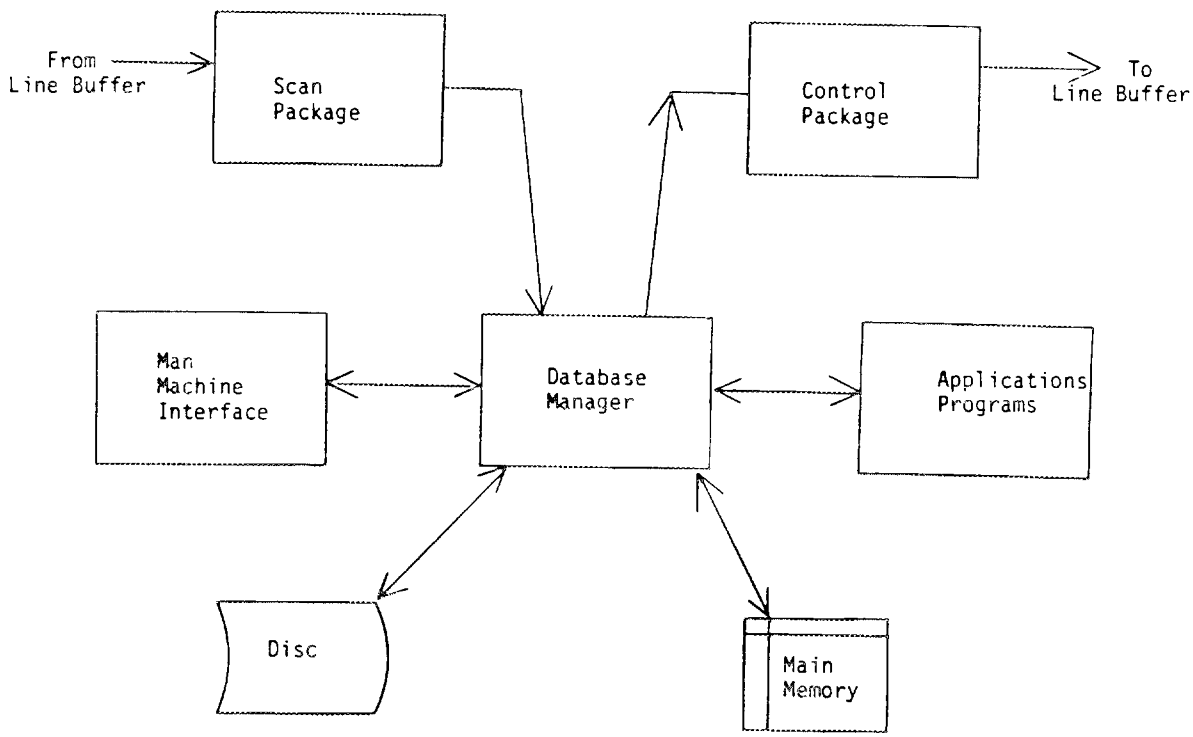
        LSU and data receiver firmware

3. Special Software

    PTU firmware

        Data collection
        Control coordination

    Application programs


From
Line Buffer
Scan
Package
Control
Package
To
Line Buffer
Man
Machine
Interface
Database
Manager
Applications
Programs
Disc
Main
Memory

AACE TEST SYSTEM

The AACE Test System (AACETS) is a computer system located at Oak Ridge National Laboratory (ORNL) which is designed to develop and test applications software. Control strategies will be developed and tested on AACETS prior to implementation on the AUB system.

The Communications Control Center consists of a single Digital Equipment Corporation PDP 11/44 with associated peripherals. It will be loaded with a "stripped-down" version of the MODSCAN real-time software package supplied by Brown Boveri Control Systems, Inc. The man–machine interface is identical to the color graphics being installed at Athens Utilities Board (AUB). The remote terminal unit is identical to those being delivered for AUB's Integrated Distribution Control System.

AACETS will also serve as an operator training simulator.

Athens Automation and Control Experiment Test System (AACETS)

G. R. Wetherington Jr.
ORNL
December 5, 1984

The AACETS Is A Support Tool

Supports The Development Of Applications Software

Provides A Mechanism For Testing Of All Applications Software Prior To Installation On The Communications And Control System (CCS)

Supports The Generation And Maintenance Of The CCS Database And MODSCAN Software

Supports The Development Of Man-Machine Interface Displays

Serves As A Training System For AACE Project Personnel

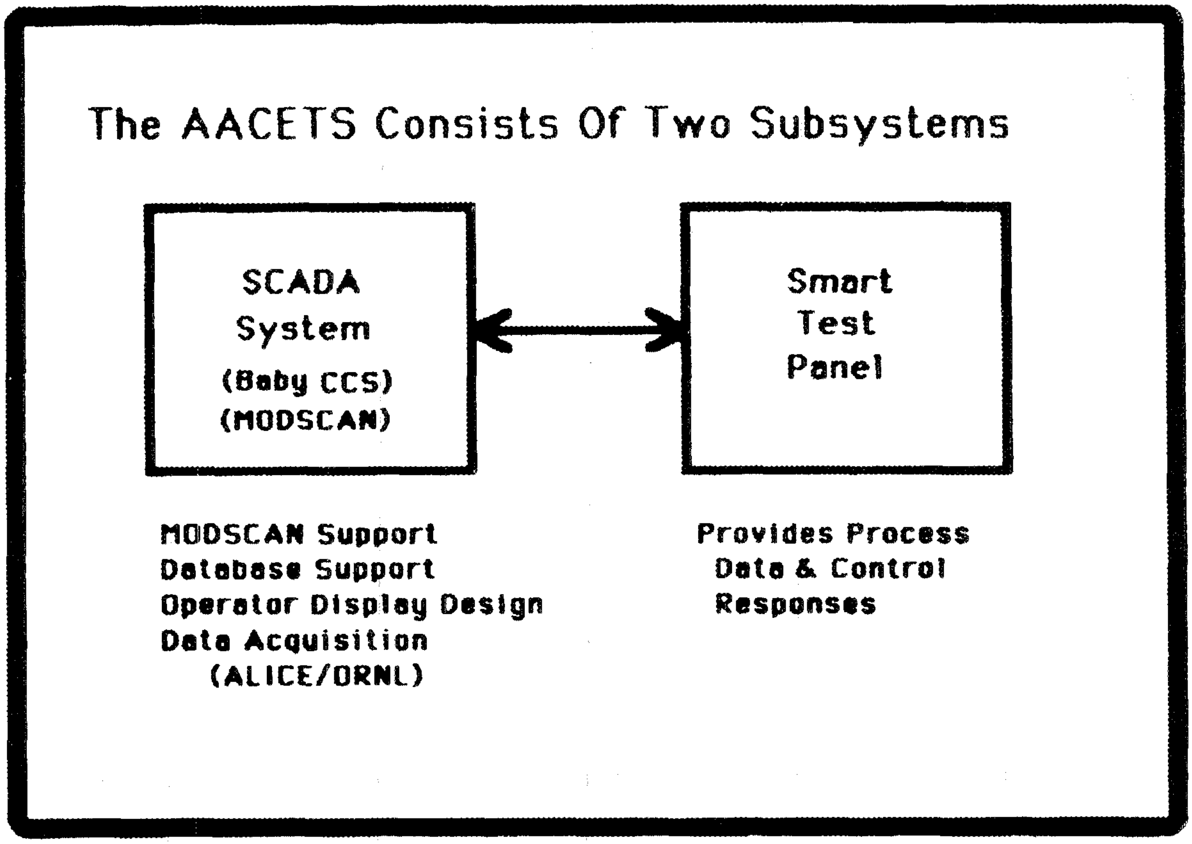
Supports The Acquisition Of Operational Data From The Athens Electrical Network For Characterization And Modeling Efforts

Why was the AACETS Necessary ?

- Significant Risks are Invloved When Performing Development Activitities on an "On-Line" Control System.
  - System Reliability
  - System Availability
  - Distribution System Operation

- The Second Athen's Host Computer Must Be In The "Backup" Mode For Successful Switchover In The Event Of A Failure In The Primary Host.
  - To Maintain Accurate Database Values
  - To Provide System Reliability

- Many System Support Activities May Require The Modification Of The MODSCAN System.


The AACETS Consists Of Two Subsystems
SCADA
System
(Baby CCS)
(MODSCAN)
Smart
Test
Panel
MODSCAN Support
Database Support
Operator Display Design
Data Acquisition
(ALICE/ORNL)
Provides Process
Data & Control
Responses

MODSCAN

Modular Supervisory Control And Data Acquisition

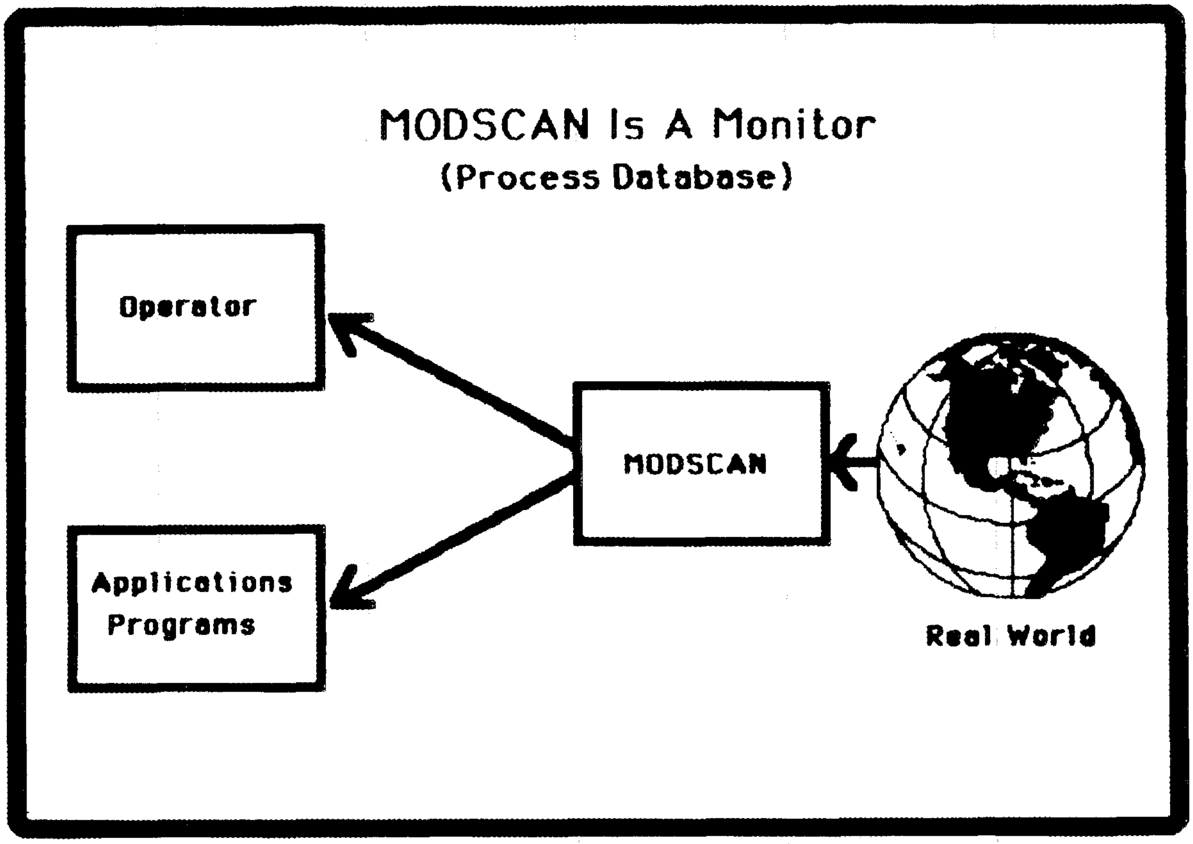
Real-Time Process Database

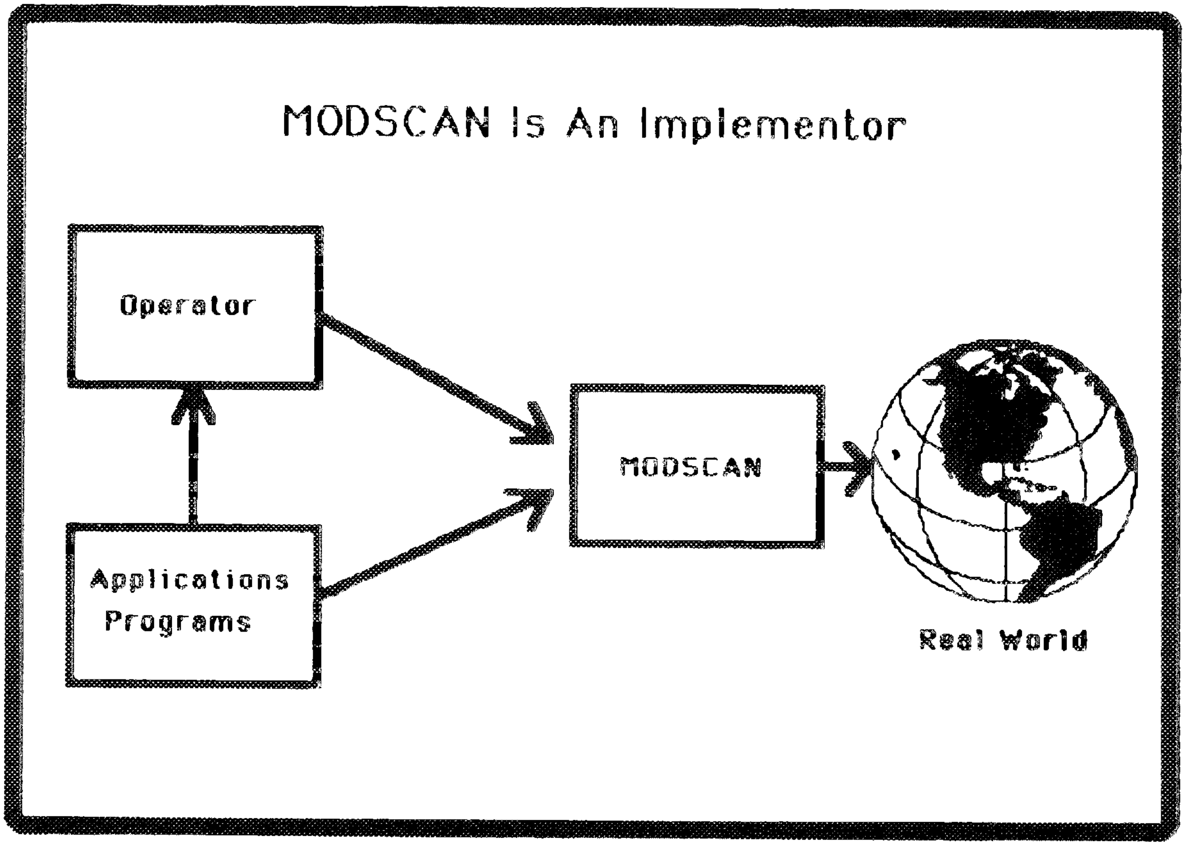
* 788 Analog Inputs
* 1,152 Status Inputs
* 6,812 Relay Outputs
  - 512 Dist. Control Relays
  - 6,300 Load Control Relays

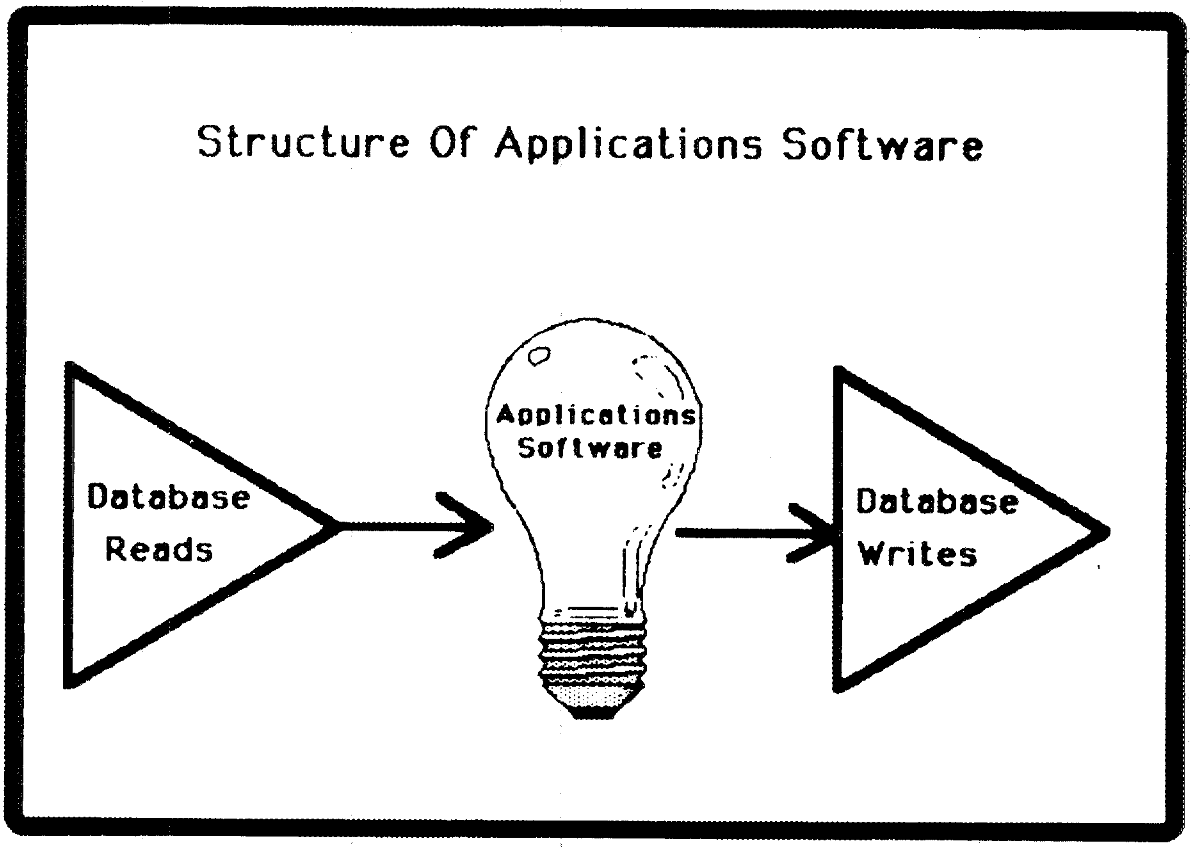
Custom Configurable And Maintainable

Supports Color CRT Operator Interfaces

* Standard Displays
* Custom Displays


MODSCAN Is A Monitor
(Process Database)
Operator
Applications
Programs
MODSCAN
Real World


MODSCAN Is An Implementor
Operator
Applications Programs
MODSCAN
Real World


Structure Of Applications Software
Database
Reads
Applications
Software
Database
Writes

The AACETS Improves Productivity

- Facilitates Software Development
- Provides More Thorough Software QA
- Assisted In Procurement And Shakedown Of The Communications And Control System
- Minimizes Project Dependency On System Support
  - Applications Software
  - System Software and Support
  - Development Activitites Are Independent Of The Communications And Control System

The AACETS Is A Support Tool

Supports The Development Of Applications Software

Provides A Mechanism For Testing Of All Applications Software Prior To Installation On The Communications And Control System (CCS)

Supports The Generation And Maintenance Of The CCS Database And MODSCAN Software

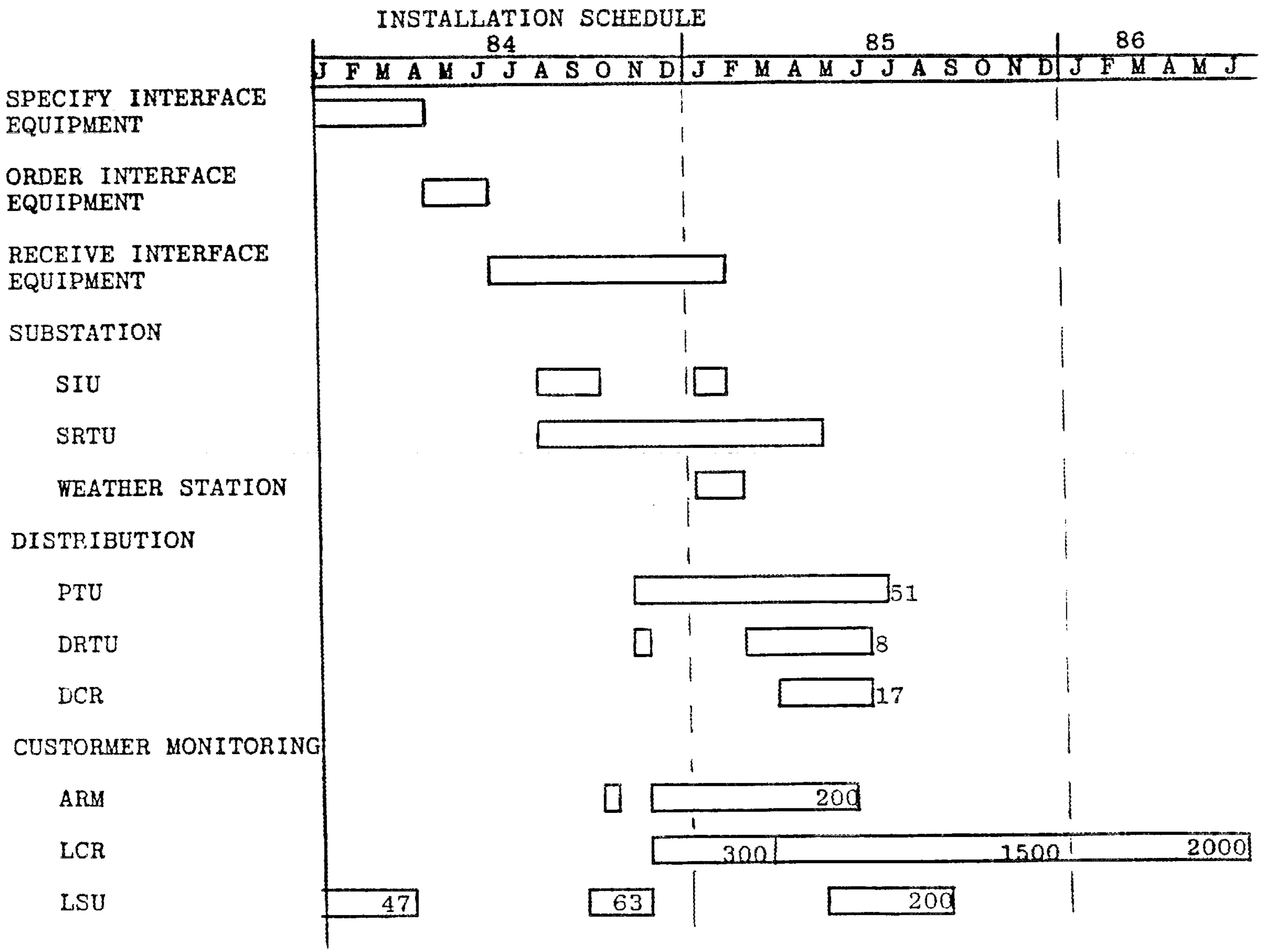
Supports The Development Of Man-Machine Interface Displays

Serves As A Training System For AACE Project Personnel

Supports The Acquisition Of Operational Data From The Athens Electrical Network For Characterization And Modeling Efforts

HARDWARE INSTALLATION STATUS

Athens Utilities Board (AUB) is responsible for the installation of the hardware on the AUB distribution system. The installation schedule and the status of equipment deliveries are provided.


INSTALLATION SCHEDULE
84
85
86
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
SPECIFY INTERFACE EQUIPMENT
ORDER INTERFACE EQUIPMENT
RECEIVE INTERFACE EQUIPMENT
SUBSTATION
SIU
SRTU
WEATHER STATION
DISTRIBUTION
PTU
51
DRTU
8
DCR
17
CUSTORMER MONITORING
ARM
200
LCR
300
1500
2000
LSU
47
63
200

EQUIPMENT STATUS

	QUANTITIES ORDERED/DELIVERED
I. SUBSTATIONS	
A) SUBSTATION INJECTION UNITS (SIU)	3/3
i) SIU POWER TRANSFORMERS	10/10
B) SUBSTATION REMOTE TERMINAL UNITS (SRTU)	3/3
i) TRANSDUCERS	72/72
C) WEATHER STATION	1/1
II. DISTRIBUTION SYSTEM	
A) DISTRIBUTION REMOTE TERMINAL UNITS (DRTU)	8/0
B) POLE TOP UNITS (PTU)	58/0
i) LOAD BREAK AIR BREAK SWITCHES	35/35
ii) MOTOR OPERATED DRIVES FOR SWITCHES	38/38
iii) CURRENT/VOLTAGE INSTRAMENT TRANSFORMERS	88/88
iv) TRANSDUCERS	182/182
v) SWITCHED CAPACITOR BANKS	26/26
vi) VAR CONTROLLERS	15/15
vii) FAULT DETECTORS	25/0
C) DISTRIBUTION CONTROL RECEIVERS	17/0
III. CUSTOMER PREMISES	
A) LOAD CONTROL RECEIVERS	2100/2100
B) LOAD SURVEY UNITS (SMART METERS)	200/128
C) ELECTRIC ARM UNITS (EPRI)	200/200

LOAD CONTROL EXPERIMENT

LOAD CONTROL

Documentation of the experiment design process, as well as the result, has been stressed in the planning for the Athens Automation and Control Equipment (AACE). A structured approach to load control was deemed necessary to cut through the multitude of options and strategies facing load control experiment planners. Both empirical data collection and theoretical modeling activities have been included in the AACE to facilitate a better understanding of the processes involved in dynamic load behavior.

Emphasis has been placed on statistical significance in data collection and analysis to ensure that the results obtained from these experiments are valid and repeatable. Experiments will focus on repetition of similar control strategies under varying conditions to obtain sufficient data to adequately model the physical and social behavior observed.

Increased emphasis has been placed on researching customer acceptance and customer reactions. Customer behavior exerts a strong influence on the load behavior. Most utilities depend on consumer willingness to participate in load control programs to make significant load changes. By identifying the rationale for customer cooperation, more effective marketing approaches can be defined.

The AACE has been designed to provide data and techniques that will be useful to other utilities. The transfer of experimental methods is expected to comprise a major contribution to the current state of load control techniques. EPRI has been active in developing generic procedures for the AACE which can be applied to many different types of electric utility systems.

Load monitoring will be carried out at the appliance level, household level, feeder section level, and feeder source level. One to three residential appliances will be independently controlled at each of 2000 locations. Appliance load control groups have been assigned by geographic location on the system feeders. The experiments will begin with load monitoring and simple control strategies and will progress in complexity and integration with the other aspects of the AACE. Controlled appliances include central electric air conditioners, central electric furnaces and heat pumps, and electric water heaters.

LOAD CONTROL TEAM MEMBERS
ATHENS AUTOMATION AND CONTROL EXPERIMENT

JOHN H. REED
PAT HU
MIKE KULIASHA
JULIA MC INTYRE
J. DOUGLAS BIRDWELL
EPRI/MINIMAX

LOAD CONTROL ISSUES

- WHAT DOES LOAD WITHOUT CONTROL LOOK LIKE FOR DIFFERENT CLASSES OF CUSTOMERS?
- WHAT DOES LOAD WITH CONTROL LOOK LIKE FOR DIFFERENT CLASSES OF CUSTOMERS?
- HOW MUCH ENERGY IS LOST BECAUSE OF LOAD CONTROL?
- HOW PROBLEMATIC ARE THE PEAKS FOLLOWING A LOAD CONTROL ACTION?

LOAD CONTROL ISSUES CONTINUED

- HOW USEFUL IS LOAD CONTROL FOR ECONOMIC DISPATCH, EMERGENCY RESTORATION, AND SPINNING RESERVE?
- HOW RELIABLE IS THE HARDWARE, THE SOFTWARE, AND THE COMMUNICATIONS MODE?
- WHAT LEVEL OF INSTRUMENTATION IS REQUIRED?
- HOW DO CUSTOMERS RESPOND TO LOAD CONTROL?

OVERVIEW OF THE PRESENTATION

- THE LOAD CONTROL SYSTEM
- CUSTOMER ISSUES
  - SELECTION
  - RECRUITMENT
  - ASSIGNMENT TO CONTROL GROUPS
- THE DATA
- ANALYSIS OF SUBSTATION LOADS
- THE EXPERIMENTS
  - TYPES
  - ANALYSIS

PROGRESS IN LOAD CONTROL
ATHENS AUTOMATION AND CONTROL EXPERIMENT

JOHN H. REED
OAK RIDGE NATIONAL LABORATORY

PROJECT REVIEW MEETING
REGISTRY HOTEL, DALLAS
DECEMBER, 1984

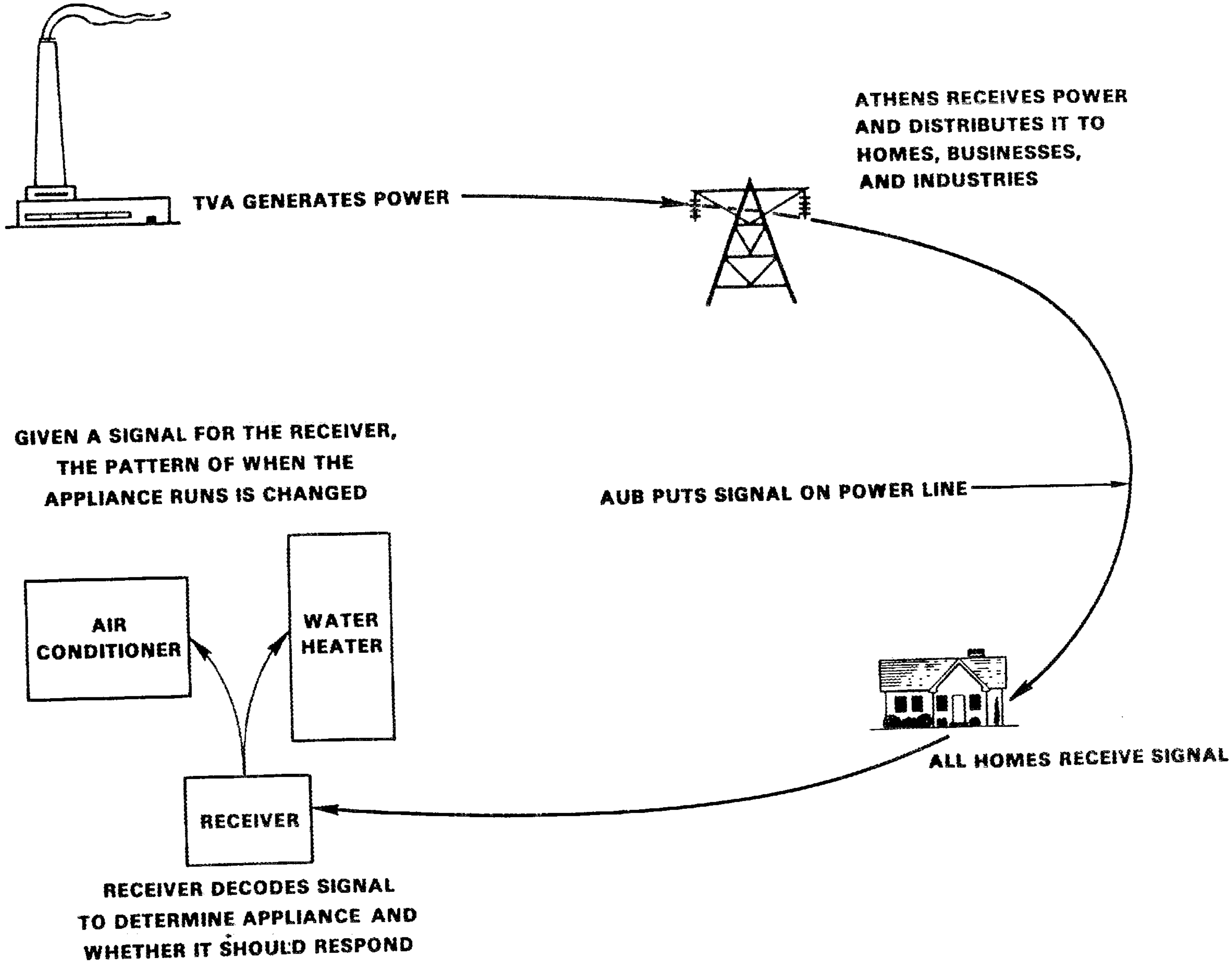
LOAD CONTROL OBJECTIVES

- CHARACTERIZATION AND MODELING
- DEVELOPMENT OF CONTROL STRATEGIES
- CUSTOMER COMFORT CONSTRAINTS
- INSTRUMENTATION REQUIREMENTS AND RELIABILITY
- CUSTOMER ACCEPTANCE
- TRANSFER TO THE UTILITY INDUSTRY

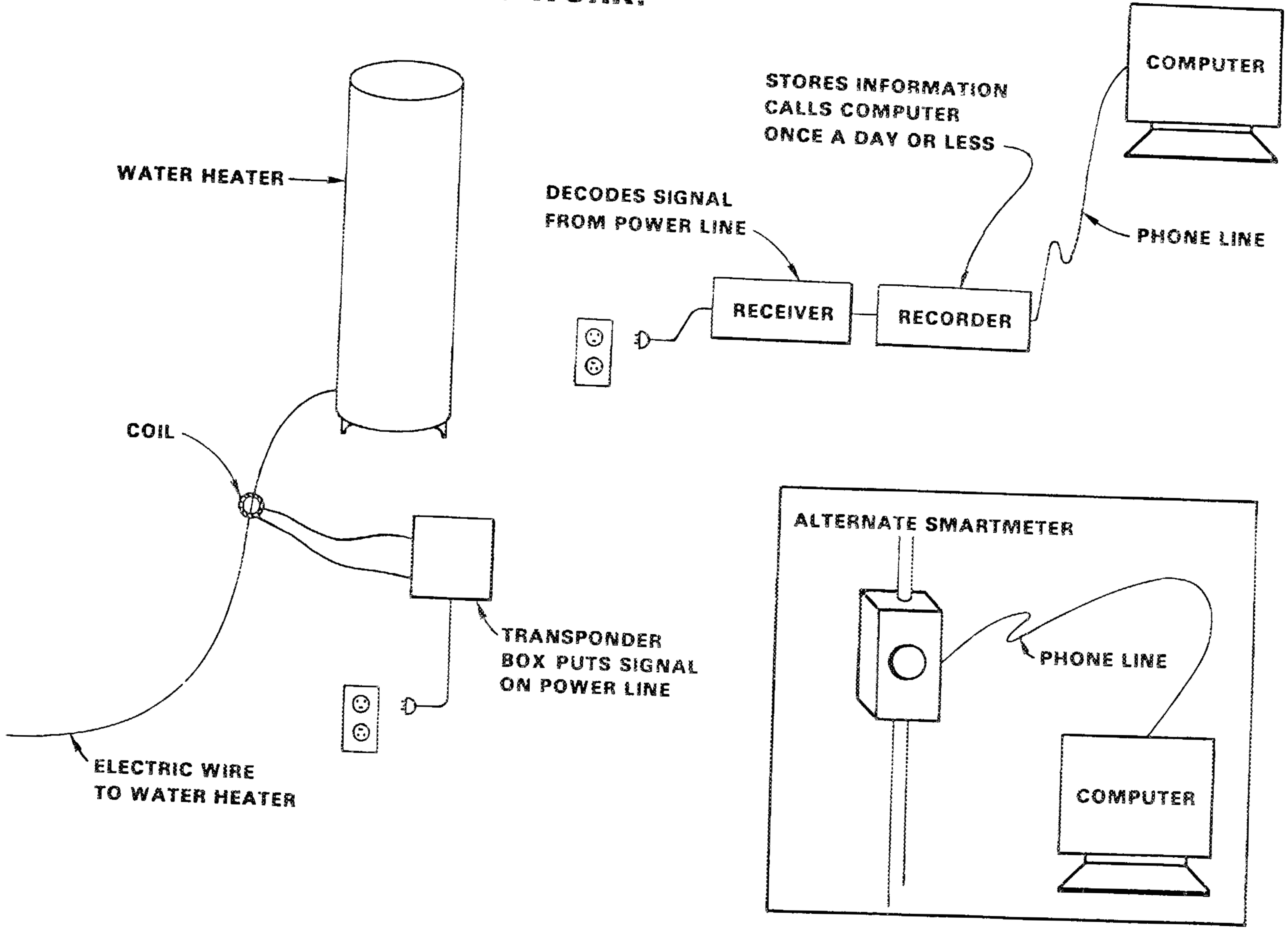
OVERVIEW OF THE PRESENTATION

- THE LOAD CONTROL SYSTEM

HOW DOES THE SYSTEM WORK?



HOW DOES MONITORING WORK?

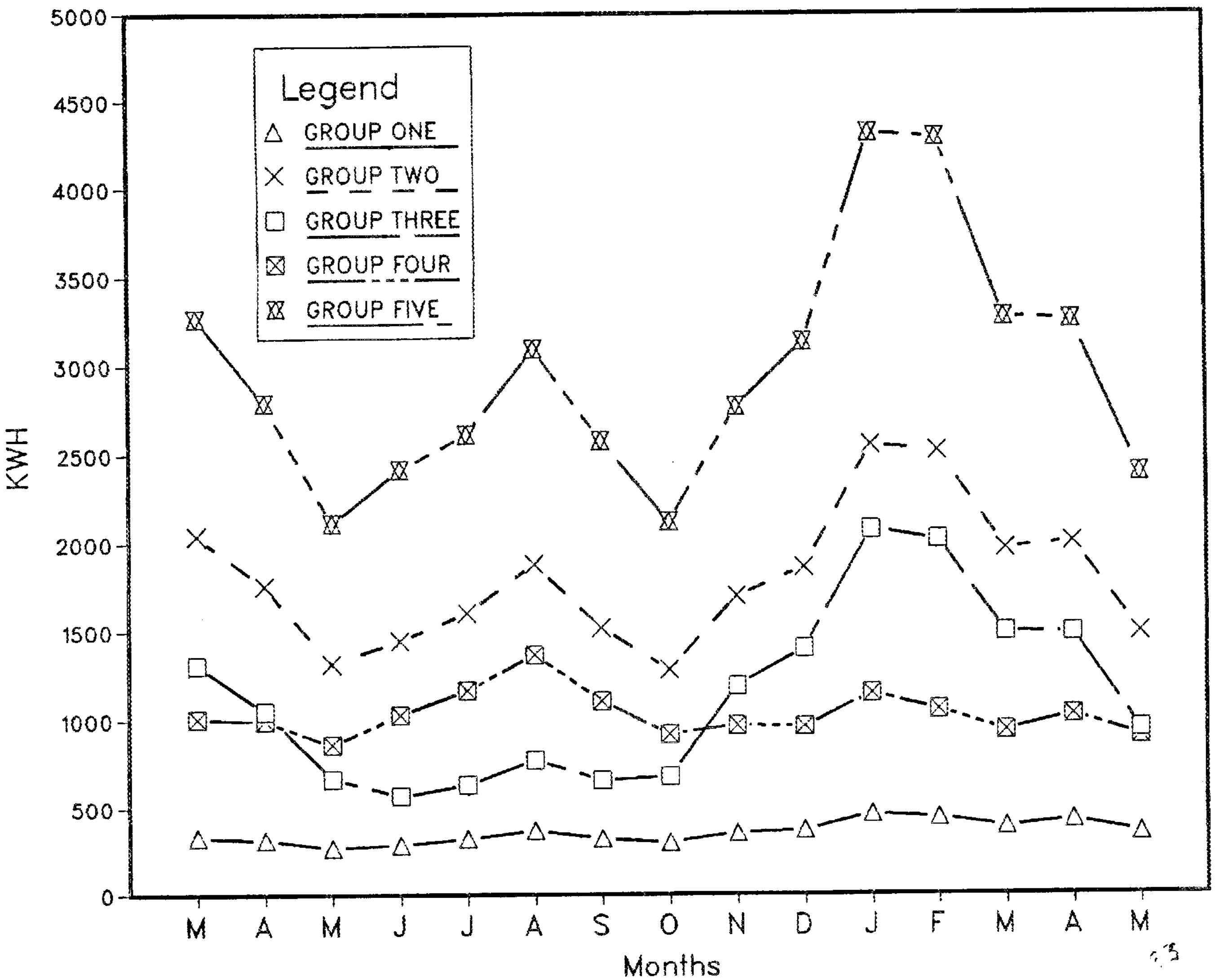


OVERVIEW OF THE PRESENTATION

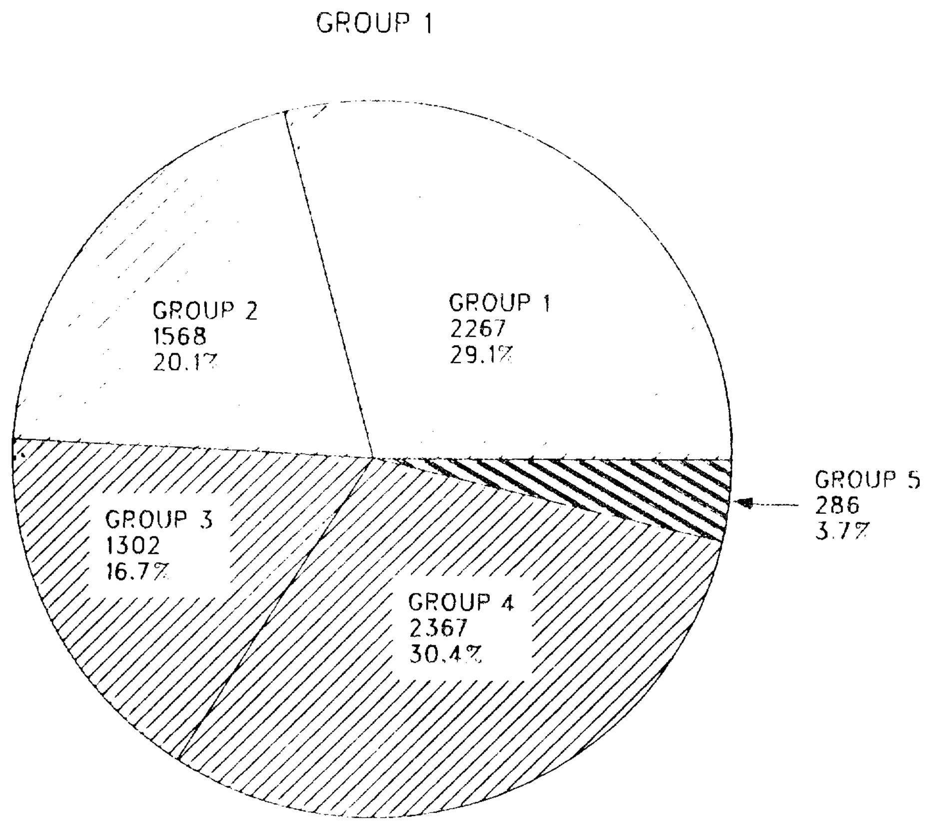
- THE LOAD CONTROL SYSTEM
- CUSTOMER ISSUES
  - SELECTION
  - RECRUITMENT
  - ASSIGNMENT TO CONTROL GROUPS

HOW ARE CUSTOMERS SELECTED?

Average Monthly Consumption Patterns for
Five Groups of Athens Customers.



NUMBER OF HOUSEHOLDS IN EACH CATEGORY

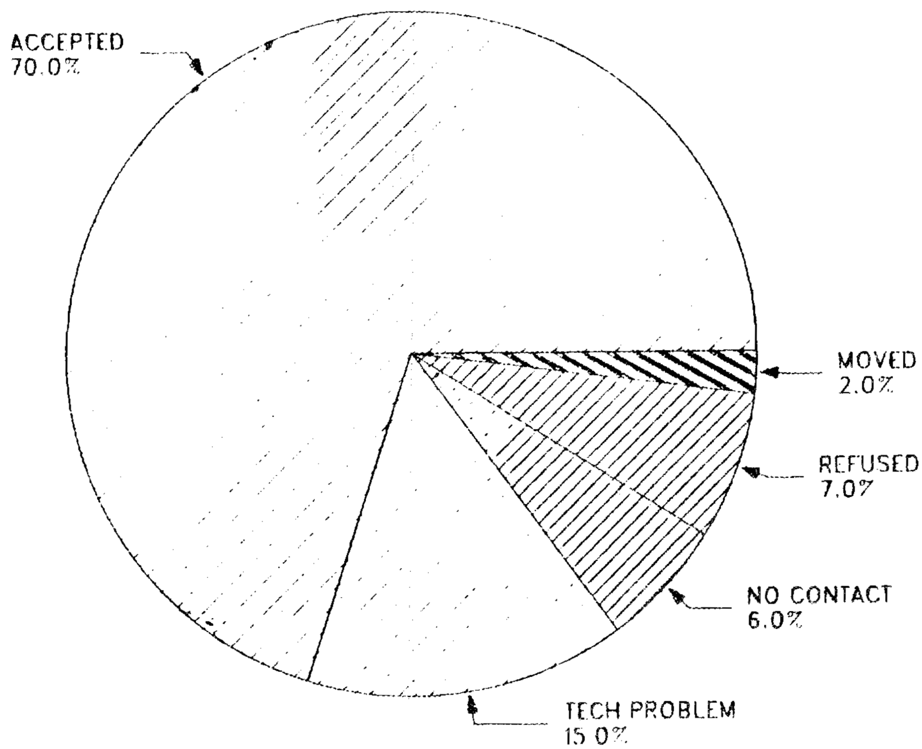


HOW ARE CUSTOMERS RECRUITED?

MARKETING IS THE KEY

- CREATING PUBLIC AWARENESS
- MAKE PERSONAL CONTACT
- PROVIDE CUSTOMER WITH INFORMATION
- MINIMIZE OBSTACLES TO CUSTOMER PARTICIPATION

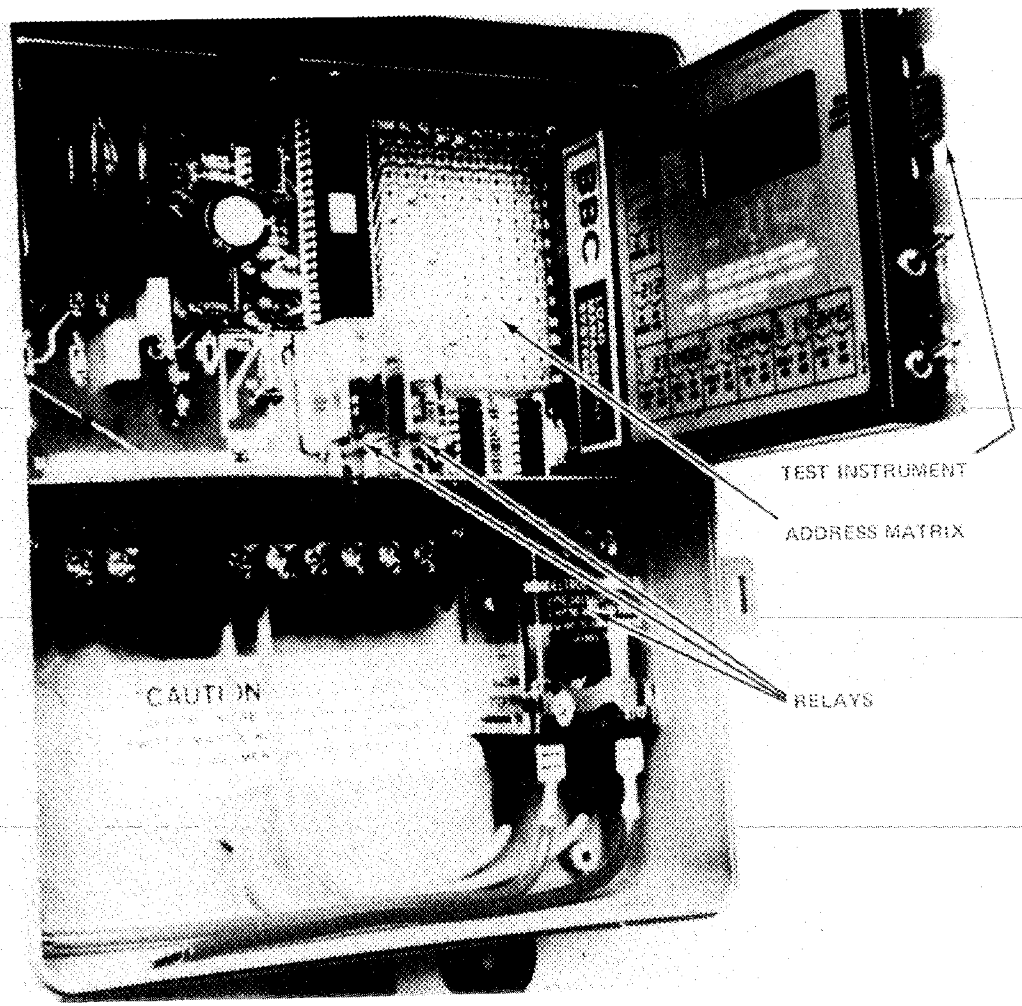
INITIAL RESULTS FROM CUSTOMER RECRUITMENT FOR RECRUITMENT ONLY



HOW ARE CUSTOMERS ASSIGNED TO CONTROL GROUPS?

ORNL PHOTO 2396-84R

BBC LOAD CONTROL RECEIVER



CONTROL APPLIANCES BY:

- FEEDER
- FEEDER SECTION
- APPLIANCE GROUPS

12 APPLIANCE CONTROL GROUPS

- THREE WATER HEATER
- TWO CENTRAL ELECTRIC HEAT
- TWO HEAT PUMP
- TWO AIR CONDITIONER
- THREE COMMERCIAL

WATER HEATER CONTROL GROUPS ARE DEFINED BY USAGE

- FAMILY SIZE
- CLOTHES WASHER
- DISHWASHER
- BATHROOMS

SPACE CONDITIONING CONTROL GROUPS ARE DEFINED BY SIZING RATIO

SIZING RATIO IS THE APPLIANCE BTU RATING DIVIDED BY THE BTU'S REQUIRED TO MAINTAIN TEMPERATURE IN A SPECIFIC HOUSEHOLD AT SEVERE HEAT OR COLD

WHY USE SIZING RATIO TO DEFINE CONTROL GROUPS?

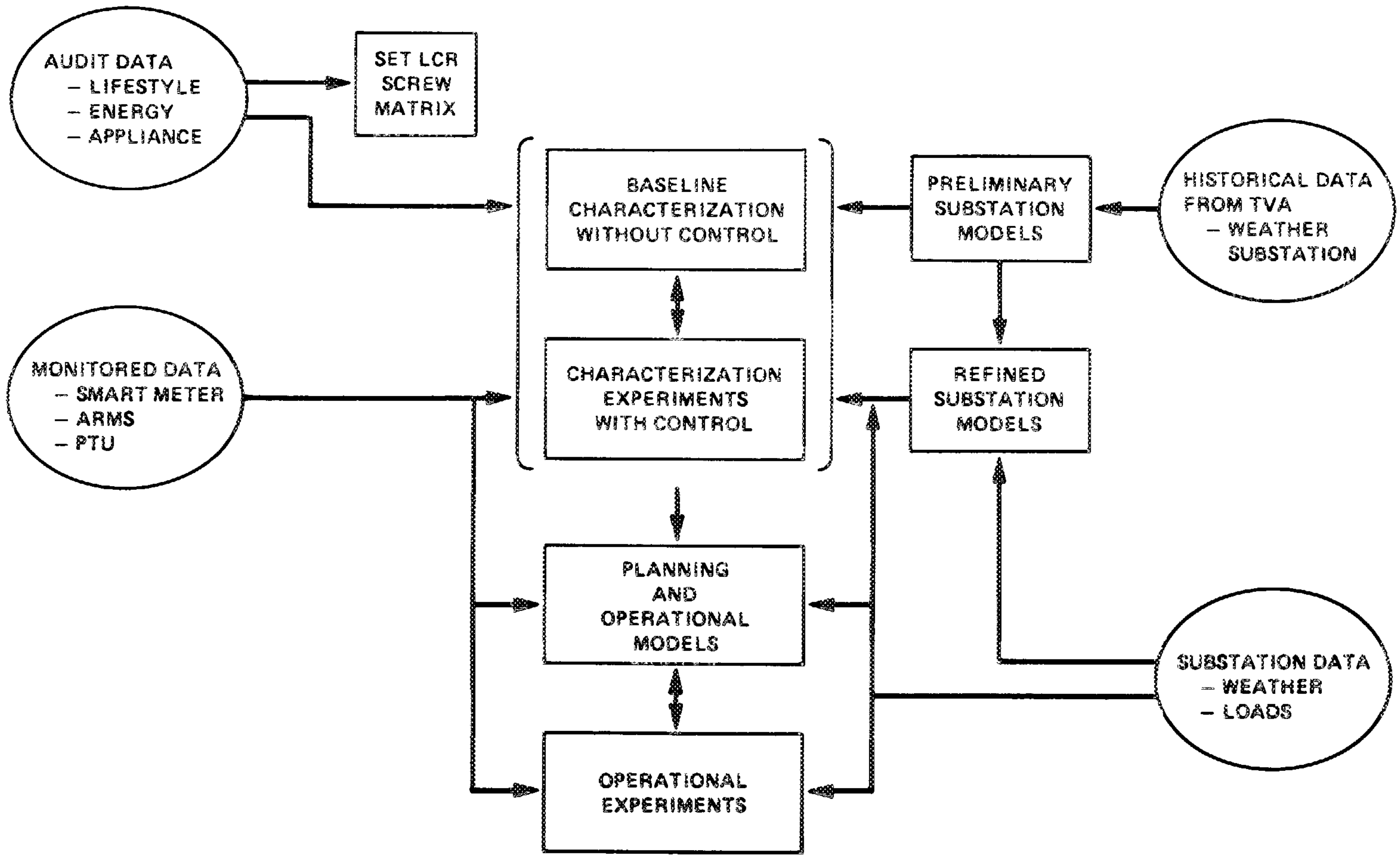
- IT PERMITS DIFFERENT CONTROL STRATEGIES FOR DIFFERENT GROUPS
- IT SHOULD REDUCE OVER OR UNDER CONTROLLING OF INDIVIDUAL APPLIANCES
- IT WILL INCREASE THE IMPACT OF CONTROL ACTIONS
- IT WILL HELP TO DEFINE INSTRUMENTATION NEEDS OF THE FUTURE

OVERVIEW OF THE PRESENTATION

- THE LOAD CONTROL SYSTEM
- CUSTOMER ISSUES
  - SELECTION
  - RECRUITMENT
  - ASSIGNMENT TO CONTROL GROUPS
- THE DATA

ORNL–DWG 84-17909

DATA FLOWS FOR LOAD CONTROL PORTION OF THE ATHENS AUTOMATION AND CONTROL EXPERIMENT

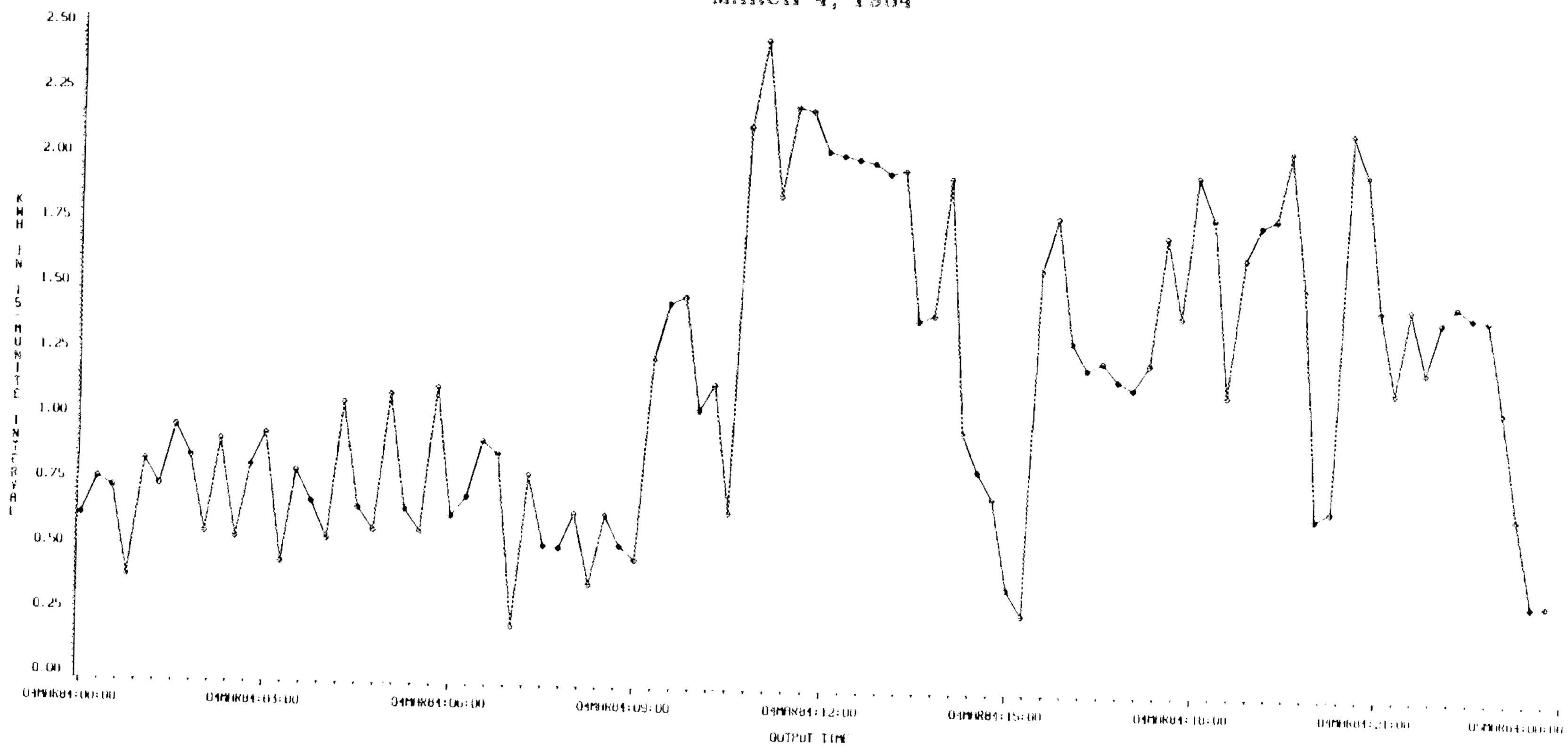


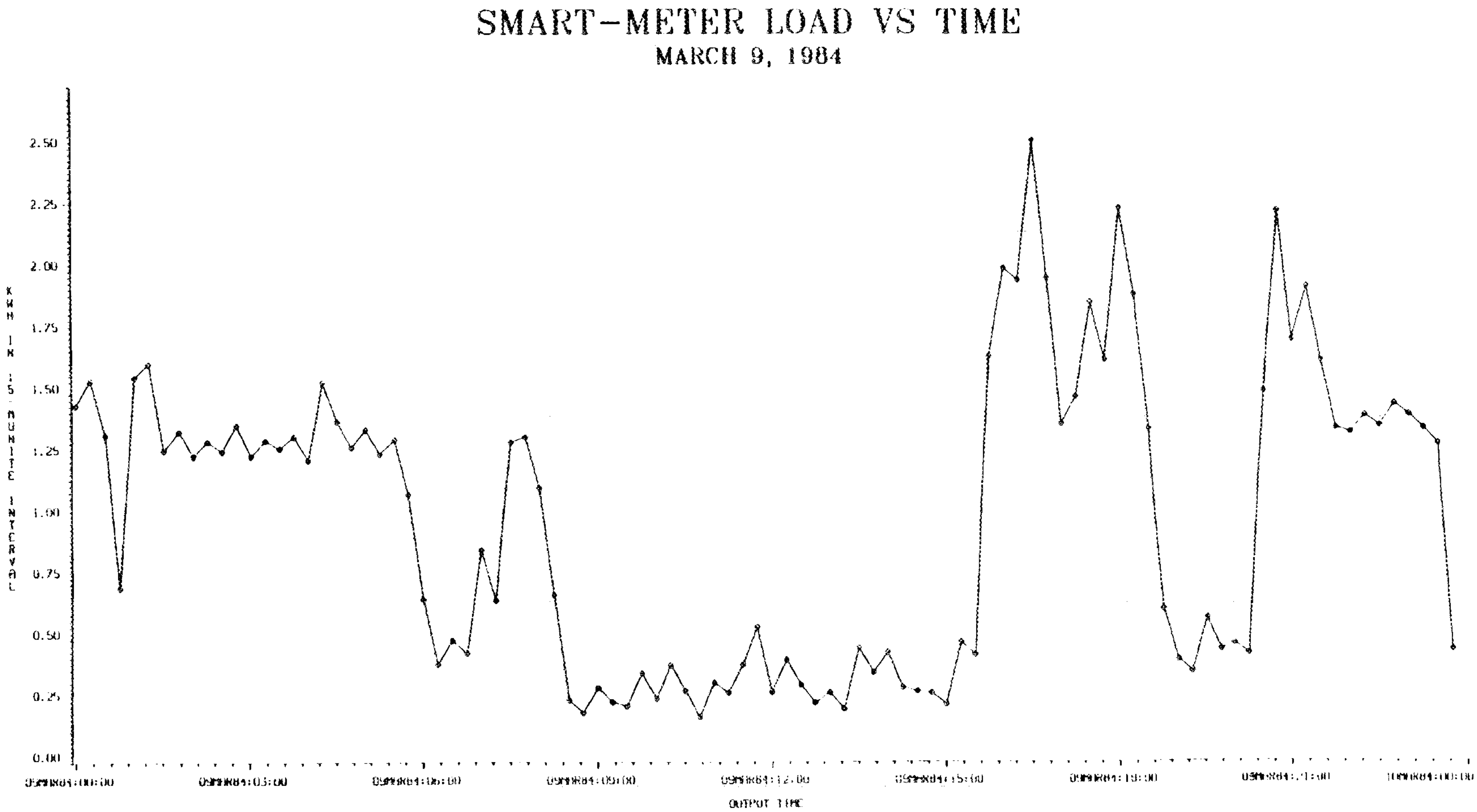
WHAT ARE THE MONITORING DATABASES?

- SMARTMETERS
  - 15 MINUTE DATA
  - 200 HOUSEHOLDS
  - COLLECTED IN "REAL TIME"
- ARMS
  - 1 MINUTE DATA
  - 1 - 4 APPLIANCES
  - 40 HOMES WITH TEMPERATURE PROBES
  - 200 HOMES COLLECTED DAILY
- PTU
  - REPORT BY EXCEPTION OR POLLED
  - P, V, Q
  - 50 + POINTS ON SYSTEM
- RTU
  - SCAN EVERY 20 SECONDS
  - EVERY FEEDER
  - P, V, Q
  - WEATHER DATA

SMART-METER LOAD VS TIME

MARCH 4, 1984

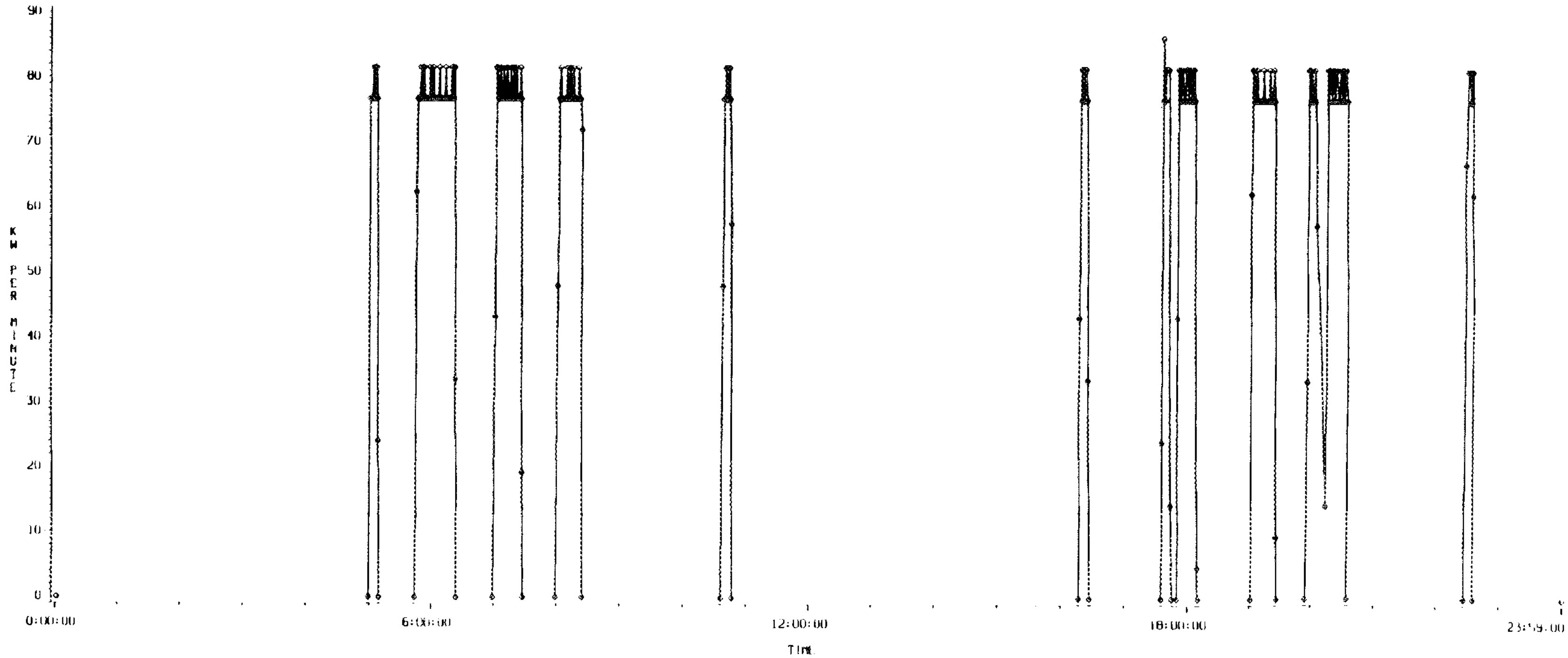




SMART-METER LOAD VS TIME
MARCH 9, 1984
KWH IN 15-MINUTE INTERVAL
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
09MAR84:03:00
OUTPUT TIME

WATER HEATER DATA FROM A ROBINTON ARM DEVICE

ATHENS, TENNESSEE
OCTOBER 29, 1984



WHO WILL BE AUDITED?

ALL 2,000 HOUSEHOLDS WHICH RECEIVE MONITORING AND CONTROL EQUIPMENT

CASE 13
THE APPLIANCE AUDIT SHOWS THIS CUSTOMER HAS:

- 3 ELECTRIC STACK HEATERS
- ROOM AIR CONDITIONERS
- WRAPPED 30 GALLON ELECTRIC WATER HEATER

CASE 13
THE ENERGY EFFICIENCY AUDIT SHOWS:

- THIS IS A DETACHED SINGLE FAMILY DWELLING
- THERE ARE:
  - 6 INCHES OF CEILING INSULATION
  - 3 INCHES OF WALL INSULATION
  - 6 INCHES OF FLOOR INSULATION
- THERE ARE:
  - 9 WINDOWS WITH STORMS
  - 2 DOORS WITH NO STORMS
- THE HOUSE HAS 1555 SQ. FT. AND FACES EAST

CASE 13
THE LIFESTYLE AUDIT SHOWS THAT THE PEOPLE IN THIS HOUSEHOLD:

- OWN THE HOME
- HAVE AN ELECTRIC STOVE, OVEN, DRYER FREEZER, WATER PUMP, CEILING FANS, AND ELECTRIC BATHROOM HEATERS
- SOMETIMES RUN WINDOW AIR CONDITIONERS FROM 3 TO 7 IN THE AFTERNOON
- HAVE NOT EXPERIENCED RUNNING OUT OF HOT WATER IN THE LAST 3 MONTHS
- ARE THREE IN NUMBER, 2 OF WHOM WORK, NO PERSONS ARE HOME DURING THE DAY

THE DATA ARE BEING ORGANIZED INTO DATABASES

- TO COPE WITH THE VAST QUANTITY OF DATA
- TO MAKE THE DATA EASILY ACCESSIBLE
- TO FACILITATE ANALYSIS
- TO PRESERVE DATA SO THAT NEW QUESTIONS CAN BE ANSWERED AS THEY ARISE
- TO PROVIDE A TOOL TO HELP CONVEY RESULTS

OVERVIEW OF THE PRESENTATION

- THE LOAD CONTROL SYSTEM
- CUSTOMER ISSUES
  - SELECTION
  - RECRUITMENT
  - ASSIGNMENT TO CONTROL GROUPS
- THE DATA
- ANALYSIS OF SUBSTATION LOADS

OVERVIEW OF THE PRESENTATION

- THE LOAD CONTROL SYSTEM
- CUSTOMER ISSUES
  - SELECTION
  - RECRUITMENT
  - ASSIGNMENT TO CONTROL GROUPS
- THE DATA
- ANALYSIS OF SUBSTATION LOADS
- THE EXPERIMENTS
  - TYPES
  - ANALYSIS

LOAD CONTROL TASKS

1. CHARACTERIZE LOAD BEHAVIOR
2. DETERMINE APPLIANCE LOAD REDUCTION DUE TO CONTROL
3. DETERMINE AGGREGATE LOAD REDUCTION DUE TO CONTROL
4. DETERMINE LOAD CHANGES FOLLOWING CONTROL

LOAD CONTROL TASKS CONTINUED

5. DETERMINE IMPACTS OF LOAD CONTROL ON SYSTEM OPERATIONS
6. DETERMINE RELIABILITY OF LOAD CONTROL AND EFFECTIVE LEVELS OF INSTRUMENTATION
7. DETERMINE CUSTOMER RESPONSE TO LOAD CONTROL

CONTROL STRATEGY PHILOSOPHY

- DEVELOP CONTROLLED AND UNCONTROLLED LOAD DATABASE
- MAINTAIN ACCEPTABLE CUSTOMER COMFORT LEVELS
- DISTRIBUTE CUSTOMER IMPACTS EQUITABLY
- APPLY CONTROL STRATEGIES APPROPRIATE TO KNOWN LOAD AND CUSTOMER CHARACTERISTICS

CONTROL STRATEGY PHILOSOPHY CONTINUED

- CONTROL LOAD AT PEAK AND OFF-PEAK TIMES
- RELEASE LOAD GRADUALLY TO AVOID EXTREME LOAD CHANGES
- MAINTAIN ELECTRIC SYSTEM INTEGRITY

PHASE 1 -- LOAD CONTROL TASKS

1. CHARACTERIZE LOAD BEHAVIOR
2. DETERMINE APPLIANCE LOAD REDUCTION DUE TO CONTROL
3. DETERMINE AGGREGATE LOAD REDUCTION DUE TO CONTROL
4. DETERMINE LOAD CHANGES FOLLOWING CONTROL
7. DETERMINE CUSTOMER RESPONSE TO CONTROL

EXPERIMENTAL METHODS

- PERFORM LOAD CHARACTERIZATION
  DATA COLLECTION
- PERFORM 'NICKING' TESTS --
  BRIEF LOAD REDUCTION AND RESTORATION
- PERFORM SUSTAINED LOAD CONTROL TESTS --
  DISABLING OR CYCLING APPLIANCES
  FOR EXTENDED TIME PERIODS

LOAD CHARACTERIZATION DATA

- COLLECT LOAD CHARACTERIZATION DATA ON ALL DAY TYPES
- MONITOR ALL CONTROLLABLE APPLIANCE TYPES
- RECORD DATA FROM EACH MONITORED LEVEL OF THE SYSTEM
- BUILD LOAD CHARACTERIZATION DATABASE

USE THE LOAD CHARACTERIZATION DATABASE

- TO DETERMINE LOAD CYCLING DATA FOR USE IN DESIGNING CONTROL STRATEGIES
- TO CONSTRUCT DIVERSIFIED LOAD PROFILES FOR EACH MONITORED LEVEL
- AS INPUT DATA FOR THE LOAD PREDICTION SOFTWARE
- AS A REFERENCE TO CALCULATE LATER CONTROL EFFECTS

NICKING TESTS

- CONTROL SIMULTANEOUSLY BY APPLIANCE TYPE RELEASE LOAD CONTROL AFTER 5 MINUTES
- STAGGER START TIME FOR EACH APPLIANCE TYPE
- CONDUCT TESTS HOURLY ON ALL DAY TYPES
- RECORD DATA AT EACH MONITORED LEVEL
- CONSTRUCT NICKING TEST DATABASE

USE NICKING TEST RESULTS

- TO CALCULATE DIVERSIFIED LOAD PROFILES FOR EACH APPLIANCE AT EACH MONITORED LEVEL OF THE SYSTEM
- AS A FIRST ESTIMATE OF THE LOAD AVAILABLE
- FOR COMPARISON WITH DIVERSIFIED APPLIANCE LOAD PROFILES OBTAINED FROM RECORDED LOAD CHARACTERIZATION DATA

ORNL-DWG 84C-17961

NICKING TEST SCHEDULE

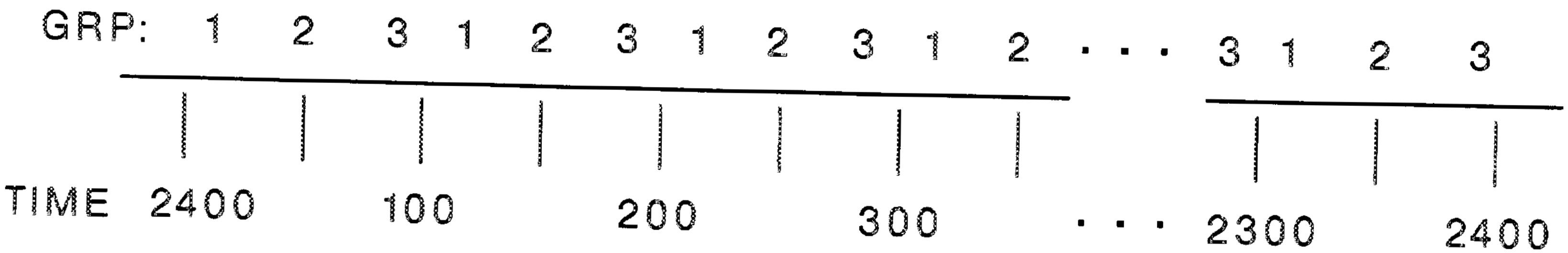
MAY - SEPTEMBER

GROUP	APPLIANCE
1	WATER HEATERS
2	AIR CONDITIONERS
3	NONE

OCTOBER - APRIL

GROUP	APPLIANCE
1	WATER HEATERS
2	RESISTIVE HEAT SYSTEMS
3	HEAT PUMPS

DISABLE ALL APPLIANCES IN EACH LOAD GROUP
AT THE INDICATED TIMES



SUSTAINED CONTROL TESTS

- IMPLEMENT ON ALL DAY TYPES
- ON SEPARATE DAYS, USE LOAD DIVERSITY GROUPS OR CONTROL ALL LOADS OF EACH TYPE SIMULTANEOUSLY
- APPLY CONTROL STRATEGIES SEPARATELY AND IN SEQUENCE
- RECORD EFFECTS AND BUILD SUSTAINED LOAD CONTROL DATABASE

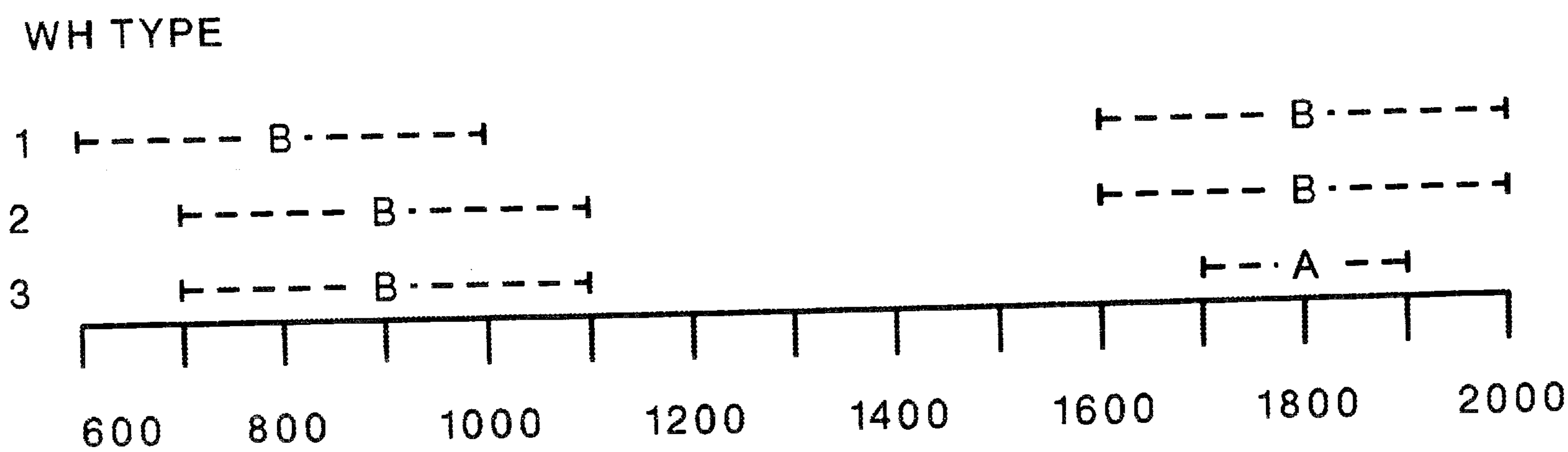
USE SUSTAINED CONTROL TEST RESULTS

- TO COMPARE LOAD RESPONSE TO CONTROL AT EACH MONITORED LEVEL OF THE SYSTEM
- TO MEASURE AND CALCULATE LOAD RESPONSE TO VARIATIONS IN CONTROL STRATEGY PARAMETERS
- TO DETERMINE ENERGY CHANGES DURING CONTROL
- TO DETERMINE LOAD CHANGES FOLLOWING CONTROL

ORNL-DWG 84C-17960

WATER HEATER CONTROL STRATEGIES
WINTER

PEAK DAY - 14 HOUR DURATION



ASSESSMENT OF LOAD CONTROL EFFECTS

- DAILY - OPERATOR REVIEW OF CONTROL EFFECTS
  MODIFICATION OF CONTROL STRATEGY
  AS REQUIRED
- SEASONAL - PRELIMINARY ANALYSIS OF RESULTS
  DEVELOPMENT OF IMPROVED STRATEGIES
- ANNUAL - INTENSIVE DATA ANALYSIS

PHASE 2 -- LOAD CONTROL TASKS

5. DETERMINE IMPACTS OF LOAD CONTROL ON SYSTEM OPERATION
6. DETERMINE RELIABILITY AND EFFECTIVE LEVELS OF INSTRUMENTATION FOR LOAD CONTROL
7. DETERMINE CUSTOMER RESPONSE TO LOAD CONTROL

EXPERIMENTAL METHODS FOR SYSTEM OPERATION

- DETERMINE LOAD CHARACTERISTICS AND LOAD CONTROL IMPACTS AS DESCRIBED ABOVE
- CONSTRUCT COORDINATED CONTROL STRATEGIES DESIGNED TO ACHIEVE SPECIFIC SYSTEM OBJECTIVES
- IMPLEMENT CONTROL AND ASSESS SYSTEM EFFECTS

EXPERIMENTAL METHODS FOR RELIABILITY

- MONITOR OPERATION OF THE LOAD CONTROL SUBSYSTEM
- CLASSIFY FAILURES AS HARDWARE, SOFTWARE, OR COMMUNICATION SYSTEM PROBLEMS
- CALCULATE LOAD CONTROL SYSTEM AND SUBSYSTEM RELIABILITY AND AVAILABILITY THROUGHOUT THE EXPERIMENT

EXPERIMENTAL METHODS FOR INSTRUMENTATION

- ANALYZE EFFECTIVE INSTRUMENTATION REQUIREMENTS BASED ON OBSERVED DATA
- COMPARE POTENTIAL RESULTS USING SUBSETS OF THE AVAILABLE RECORDED DATA
- DETERMINE ACCURACY AND COST USING EACH SUBSET
- DETERMINE THE MINIMUM EFFECTIVE LEVEL OF INSTRUMENTATION FOR LOAD CONTROL

ASSESSMENT OF LOAD CONTROL EFFECTS

- DAILY - OPERATOR REVIEW OF CONTROL EFFECTS
  MODIFICATION OF CONTROL STRATEGY
  AS REQUIRED
- SEASONAL - PRELIMINARY ANALYSIS OF RESULTS
  DEVELOPMENT OF IMPROVED STRATEGIES
- ANNUAL - INTENSIVE DATA ANALYSIS

LOAD CONTROL DATA ANALYSIS

- DATA CHECKING AND EDITING
- COMPACTION AND STORAGE OF DATA
- CONSTRUCTION OF DATABASES
- ANALYSIS
- EXPLANATORY MODEL CONSTRUCTION

SUMMARY OF THE LOAD CONTROL TASKS

1. CHARACTERIZE LOAD BEHAVIOR
2. DETERMINE APPLIANCE LOAD REDUCTION DUE TO CONTROL
3. DETERMINE AGGREGATE LOAD REDUCTION DUE TO CONTROL
4. DETERMINE LOAD CHANGES FOLLOWING CONTROL

SUMMARY OF LOAD CONTROL TASKS CONTINUED

5. DETERMINE IMPACTS OF LOAD CONTROL ON SYSTEM OPERATIONS
6. DETERMINE RELIABILITY AND EFFECTIVE LEVEL OF INSTRUMENTATION
7. DETERMINE CUSTOMER RESPONSE TO LOAD CONTROL

OVERVIEW OF THE PRESENTATION

- THE LOAD CONTROL SYSTEM
- CUSTOMER ISSUES
  - SELECTION
  - RECRUITMENT
  - ASSIGNMENT TO CONTROL GROUPS
- THE DATA
- ANALYSIS OF SUBSTATION LOADS
- THE EXPERIMENTS
  - TYPES
  - ANALYSIS

STATISTICAL MODELS FOR FORECASTING SUBSTATION LOADS

The objectives of this study were to study the behavior of substation loads, to provide tools for determining when to implement load control actions, and to provide input to the operational load control models. The hourly substation load data used in this study were collected by the Tennessee Valley Authority (TVA) from June 1980 through November 1983. The hourly weather data were also collected by TVA at the Tennessee Watts Bar area.

Two statistical models for forecasting substation loads were developed by using a least-squares regression analysis technique. One model was constructed under the theory that the current hourly load can be predicted as a function of previous hourly loads. Hourly loads 1 to 2 h old, as well as those 24 and 25 h old, were all statistically significant in forecasting the current hourly load. The R^2 of this model was 0.984. The other model, considerably more complex, defined the current load as a function of not only previous loads, but also of weather variables and seasonal influences. This model had an R^2 of 0.98. Both models were checked for autocorrelation in the error terms. None of them was statistically significant. Superimposing the actual loads over the estimated ones made it obvious that both models gave equally powerful and accurate estimates of the "real-time" control and load management. Given that, the straightforward lagged-load model was preferable and recommended.

STATISTICAL MODELS FOR FORECASTING SUBSTATION LOADS

PATRICIA HU
ENERGY DIVISION
OAK RIDGE NATIONAL LABORATORY

DECEMBER 5, 1984

OBJECTIVES OF THE STUDY ARE TO:

- UNDERSTAND THE NATURE OF SUBSTATION LOADS,
- PROVIDE TOOLS FOR DETERMINING WHEN TO IMPLEMENT LOAD CONTROL ACTIONS,
- PROVIDE INPUT TO THE OPERATIONAL LOAD CONTROL MODELS.

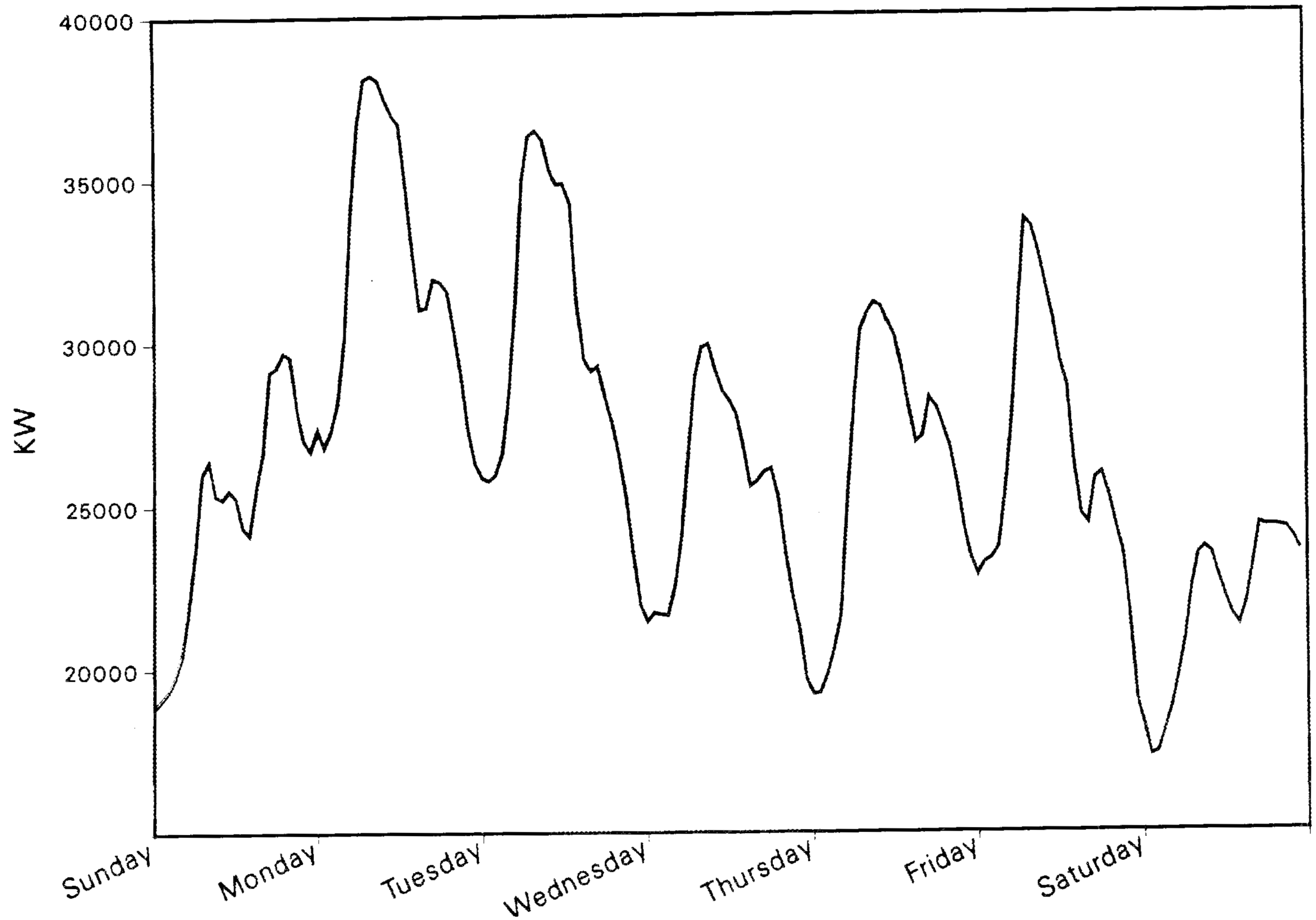
TWO DATA BASES WERE USED:

- HOURLY SUBSTATION LOADS, AND
- HOURLY WEATHER DATA.

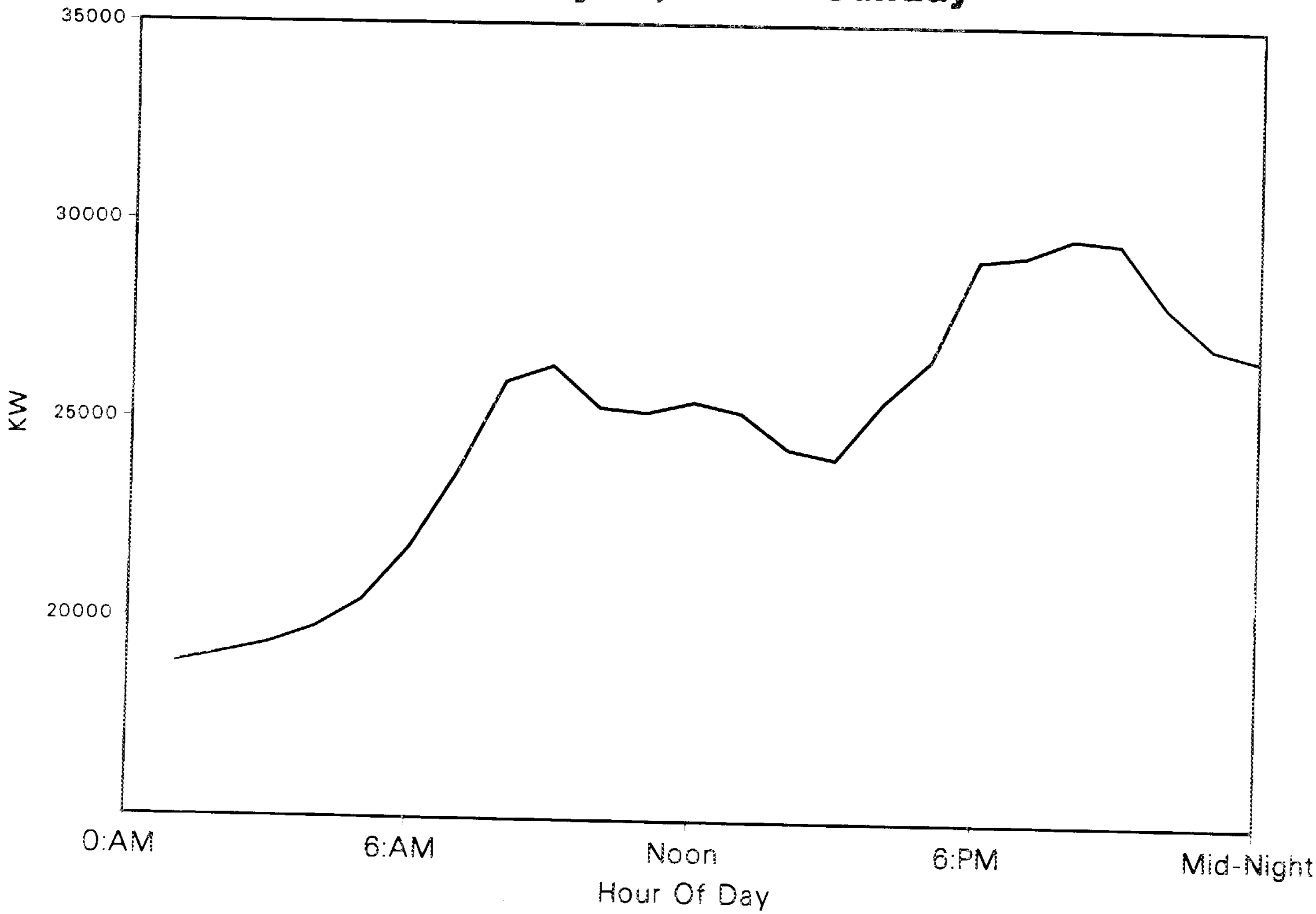
SUBSTATION LOADS DATA BASE:

- HISTORICAL HOURLY SUBSTATION LOADS DATA COLLECTED BY TVA ,
- COVERED THE PERIOD BETWEEN JUNE 1980 AND NOVEMBER 1983,
- INCLUDED 3 OF THE ATHENS SUBSTATIONS.

ACTUAL SUBSTATION LOADS
North Athens
January 10 - 16, 1982



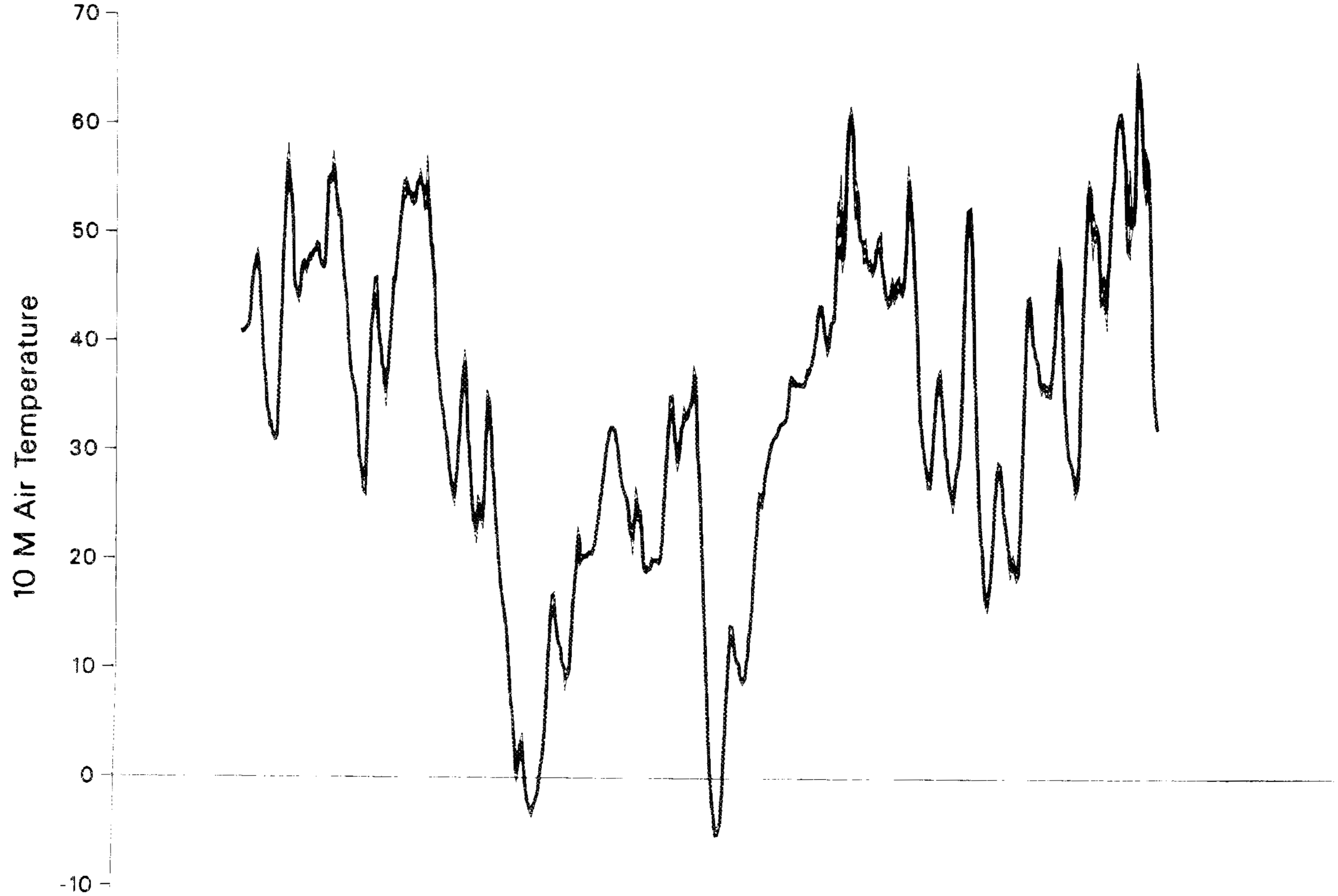
ACTUAL SUBSTATION LOAD
North Athens
January 10, 1982 - Sunday



WEATHER DATA BASE:

- COLLECTED BY TVA AT WATTS BAR AREA,
- COVERED THE PERIOD BETWEEN JANUARY 1980 AND MARCH 1984,
- INCLUDED HOURLY WEATHER VARIABLES, SUCH AS AIR TEMPERATURE, WIND DIRECTION AND SPEED, DEW POINT, SOLAR RADIATION AND RAINFALL.

HOURLY AIR TEMPERATURE
Watts Bar Area
January 1982



TWO MODELS WERE DEVELOPED:

- ONE WAS BASED ON PREVIOUS HOURLY LOADS ONLY.
- ONE WAS BASED ON PREVIOUS HOURLY LOADS PLUS WEATHER AND SEASONAL VARIABLES.

LAGGED-LOAD REGRESSION MODEL
North Athens Substation

Hourly Load = 500.21

+1.35*(Load:1 Hour Ago)

-0.38*(Load:2 Hour Ago)

-0.45*(Load:25 Hour Ago)

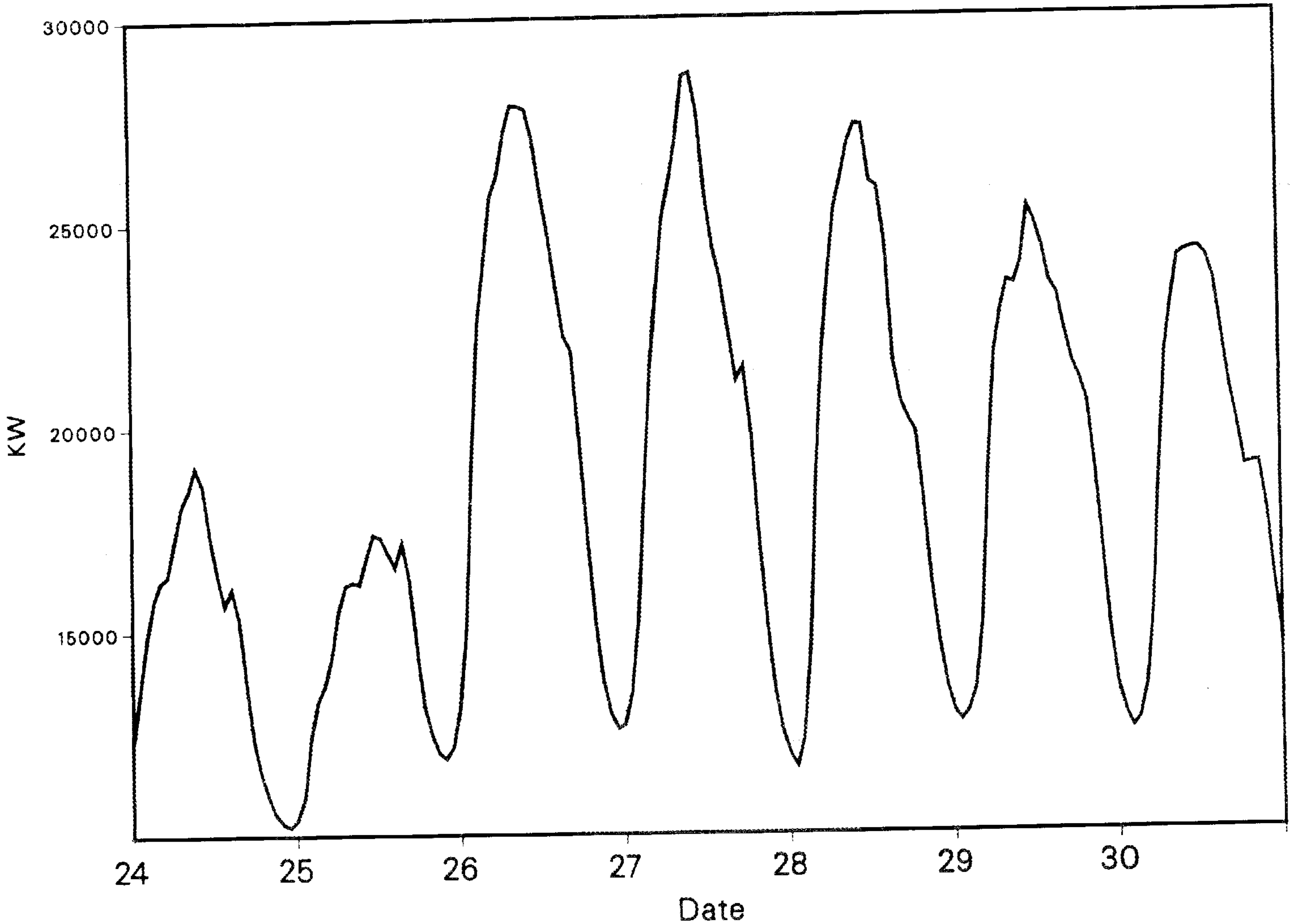
+0.32*(Load:24 Hour Ago)

+0.14*(Load:23 Hour Ago)

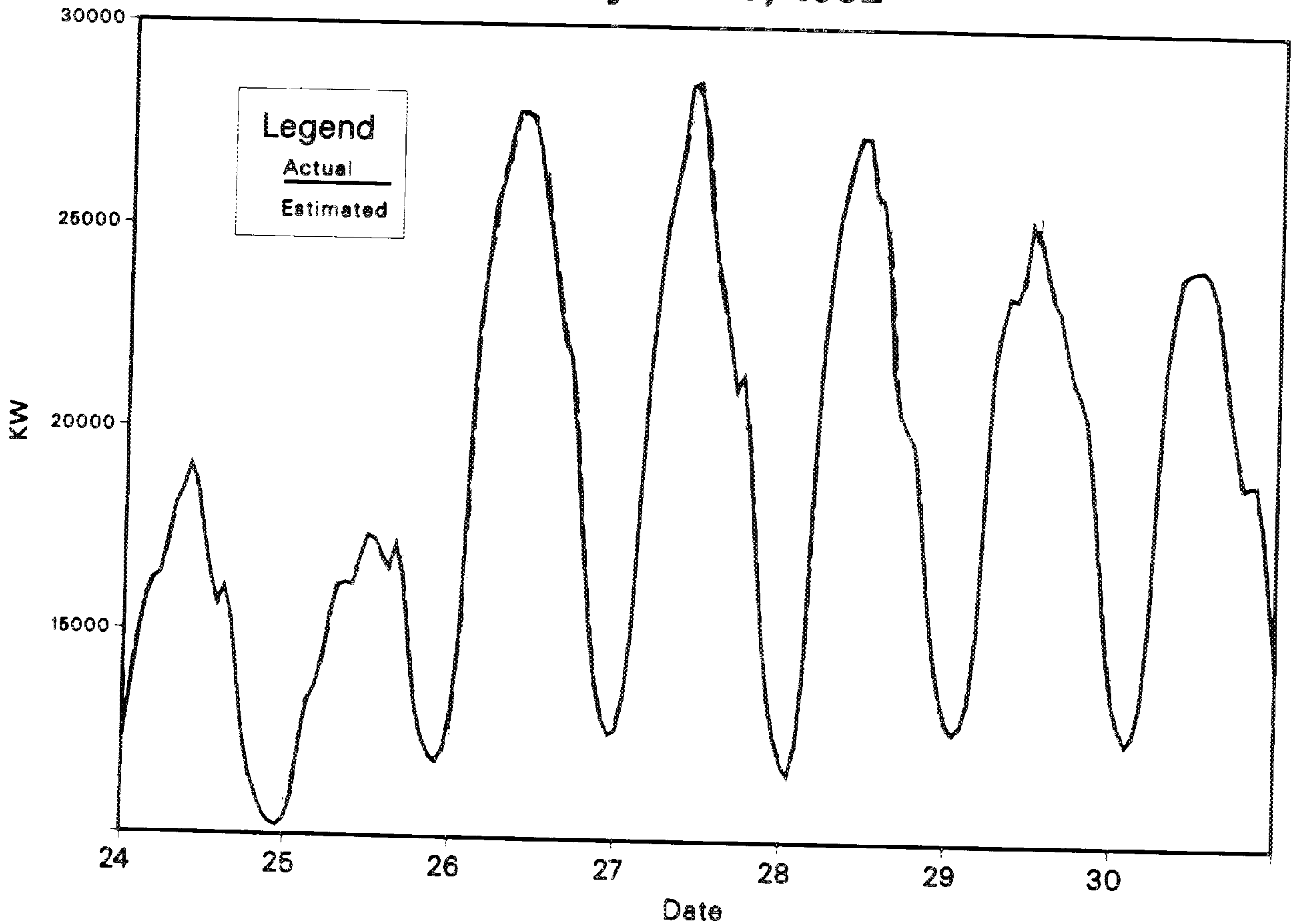
R-Square = 0.984

Durbin-Watson D = 1.753

ACTUAL SUBSTATION LOADS
North Athens
July 24-30, 1982



ACTUAL VS. ESTIMATED SUBSTATION LOADS
North Athens
July 24-30, 1982



LAGGED-LOAD-PLUS-WEATHER REGRESSION MODEL

North Athens

Hourly Load = 2356.26

+ 1.47 * (Load:1-Hour Ago)

- 0.59 * (Load:2-Hour Ago)

- 739.7 * (2nd Hourly Cycle)

+ 57.32 * (Cooling Degree Days)

+ 657.6 * (Tuesday Index)

+ 23.7 * (Heating Degree Days)

LAGGED-LOAD-PLUS-WEATHER REGRESSION MODEL

North Athens

(Cont'd)

+ 590.3 * (Monday Index)

+ 566.5 * (Thursday Index)

+ 572.3 * (Wednesday Index)

+ 474.0 * (Friday Index)

+ 238.2 * (1st Hourly Cycle)

- 224.1 * (2nd Seasonal Cycle)

- 158.5 * (Sunday Index)

LAGGED-LOAD-PLUS-WEATHER REGRESSION MODEL

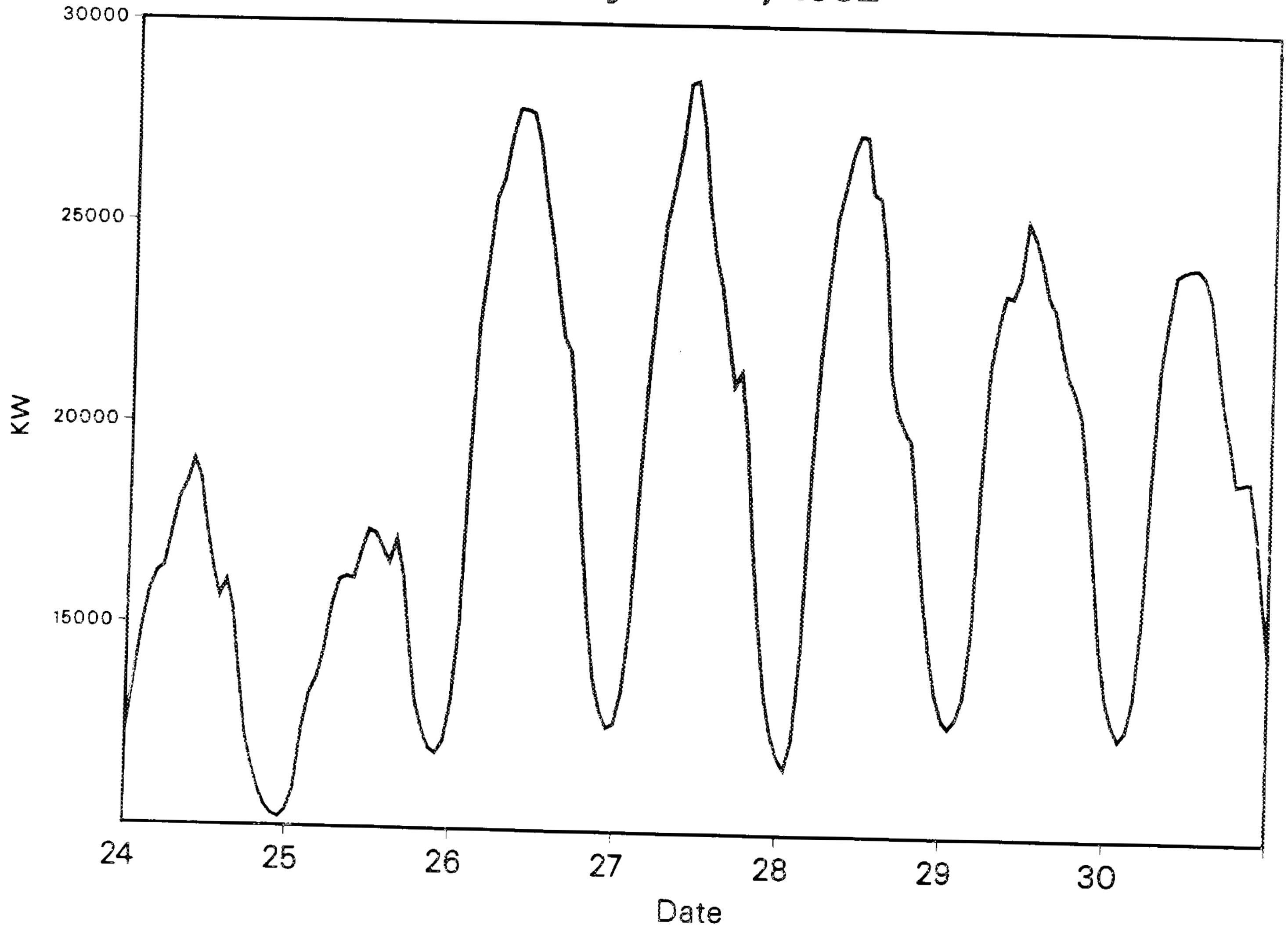
North Athens

(Cont'd)

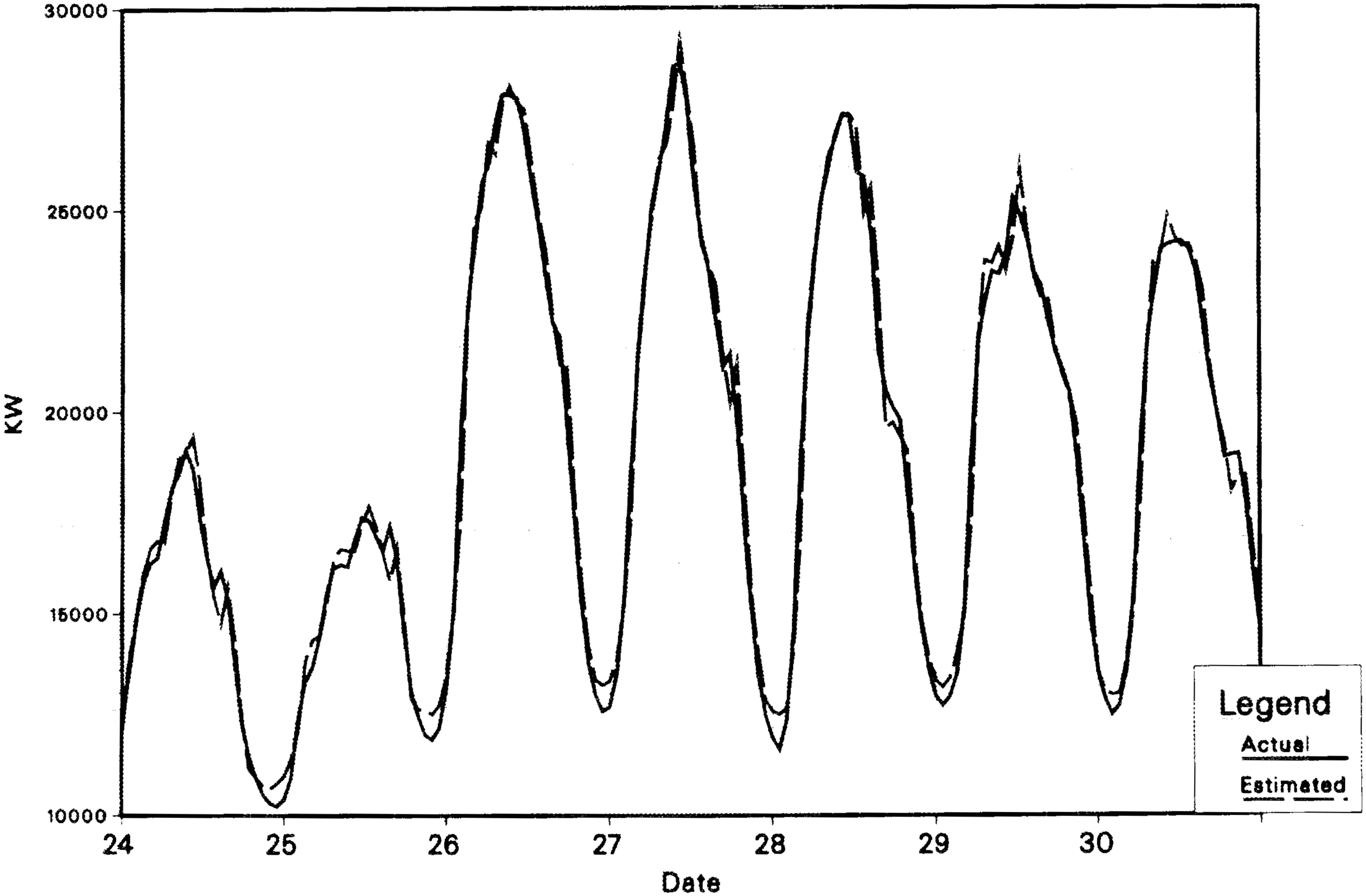
R-Square = 0.98

Durbin-Watson = 1.77

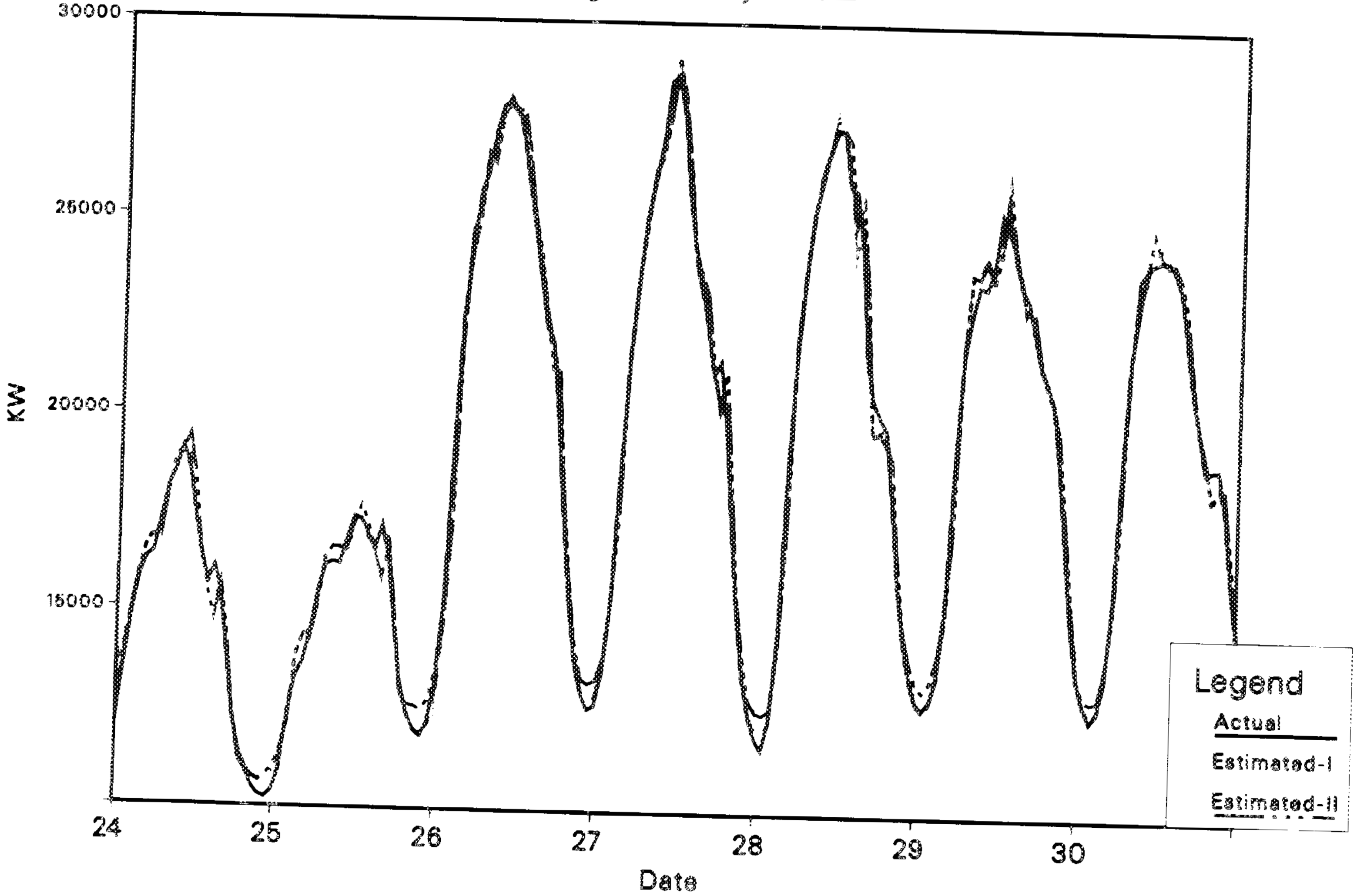
ACTUAL SUBSTATION LOADS
North Athens
July 24-30, 1982



ACTUAL VS. ESTIMATED SUBSTATION LOADS
North Athens
July 24-30, 1982



ACTUAL VS. ESTIMATED SUBSTATION LOADS
North Athens
July 24-30, 1982



CONCLUSION:

A STRAIGHTFOWARD LAGGED-LOAD MODEL GIVES ACCURATE FORECASTS OF HOURLY SUBSTATION LOADS THAT CAN BE USED TO GUIDE "REAL-TIME" CONTROL AND LOAD CONTROL, AND IT IS SIMPLE !

LOAD CONTROL ANALYSIS AND EPRI CONTRIBUTION

The following viewgraphs present the results of Minimax Research Corporation's activities in 1984 on the AACE load control experiments. This work has been funded by the Electric Power Research Institute (EPRI). As shown, Minimax's work has been focused primarily in two areas: (1) the design of the submetering experiments and (2) the analysis design of these experiments.

Minimax has developed sampling and analysis methods for the Athens experiments which will be transferable to other utilities. The PC-based DESIGN model plots are presented which illustrate the appliance and household metering requirements for the experiment in order to ensure that adequate and reliable data are collected. Our analysis activities include initial development of impact assessment methods as well as designing the appliance control strategies for the 200 ARMs (appliance metering) households.

A Presentation On The

ATHENS LOAD CONTROL EXPERIMENTS

Through The

ELECTRIC POWER RESEARCH INSTITUTE's

GENERALIZING UTILITY EXPERIMENTS PROJECT (RP 2342-1)

Minimax Research Corporation
2435 Durant Avenue
Berkeley, California 94704

415/548-2548

EPRI PROJECT OVERVIEW

- OBJECTIVES
- FIRST YEAR ACTIVITIES
- RESULTS

PROJECT OBJECTIVES

- o DEVELOP A TRANSFERABLE DATA BASE THAT REPRESENTS IMPACTS OF RESIDENTIAL DEMAND–SIDE PROGRAMS

- o DEVELOP ANALYSIS TOOLS FOR PROGRAM DESIGN & ASSESSMENT

  – EXPERIMENTAL DESIGN
    * Sample Design
    * Experimental Plan

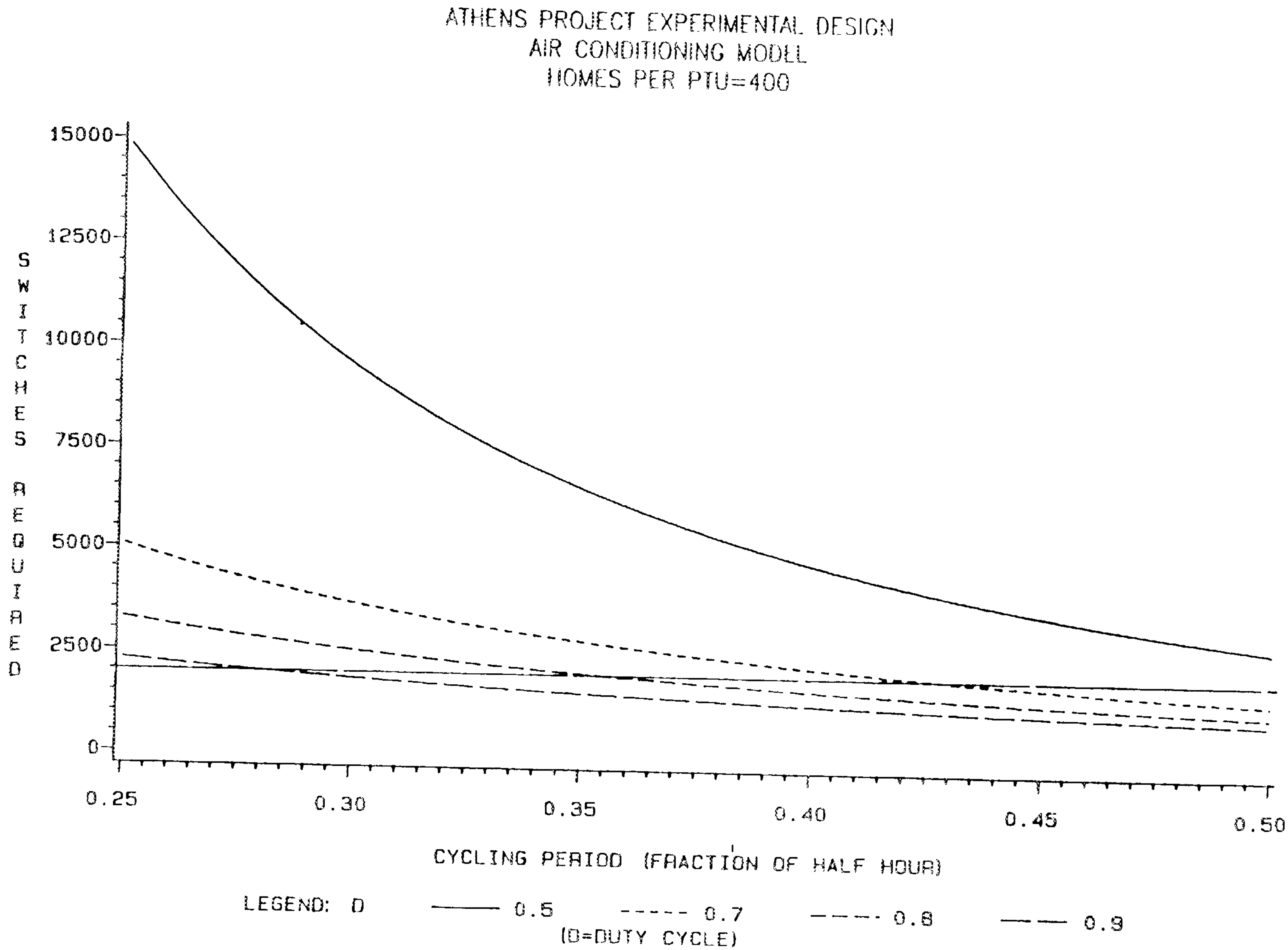
  – ANALYSIS DESIGN
    * Analysis Plan
    * Data Base Design
    * Impact Assessment Models

PROJECT ACTIVITIES

- DEVELOPMENT OF SAMPLE DESIGN AND ANALYSIS PLAN FOR THE ATHENS SUBMETERING EXPERIMENT
- SPECIFICATION OF EQUIPMENT REQUIREMENTS
  - Electric ARMs/LPRs
  - Telecommunications
  - Household Temperature Sensors
- DEVELOPMENT OF ANALYSIS SYSTEMS TO MEASURE IMPACTS OF RESIDENTIAL DEMAND-SIDE EXPERIMENTS

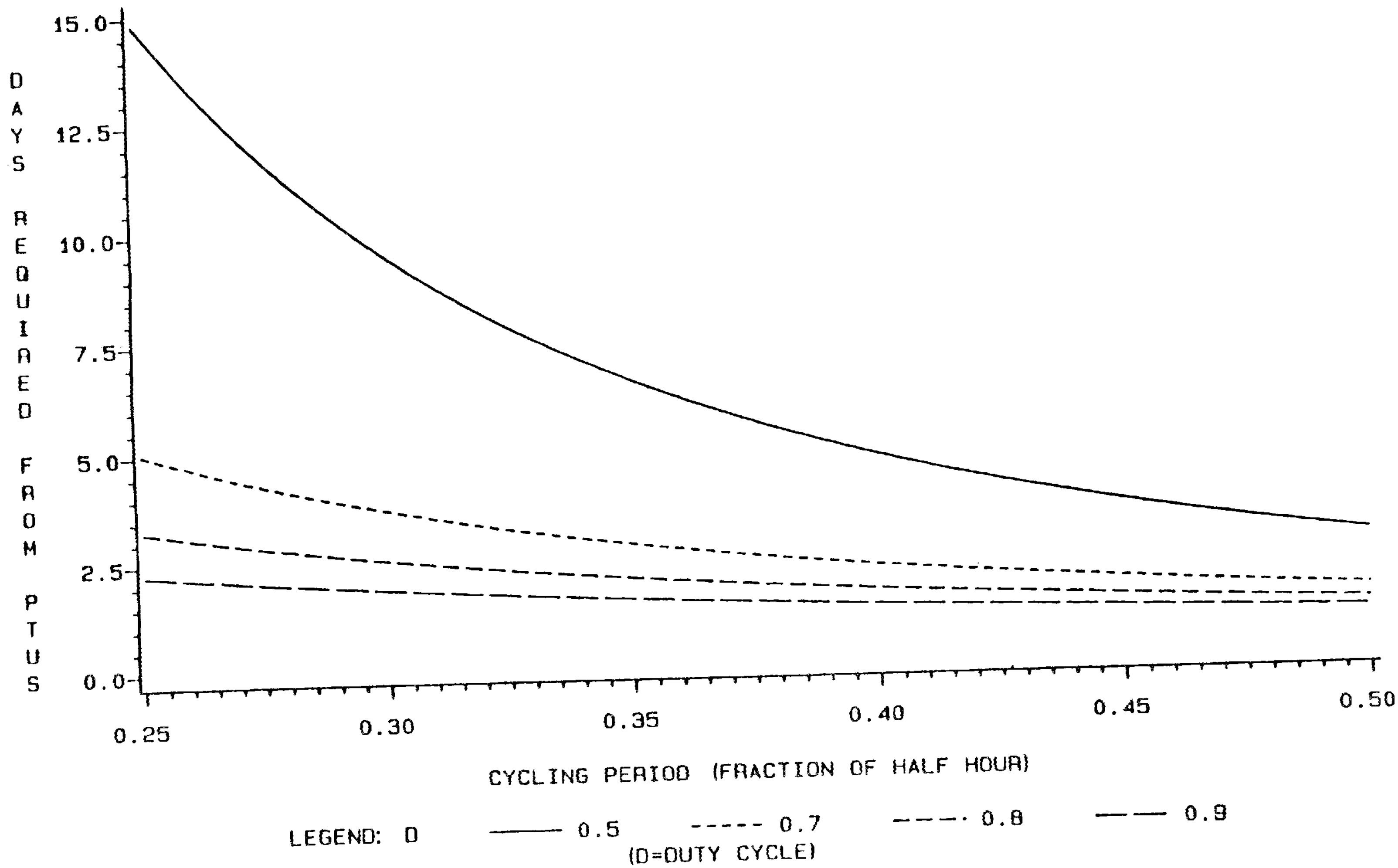
THE DESIGN *MODEL*

- PRODUCES SAMPLE SIZES AND METER REQUIREMENTS FOR RESIDENTIAL DEMAND-SIDE EXPERIMENTS
- INSURES THAT EXPERIMENTAL RESULTS WILL PROVIDE ACCURATE, USEFUL DATA FOR DECISION-MAKING
- DEFINES TRADE-OFFS BETWEEN SAMPLE SIZE, DATA TYPE, CONTROL STRATEGIES, APPLIANCE TYPE, AND CUSTOMER BEHAVIOR
- ANSWERS THE FOLLOWING QUESTIONS:
  - How Many Switches and Meters Are Needed to *Detect* Load Drop Accurately?
  - How Many Households/Appliances Must Be Controlled to *Measure* Load Drop Accurately?

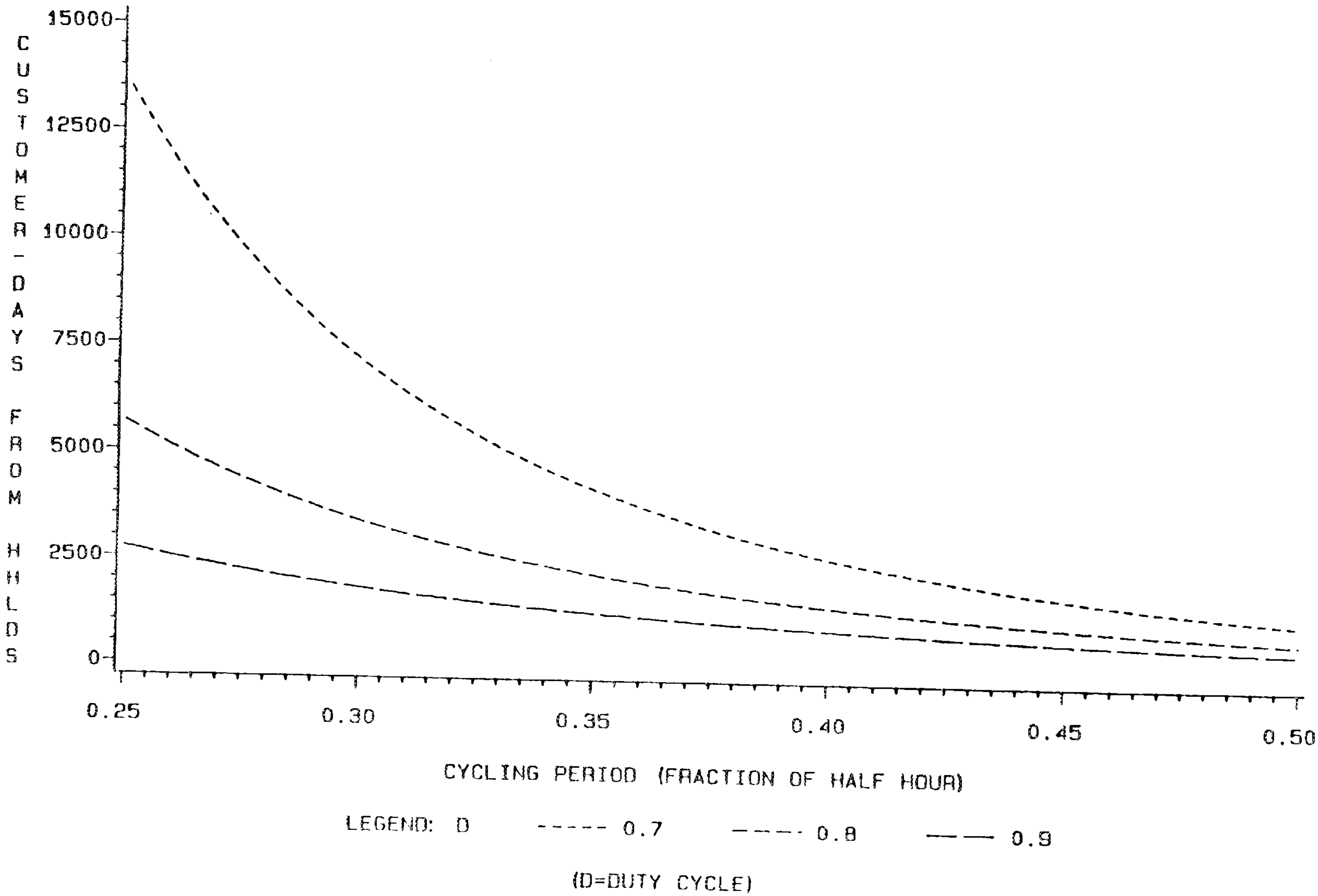


Vertical reference at 2000 switches.

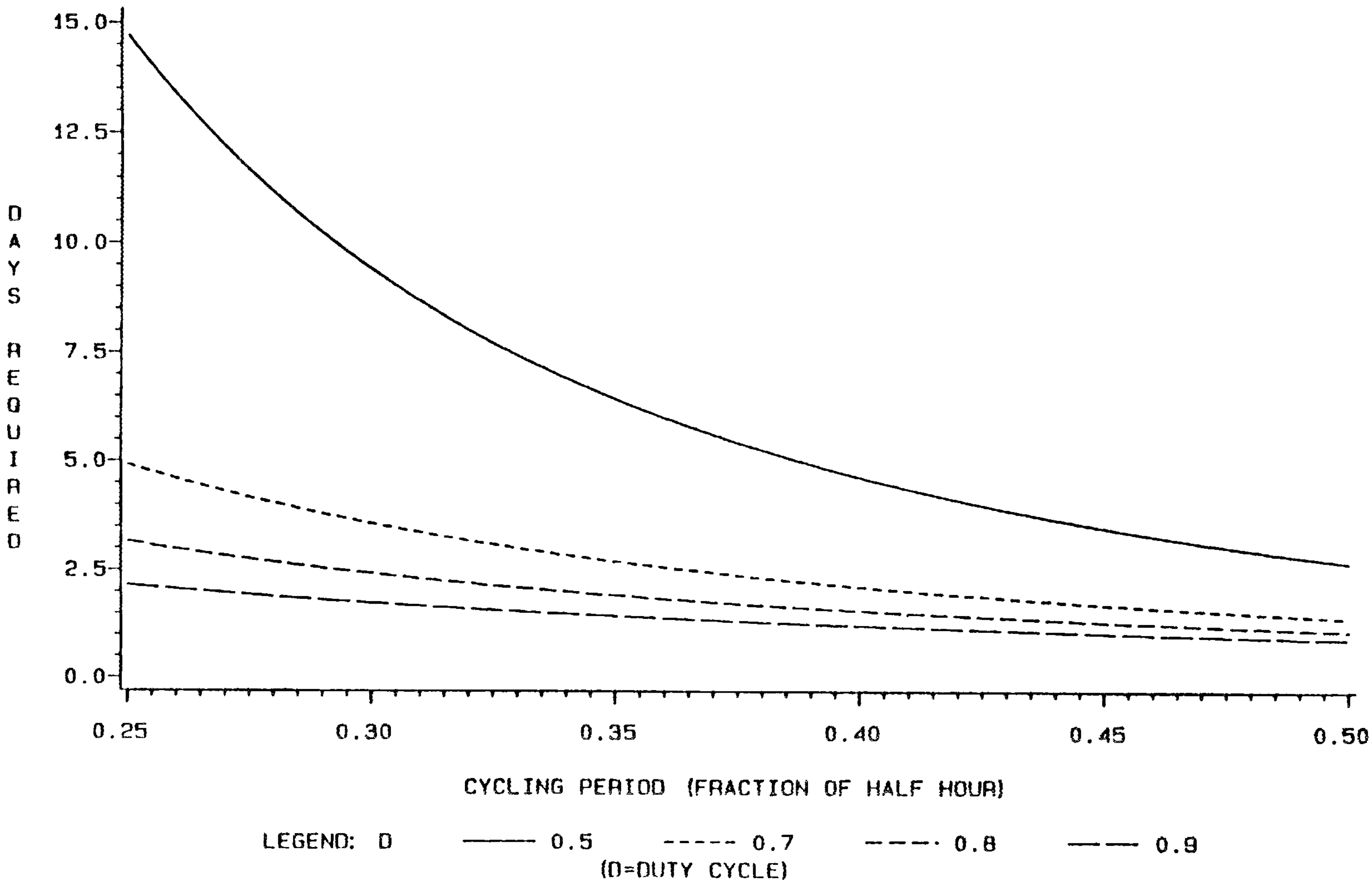
ATHENS PROJECT EXPERIMENTAL DESIGN
AIR CONDITIONING MODEL
NUMBER OF SWITCHES=2000   HOMES PER PTU=400



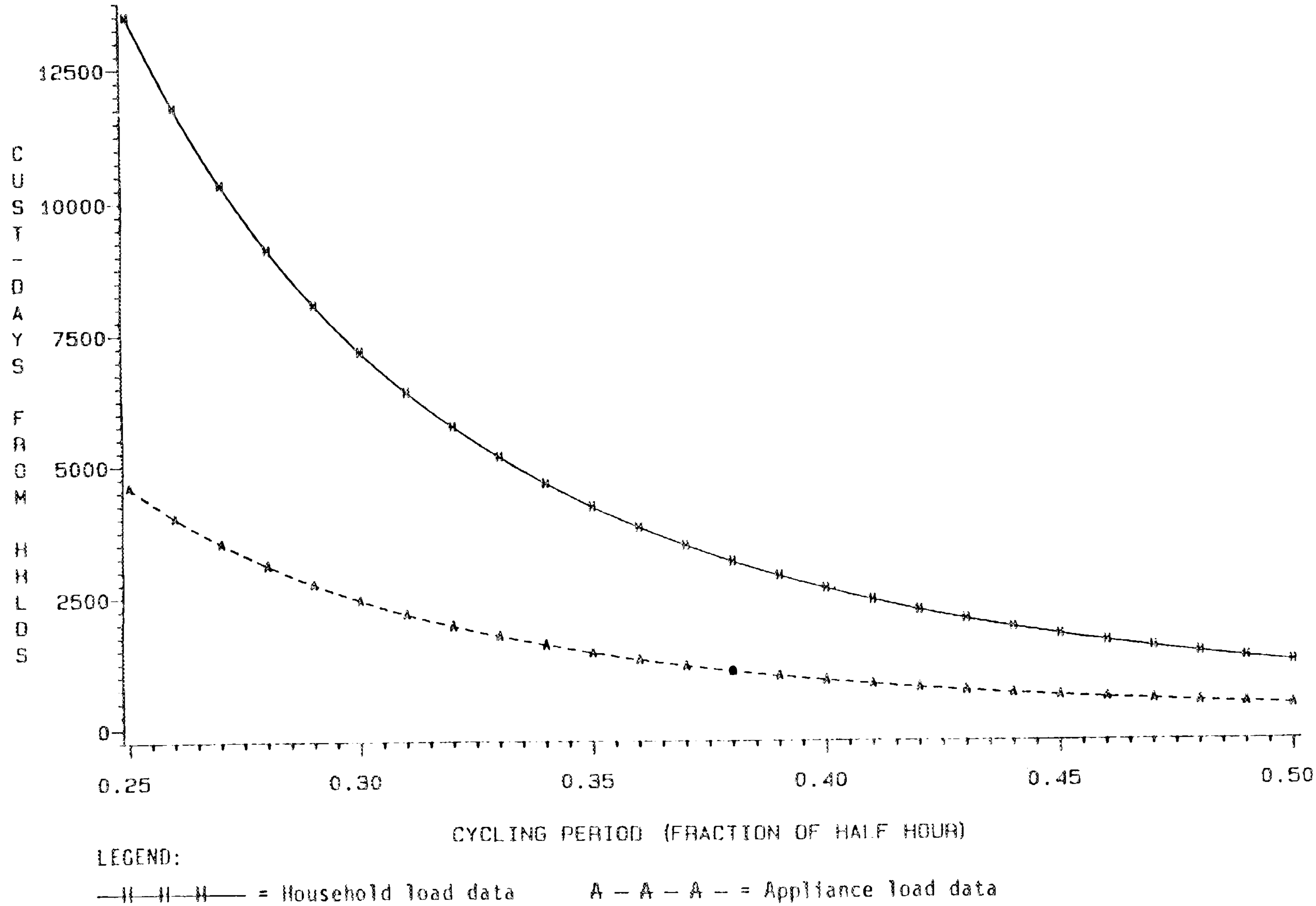
ATHENS PROJECT EXPERIMENTAL DESIGN
AIR CONDITIONING MODEL



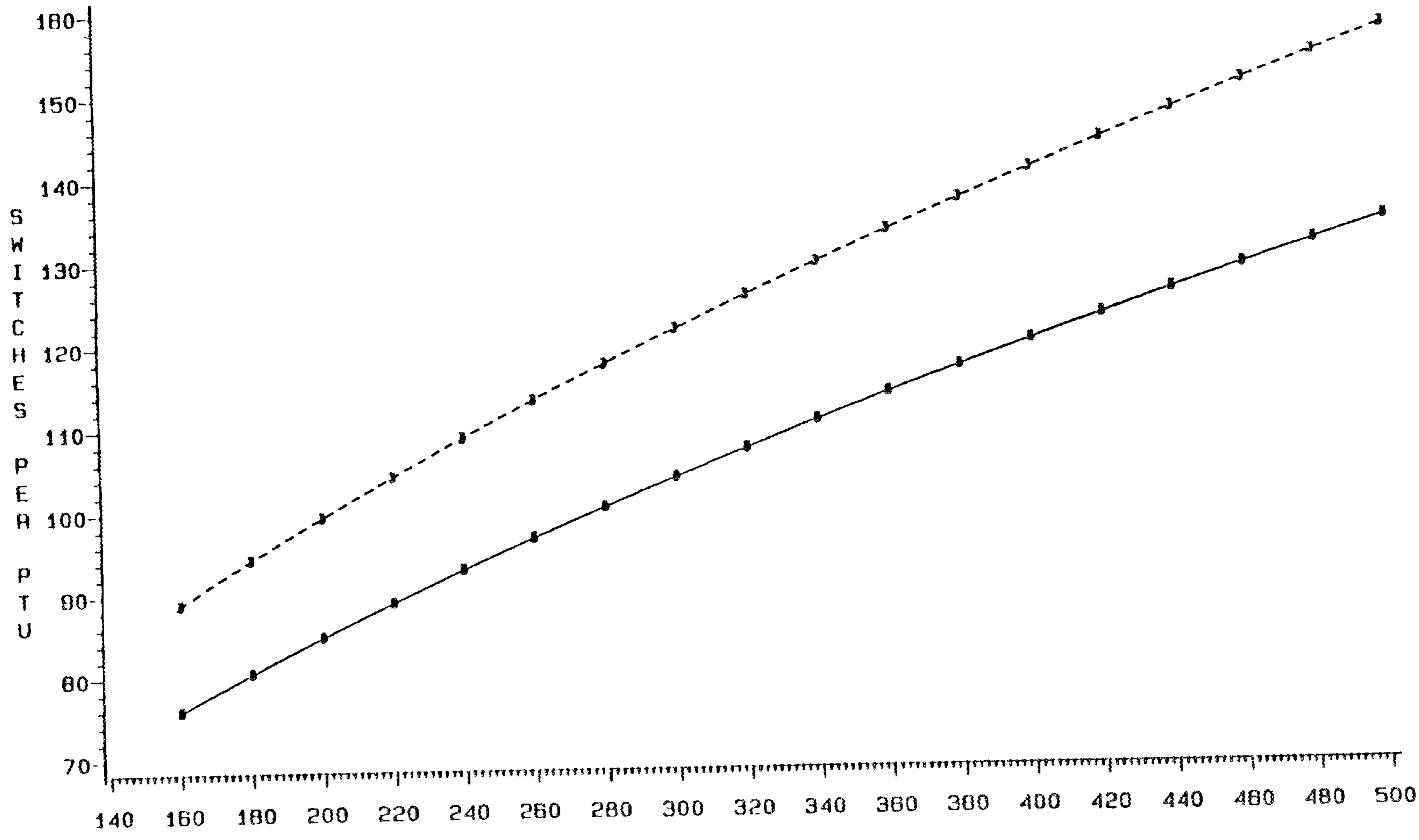
ATHENS PROJECT EXPERIMENTAL DESIGN
AIR CONDITIONING MODEL
NUMBER OF SWITCHES=2000 HOMES PER PTU=400



ATHENS PROJECT EXPERIMENTAL DESIGN
AIR CONDITIONING MODEL
COMPARISON OF HOUSEHOLD VS APPLIANCE LOAD MONITORING

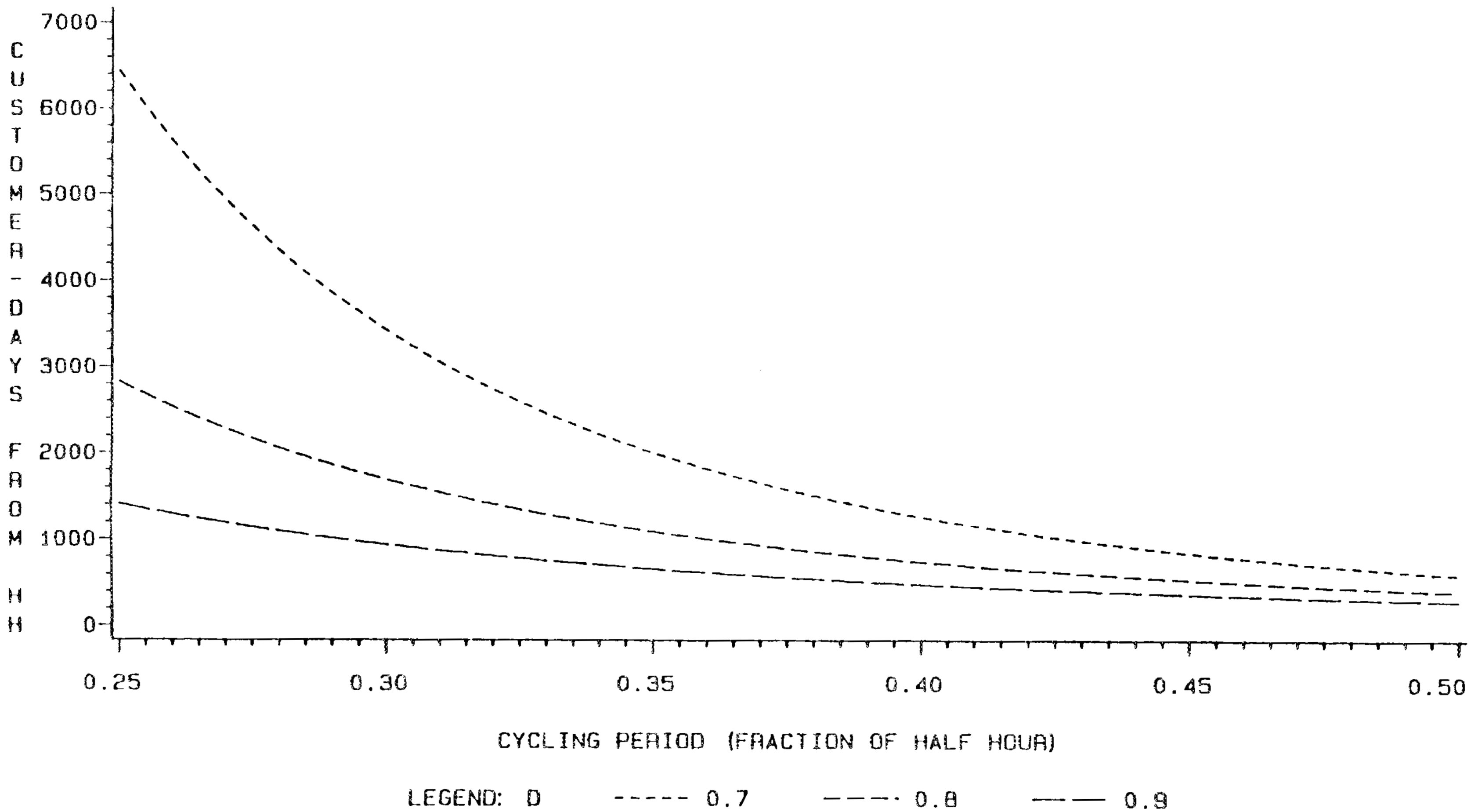


ATHENS PROJECT EXPERIMENTAL DESIGN
AIR CONDITIONING MODEL
COMPARISON OF 5 MINUTE AND 30 MINUTE LOAD DATA



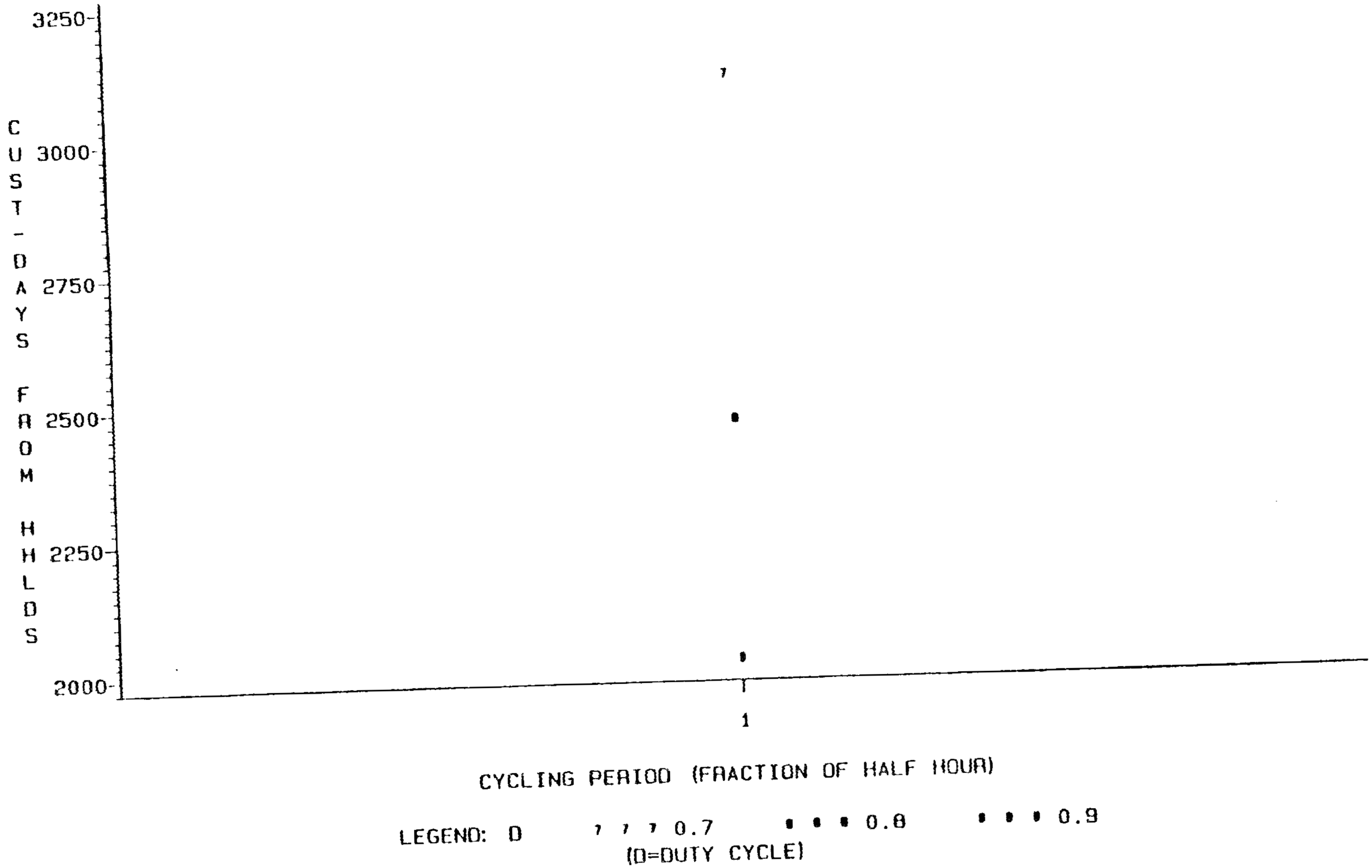
LEGEND:
3 – 3 – = 30 minute data; 5 — 5 — = 5 minute data

ATHENS PROJECT EXPERIMENTAL DESIGN
SPACE HEATING MODEL

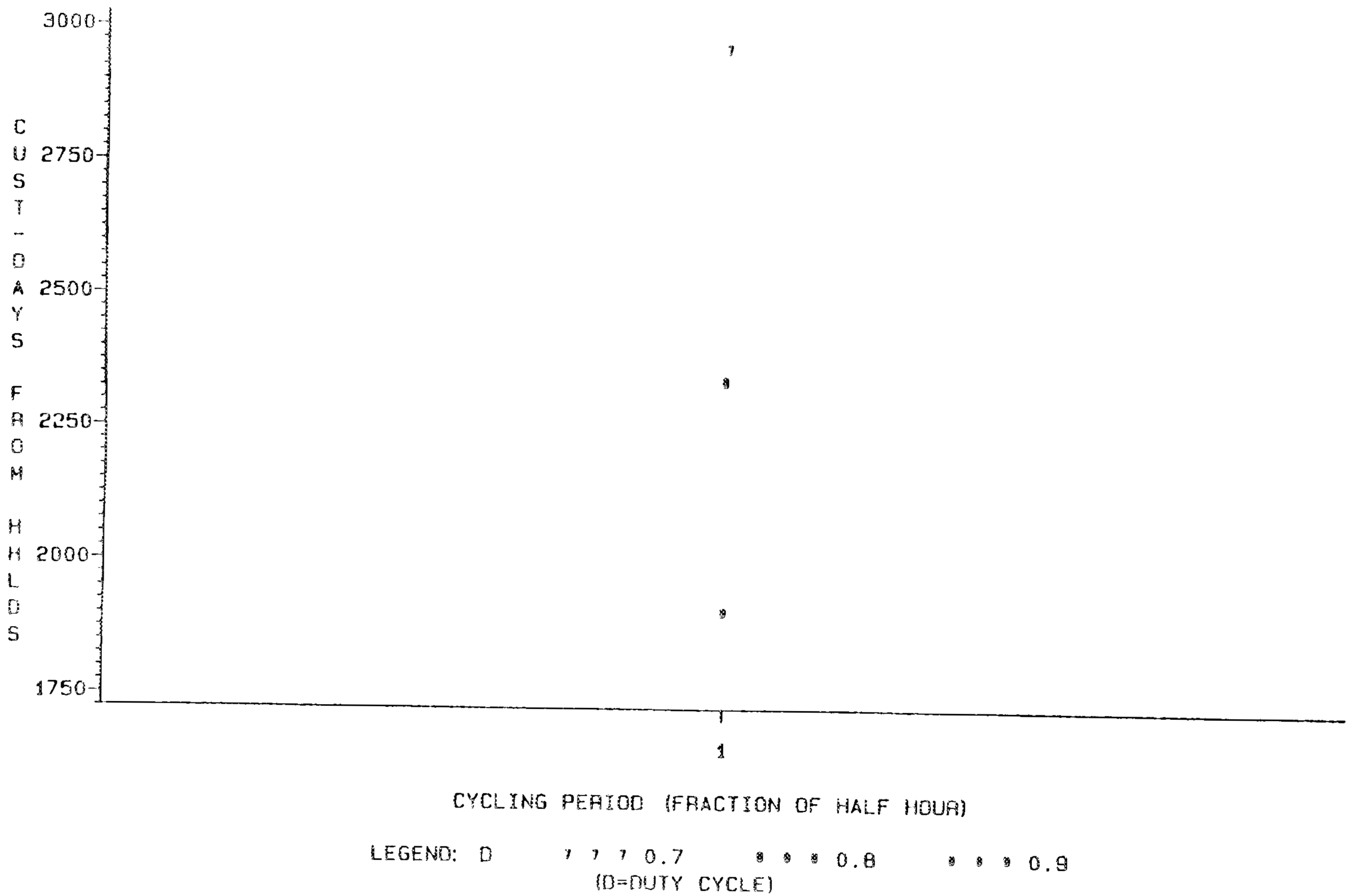


(D=DUTY CYCLE)

ATHENS PROJECT EXPERIMENTAL DESIGN
SUMMER WATER HEATING MODEL



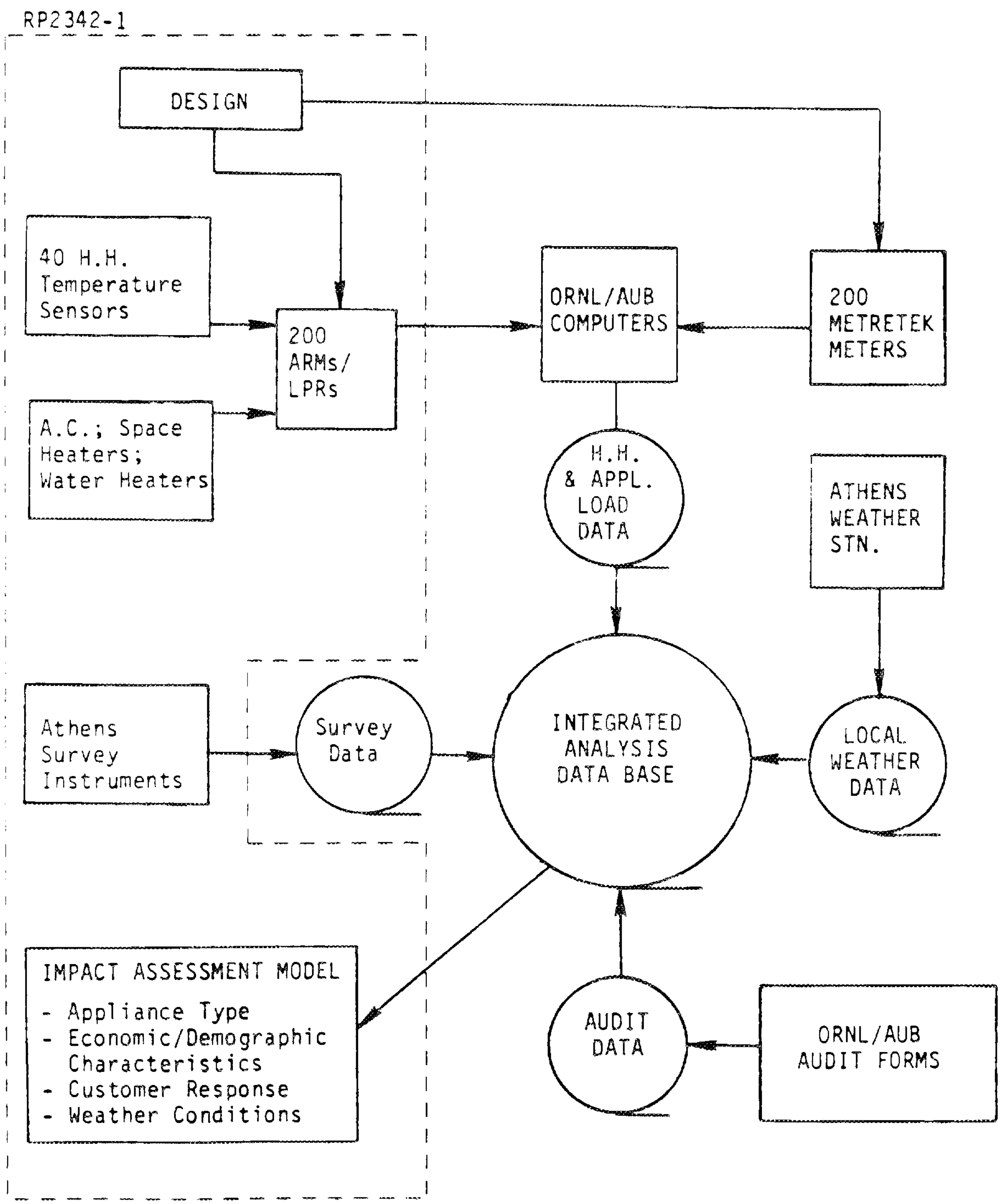
ATHENS PROJECT EXPERIMENTAL DESIGN
WINTER WATER HEATING MODEL



ATHENS ANALYSIS DATA BASE

- HOUSEHOLD AND APPLIANCE LOAD DATA
- HOUSEHOLD TEMPERATURE DATA
- LOCAL WEATHER DATA
- HOUSEHOLD AUDIT INFORMATION
- PARTICIPANT AND DROPOUT SURVEY INFORMATION

ATHENS PROJECT ANALYSIS SYSTEM



EPRI PROJECT RESULTS

- DESIGN -- Experimental Design Model
- PLANNING AND DESIGN OF THE SUBMETERING EXPERIMENT
- INITIAL DEVELOPMENT OF THE IMPACT ASSESSMENT MODEL
  - Appliance Specific
  - Transferable
  - Physical, Economic and Behavioral Factors
- HANDBOOK FOR DESIGN AND ANALYSIS OF RESIDENTIAL EXPERIMENTS

VOLTAGE AND CAPACITOR CONTROL EXPERIMENT

OVERVIEW

The ultimate objective of the volt/var experiment is to automate the control of load tap changing transformers (LTCs), voltage regulators, and shunt capacitors on the Athens Utilities Board distribution system. LTCs and regulators will be controlled to levelize voltage drops and reduce voltage for load release, and shunt capacitors will be controlled to minimize losses. Five experiments have been developed for the volt/var experiment area. They are as follows: (1) to develop reduced feeder models and build operator displays for controlling and studying the control of LTCs, regulators, and capacitors; (2) to test computer-assisted (operator in the control loop) and automated (operator out of the control loop) capacitor control; (3) to test computer-assisted and -automated regulator control; (4) to test voltage reduction for indirect load control; and (5) to integrate capacitor and regulator control with load control and system reconfiguration. In the first experiment, feeder models will be developed from available feeder and load data and will be validated using monitored data collected by the Integrated Distribution Control System (IDCS). The modeling efforts of this experiment will provide regulator control techniques to be developed and validated in experiments 2 through 5.

Initially, the control of capacitors and regulators via the IDCS will be concentrated on North Athens Circuit No. 5. A reduced model for circuit No. 5 has been developed along with an operator display. The performance of circuit No. 5 (loss reduction and voltage drop) was analyzed for capacitor switching and regulator tap changes using a full electrical model of the feeder and a Newton–Raphson Power Flow. These feeder performance results were used to validate the reduced feeder model developed for circuit No. 5; they show that the reduced model is a reasonably accurate model in comparison to the full electrical model. The next step will be to refine the feeder reduction method, reduce other feeders to be tested in the volt/var experiment, validate the reduced feeder models against monitored data to be collected during the characterization year, and then use the models in experiments 2 through 5 to automate the control of LTCs, regulators, and capacitors.

VOLT/VAR PROJECT TEAM

Tom Rizy - TEAM LEADER

Bob Sullivan

Dennis Reed

VOLT/VAR PRESENTATION TOPICS

- EXPERIMENT OBJECTIVES
- VOLT/VAR EXPERIMENTS
- FEEDER MODELING AND DISPLAYS FOR CIRCUIT #5, NORTH ATHENS SUBSTATION

MOTIVATING QUESTIONS FOR THE VOLT/VAR EXPERIMENT

1. WHAT ARE THE BENEFITS OF REALTIME CAPACITOR & REGULATOR CONTROL?
2. HOW MUCH & WHAT TYPE OF AUTOMATION IS ENOUGH AND WHAT TYPE OF AUTOMATION IS MOST EFFECTIVE?
3. HOW MUCH & WHAT TYPE OF HARDWARE IS REQUIRED TO SUPPORT CAPACITOR & REGULATOR CONTROL?
4. WHAT ARE THE ADDITIONAL BENEFITS OF COORDINATING CAPACITOR & REGULATOR CONTROL WITH LOAD CONTROL AND SYSTEM RECONFIGURATION?
5. FROM A SECOND GENERATION PERSPECTIVE, HOW SHOULD CAPACITORS & REGULATORS BE CONTROLLED?

VOLT/VAR EXPERIMENT

Tom Rizy - TECHNICAL LEADER

PRESENTATION BY Bob Sullivan

VOLT/VAR EXPERIMENT OBJECTIVES

1. OPTIMALLY PLACED FIXED-SIZE CAPACITORS
2. DEVELOP & TEST REDUCED FEEDER MODELS & DISPLAYS
3. DEVELOP & TEST COMPUTER-ASSISTED CAPACITOR CONTROL
4. DEVELOP & TEST COMPUTER-ASSISTED REGULATOR CONTROL
5. TEST VOLTAGE REDUCTION FOR INDIRECT LOAD CONTROL

VOLT/VAR EXPERIMENT OBJECTIVES (CONT.)

6. INTEGRATE CAPACITOR & REGULATOR CONTROL WITH LOAD CONTROL & SYSTEM RECONFIGURATION
7. TEST DIFFERENT LEVELS OF INSTRUMENTATION & CONTROL
8. SIMULATE CONTROL TECHNIQUES ON ACCETS
9. IMPLEMENT & EVALUATE CONTROL TECHNIQUES ON AUB SYSTEM
10. TRANSFER INFORMATION AND METHODS TO INDUSTRY

TRANSFER RESULTS TO THE ELECTRIC UTILITY INDUSTRY

- REPORT ON BENEFITS ACHIEVED WITH DIFFERENT LEVELS OF INSTRUMENTATION & CONTROL
- REPORT ON HARDWARE & SOFTWARE REQUIRED TO ACHIEVE A DESIRED LEVEL OF CONTROL
- IDENTIFY CONTROL STRATEGIES USED TO OPTIMIZE FEEDER OPERATIONS
- REPORT ON PROCEDURES USED FOR ANALYZING DATA

VOLT/VAR EXPERIMENTS

1. FEEDER MODELING & DISPLAYS
2. COMPUTER-ASSISTED CAPACITOR CONTROL
3. COMPUTER-ASSISTED REGULATOR CONTROL
4. VOLTAGE REDUCTION FOR INDIRECT LOAD CONTROL
5. ASSESS BENEFITS OF INTEGRATING CAPACITOR & REGULATOR CONTROL
6. INTEGRATE VOLT/VAR CONTROL WITH LOAD CONTROL & SYSTEM RECONFIGURATION

FEEDER MODELING AND DISPLAYS (EXPERIMENT #1)

- DEVELOP FEEDER REDUCTION METHOD
- REDUCE DETAILED ONE-LINE FEEDER MODELS
- TEST REDUCED FEEDER MODELS
- DEVELOP FEEDER DISPLAYS FOR OPERATOR TO STUDY & IMPLEMENT CAPACITOR & REGULATOR CONTROL
- TEST FEEDER DISPLAYS ON AACETS
- IMPLEMENT & EVALUATE FEEDER DISPLAYS ON AUB SYSTEM

COMPUTER-ASSISTED CAPACITOR CONTROL (EXPERIMENT #2)

- TEST REALTIME CAPACITOR CONTROL FOR REDUCING LOSSES & LEVELIZING FEEDER VOLTAGE
- DEVELOP PROCEDURE TO DISPLAY IMPACT OF CAPACITOR CONTROL ON LOSSES & VOLTAGE PROFILE
- TEST PROCEDURE ON AACETS USING REDUCED FEEDER MODELS
- DETERMINE COMPUTATIONAL PERFORMANCE OF REDUCED MODELS
- IMPLEMENT & TEST COMPUTER-ASSISTED CAPACITOR CONTROL ON AUB SYSTEM
- EVALUATE EFFECTIVENESS OF CAPACITOR CONTROL FOR REDUCING LOSSES & LEVELIZING VOLTAGE

COMPUTER-ASSISTED REGULATOR CONTROL (EXPERIMENT #3)

- TEST REALTIME REGULATOR CONTROL FOR LEVELIZING VOLTAGE & REDUCING LOSSES
- DEVELOP PROCEDURE TO DISPLAY IMPACT OF COMPUTER-ASSISTED LTC & REGULATOR CONTROL
- TEST PROCEDURE ON AACETS USING REDUCED FEEDER MODELS
- DETERMINE COMPUTATIONAL PERFORMANCE OF REDUCED FEEDER MODELS
- IMPLEMENT & TEST COMPUTER-ASSISTED REGULATOR CONTROL PROCEDURE ON AUB SYSTEM
- EVALUATE EFFECTIVENESS OF REGULATOR CONTROL TO LEVELIZE VOLTAGE & REDUCE LOSSES

TEST VOLTAGE REDUCTION FOR INDIRECT LOAD CONTROL

(EXPERIMENT #4)

- ASSESS LOAD RELEASE CAPABILITY OF AUB FEEDERS
- TEST REGULATOR CONTROL TO REDUCE VOLTAGE TO RELEASE LOAD CAPABILITY
- TEST VOLTAGE REDUCTION FOR PEAK LOAD SHAVING TO REDUCE CAPITAL COSTS
- TEST VOLTAGE REDUCTION FOR LOAD SHAPING TO REDUCE CAPITAL & OPERATING COSTS
- TEST VOLTAGE REDUCTION TECHNIQUES ON DISSIMILAR FEEDERS WITH DIFFERENT LOAD MIXES

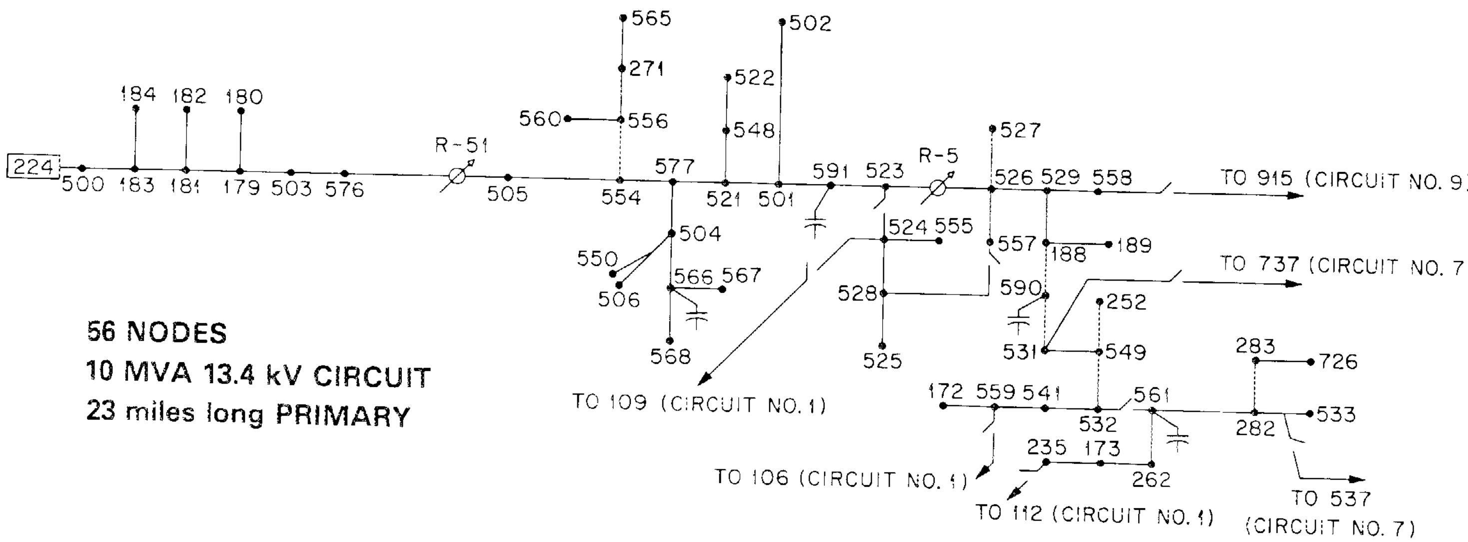
INTEGRATE CAPACITOR & REGULATOR CONTROL
(EXPERIMENT #5 & 6)

- CONSIDER SIMULTANEOUS CONTROL OF CAPACITORS & REGULATORS
- PRIORITIZE CONTROL OBJECTIVES, LOSS REDUCTION VERSUS LEVELIZING VOLTAGE
- COORDINATE CAPACITOR & REGULATOR CONTROL WITH LOAD CONTROL AND SYSTEM RECONFIGUATION

FEEDER MODELING & DISPLAYS FOR CIRCUIT #5
NORTH ATHENS SUBSTATION

- PERFORMANCE OF DETAILED FEEDER MODEL
- CAPACITOR CONTROL EFFECTS ON LOSSES & VOLTAGE
- REGULATOR CONTROL EFFECTS ON VOLTAGE & LOSSES
- OPERATOR FEEDER DISPLAYS
- MODSCAN DATA HIERARCHY FOR DRTU #6
- PERFORMANCE OF REDUCED FEEDER MODELS

CIRCUIT NO. 5 NORTH ATHENS SUBSTATION
DETAILED FEEDER MODEL



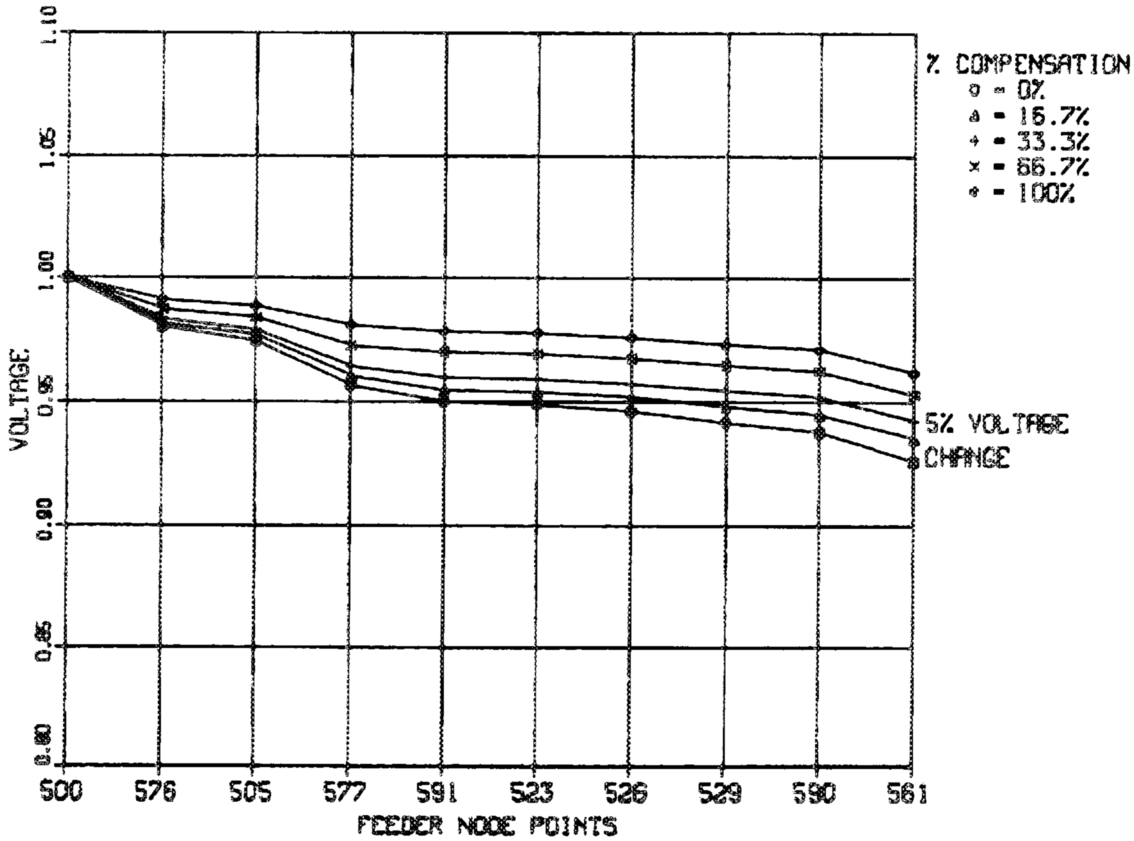
56 NODES
10 MVA 13.4 kV CIRCUIT
23 miles long PRIMARY

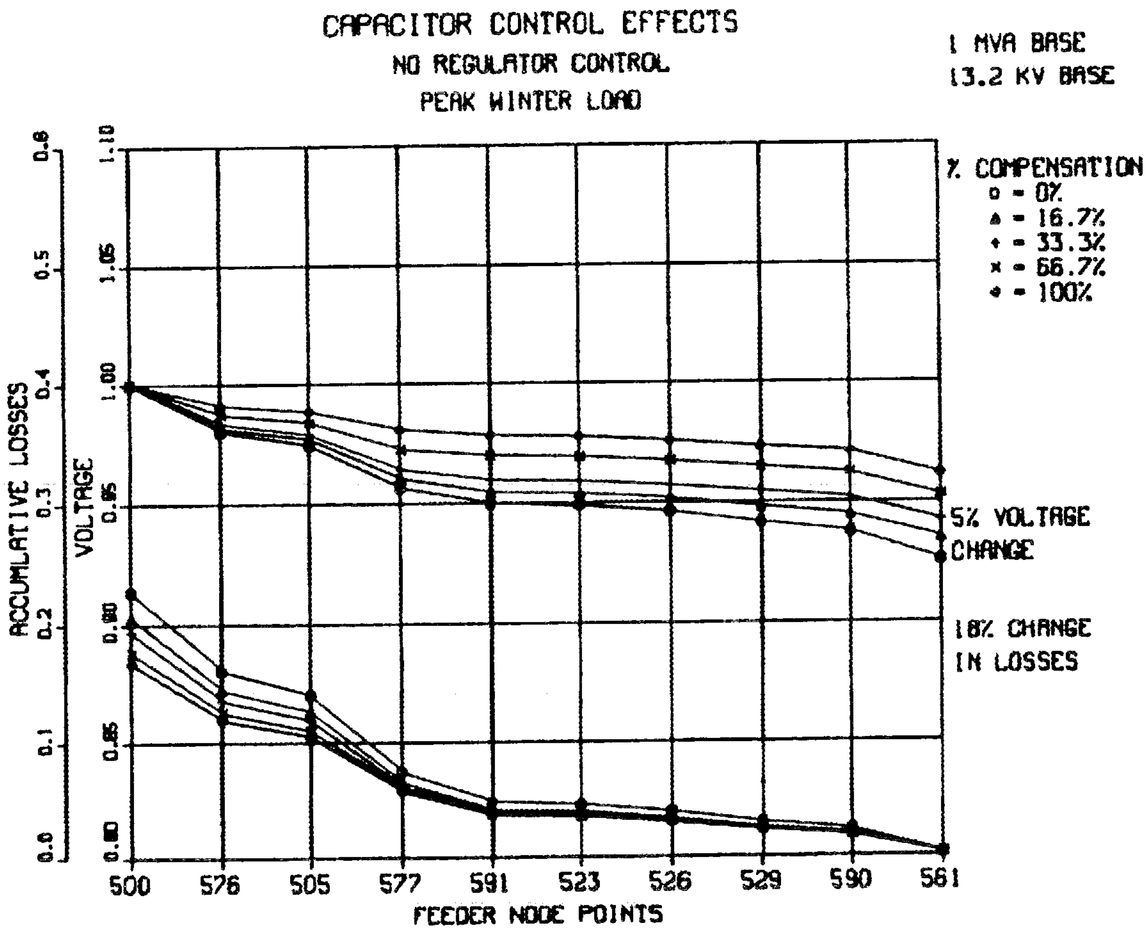
CAPACITOR CONTROL EFFECTS ON CIRCUIT #5

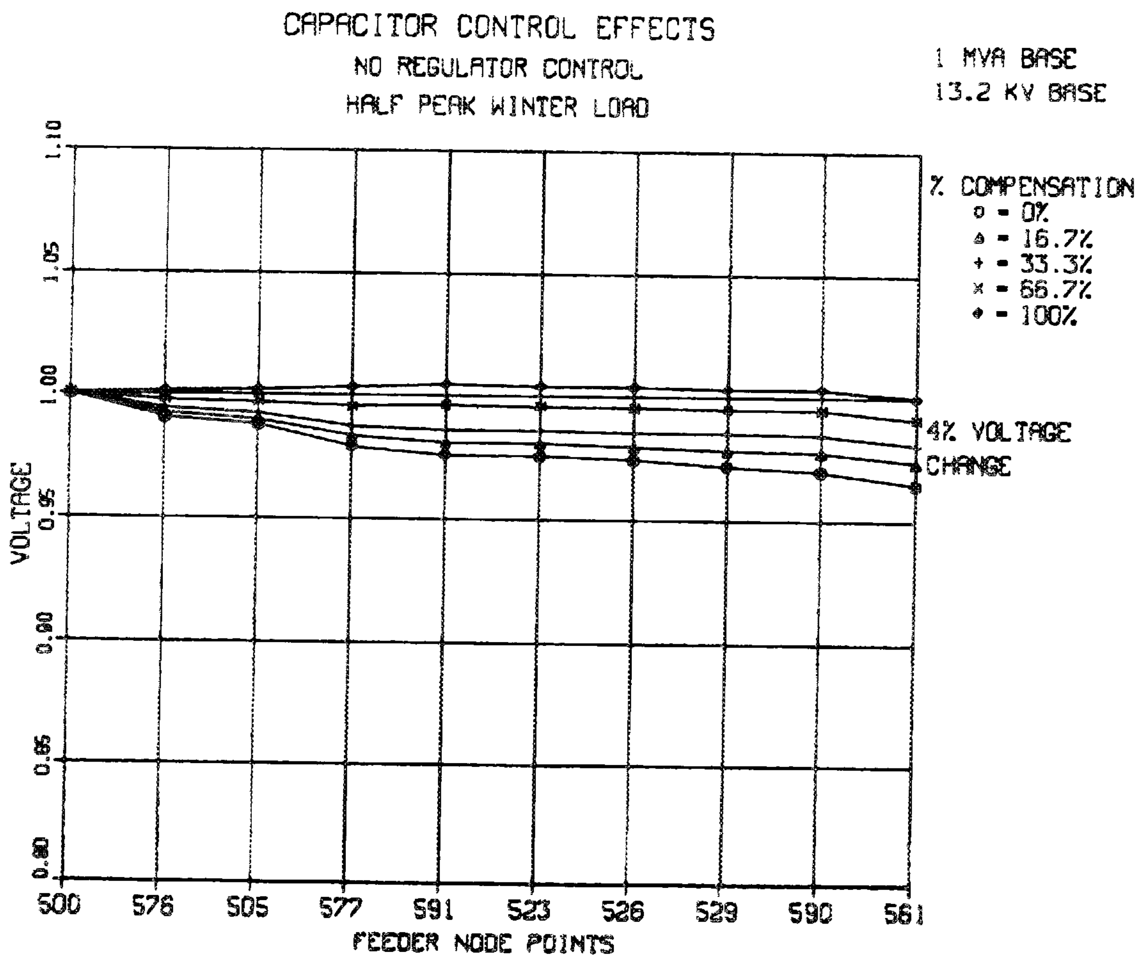
- CONSIDERED PEAK WINTER LOAD
- CONSIDERED HALF PEAK WINTER LOAD
- 0% COMPENSATION - NO CAPACITORS
- 16% COMPENSATION - ADDED 600 kVAR CAPACITOR AT 561
- 33% COMPENSATION - ADDED 600 kVAR CAPACITOR AT 590
- 66% COMPENSATION - ADDED 1200 kVAR CAPACITOR AT 591
- 100% COMPENSATION - ADDED 1200 kVAR CAPACITOR AT 566

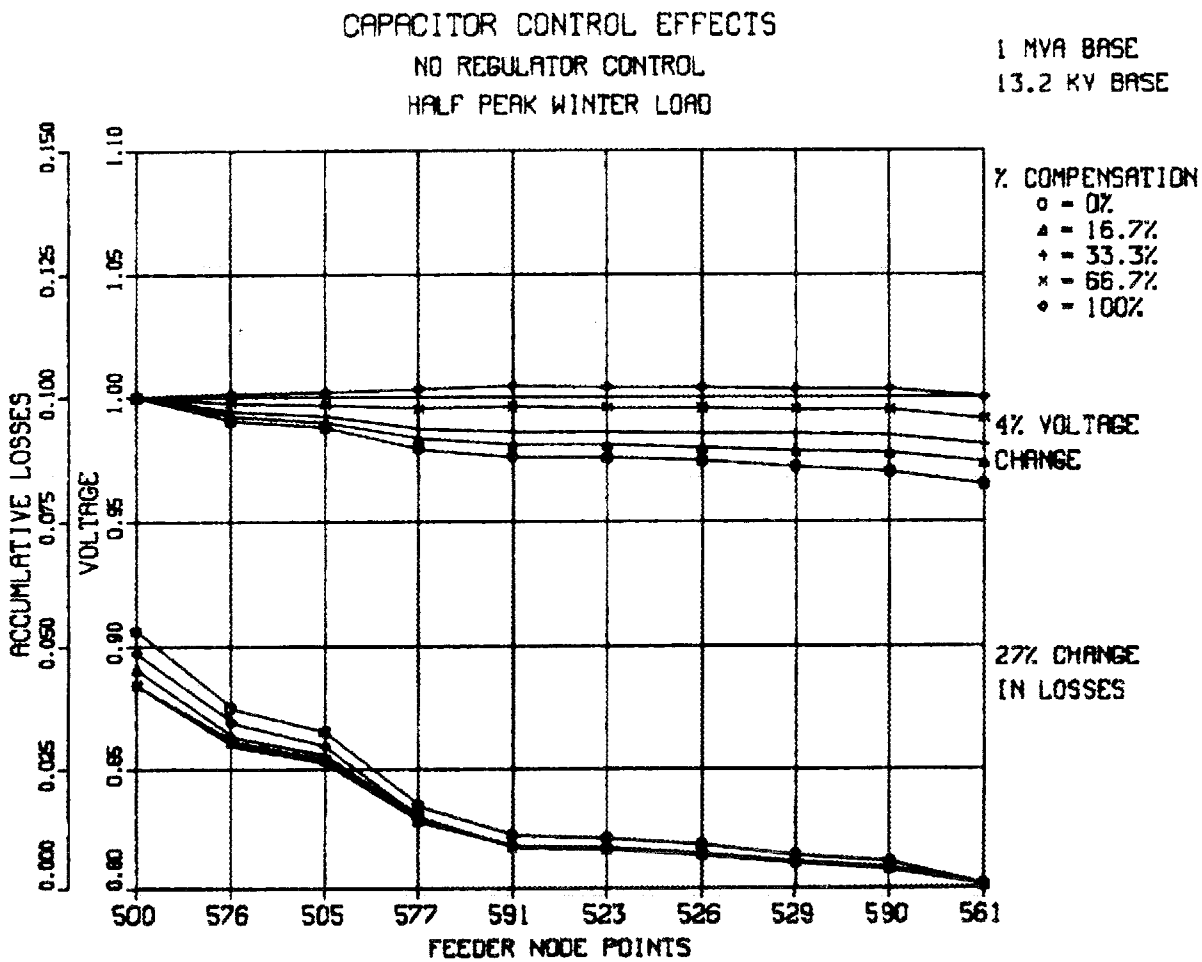
CAPACITOR CONTROL EFFECTS
NO REGULATOR CONTROL
PEAK WINTER LOAD

1 MVA BASE
13.2 KV BASE




CAPACITOR CONTROL EFFECTS
NO REGULATOR CONTROL
PEAK WINTER LOAD
1 MVA BASE
13.2 KV BASE
% COMPENSATION
o = 0%
▲ = 16.7%
+ = 33.3%
x = 66.7%
◆ = 100%
5% VOLTAGE CHANGE
18% CHANGE IN LOSSES
ACCUMLATIVE LOSSES
VOLTAGE
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.80
0.85
0.90
0.95
1.00
1.05
1.10
500
576
505
577
591
523
526
529
590
561
FEEDER NODE POINTS


CAPACITOR CONTROL EFFECTS
NO REGULATOR CONTROL
HALF PEAK WINTER LOAD
1 MVA BASE
13.2 KV BASE
% COMPENSATION
o = 0%
▲ = 16.7%
+ = 33.3%
× = 66.7%
◆ = 100%
4% VOLTAGE
CHANGE
VOLTAGE
1.10
1.05
1.00
0.95
0.90
0.85
0.80
500
576
505
577
591
523
526
529
590
561
FEEDER NODE POINTS


CAPACITOR CONTROL EFFECTS
NO REGULATOR CONTROL
HALF PEAK WINTER LOAD
1 MVA BASE
13.2 KV BASE
% COMPENSATION
o = 0%
▲ = 16.7%
+ = 33.3%
× = 66.7%
◆ = 100%
4% VOLTAGE CHANGE
27% CHANGE IN LOSSES
ACCUMLATIVE LOSSES
VOLTAGE
0.150
0.125
0.100
0.075
0.050
0.025
0.000
1.10
1.05
1.00
0.95
0.90
0.85
0.80
500
576
505
577
591
523
526
529
590
561
FEEDER NODE POINTS

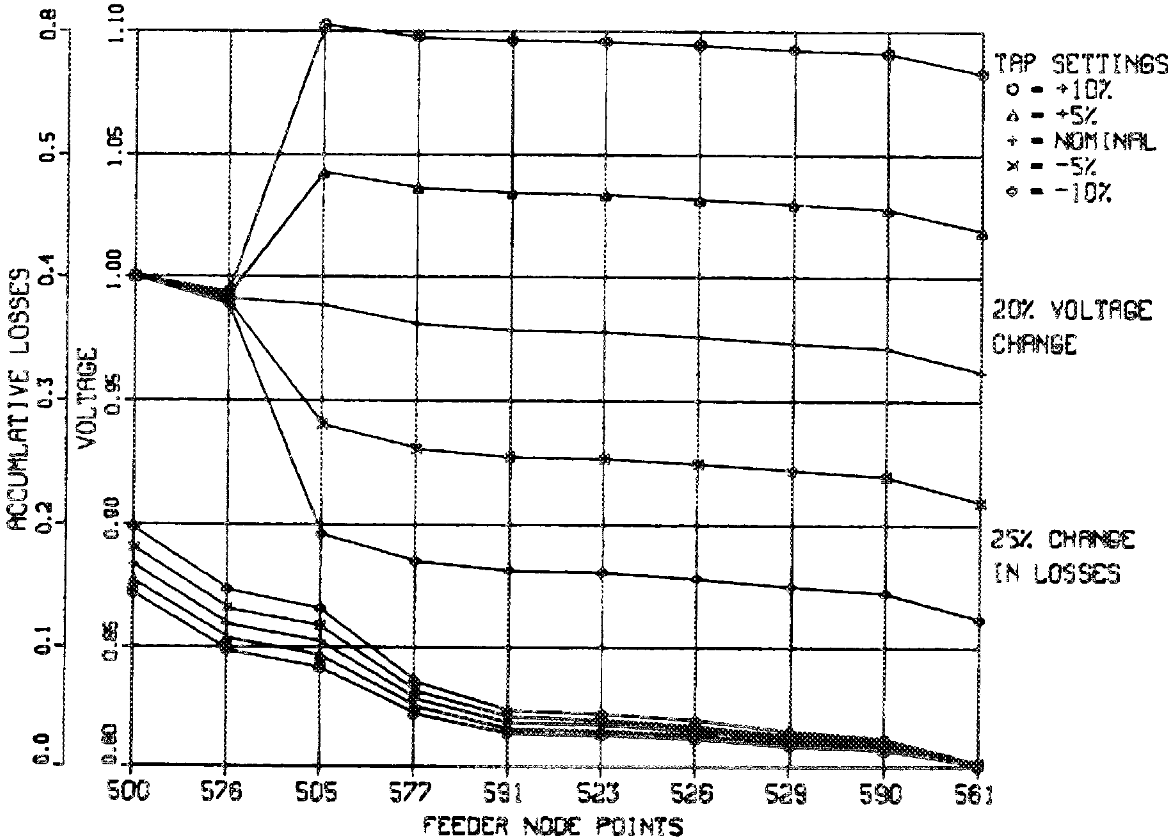
REGULATOR R-51 CONTROL EFFECTS

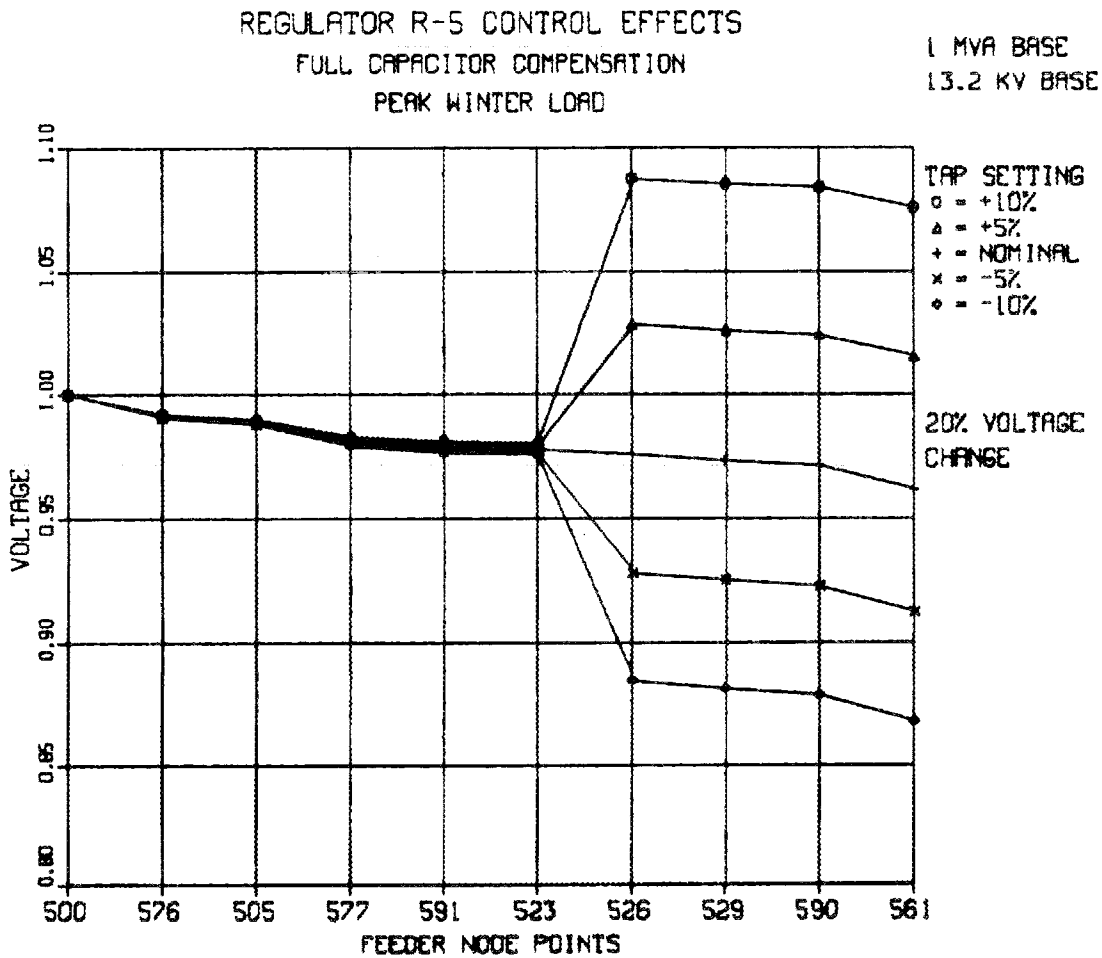
FULL CAPACITOR COMPENSATION

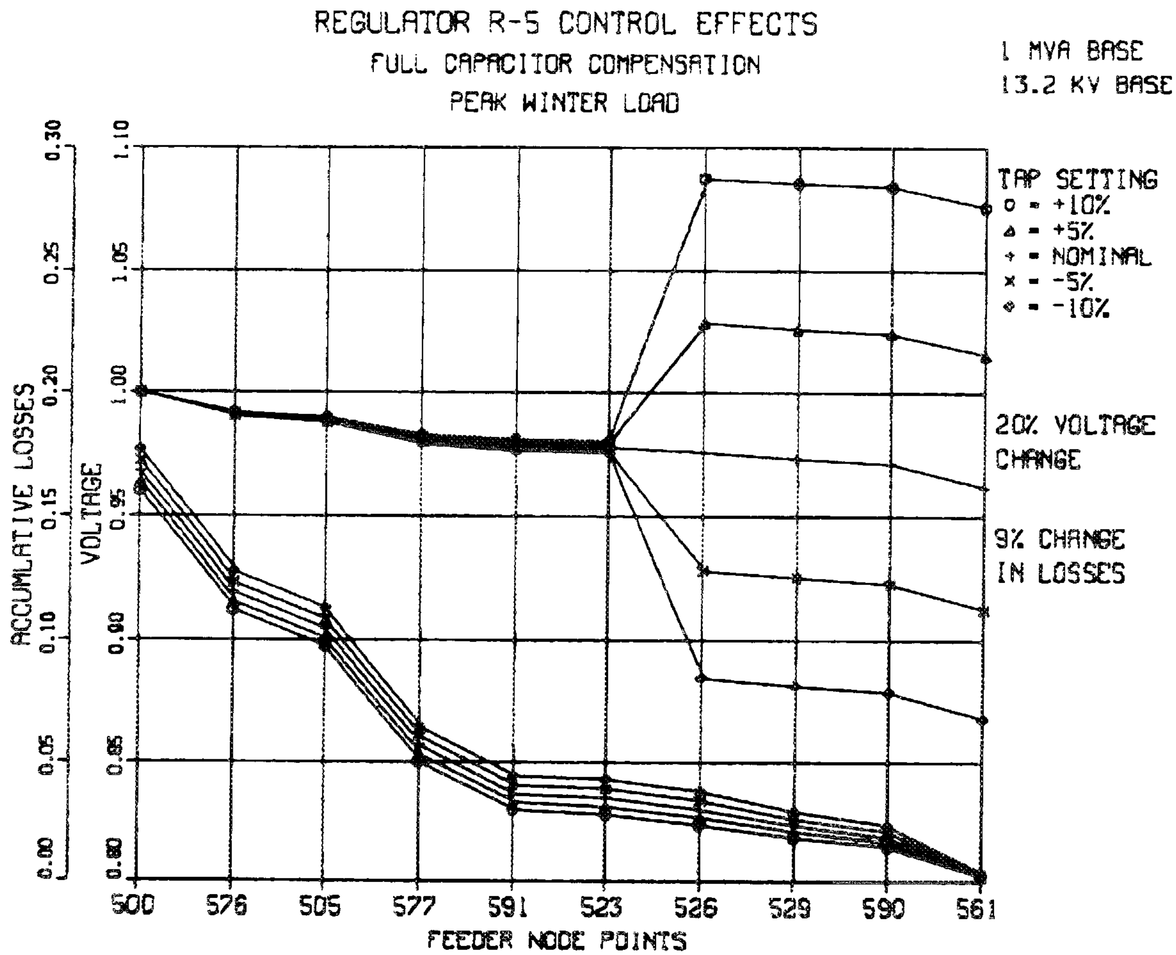
PEAK WINTER LOAD

1 MVA BASE

13.2 KV BASE




REGULATOR R-5 CONTROL EFFECTS
FULL CAPACITOR COMPENSATION
PEAK WINTER LOAD
1 MVA BASE
13.2 KV BASE
TAP SETTING
o = +10%
Δ = +5%
+ = NOMINAL
× = -5%
◇ = -10%
20% VOLTAGE
CHANGE
VOLTAGE
1.10
1.05
1.00
0.95
0.90
0.85
0.80
500
576
505
577
591
523
526
529
590
561
FEEDER NODE POINTS


REGULATOR R-5 CONTROL EFFECTS
FULL CAPACITOR COMPENSATION
PEAK WINTER LOAD
1 MVA BASE
13.2 KV BASE
ACCUMLATIVE LOSSES
0.00
0.05
0.10
0.15
0.20
0.25
0.30
VOLTAGE
0.80
0.85
0.90
0.95
1.00
1.05
1.10
TAP SETTING
o = +10%
Δ = +5%
+ = NOMINAL
x = -5%
◇ = -10%
20% VOLTAGE CHANGE
9% CHANGE IN LOSSES
500
576
505
577
591
523
526
529
590
561
FEEDER NODE POINTS

FOR THE SPECIFIC AUB CIRCUIT (#5) STUDIED, THE FOLLOWING CONCLUSIONS CAN BE MADE:

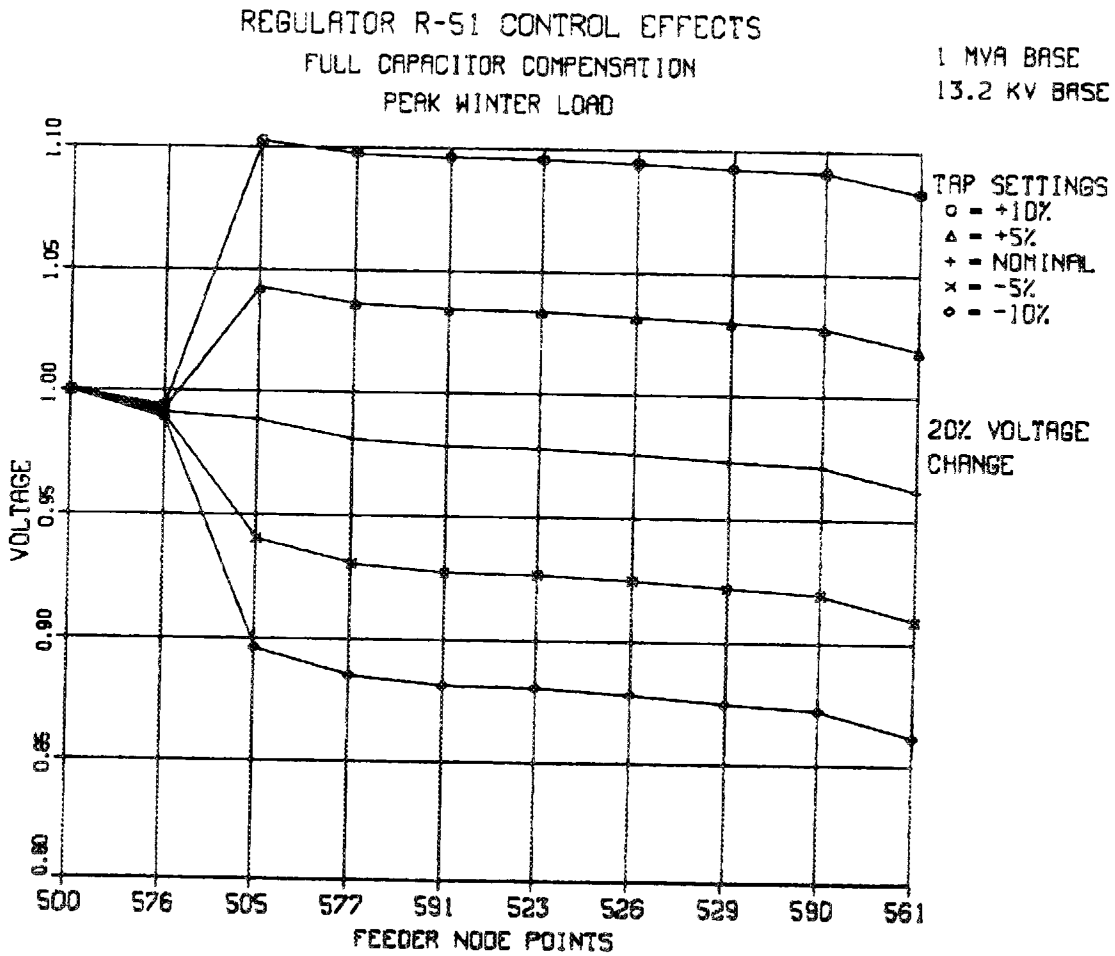
- CAPACITORS SHOULD BE USED FOR LOSS REDUCTION
- VOLTAGE REGULATORS SHOULD BE USED FOR LEVELIZING VOLTAGE
- NEED TO EVALUATE THESE PRELIMINARY CONCLUSIONS AGAINST MONITORED DATA FROM THE AUB SYSTEM

FEEDER DISPLAYS FOR OPERATOR CONTROL & STUDY

- DISPLAYS BUILT ON AACETS
- MONITORED DATA FOR DISPLAYS WAS ARTIFICALLY CREATED BY AACETS

REGULATOR CONTROL EFFECTS ON CIRCUIT #5, NORTH ATHENS SUBSTATION

- CONSIDERED PEAK WINTER LOAD
- STUDIED REGULATOR R-51 AT 576
- STUDIED REGULATOR R-5 AT 523


REGULATOR R-51 CONTROL EFFECTS
FULL CAPACITOR COMPENSATION
PEAK WINTER LOAD
1 MVA BASE
13.2 KV BASE
TAP SETTINGS
o = +10%
Δ = +5%
+ = NOMINAL
× = -5%
◇ = -10%
20% VOLTAGE CHANGE
VOLTAGE
1.10
1.05
1.00
0.95
0.90
0.85
0.80
500
576
505
577
591
523
526
529
590
561
FEEDER NODE POINTS

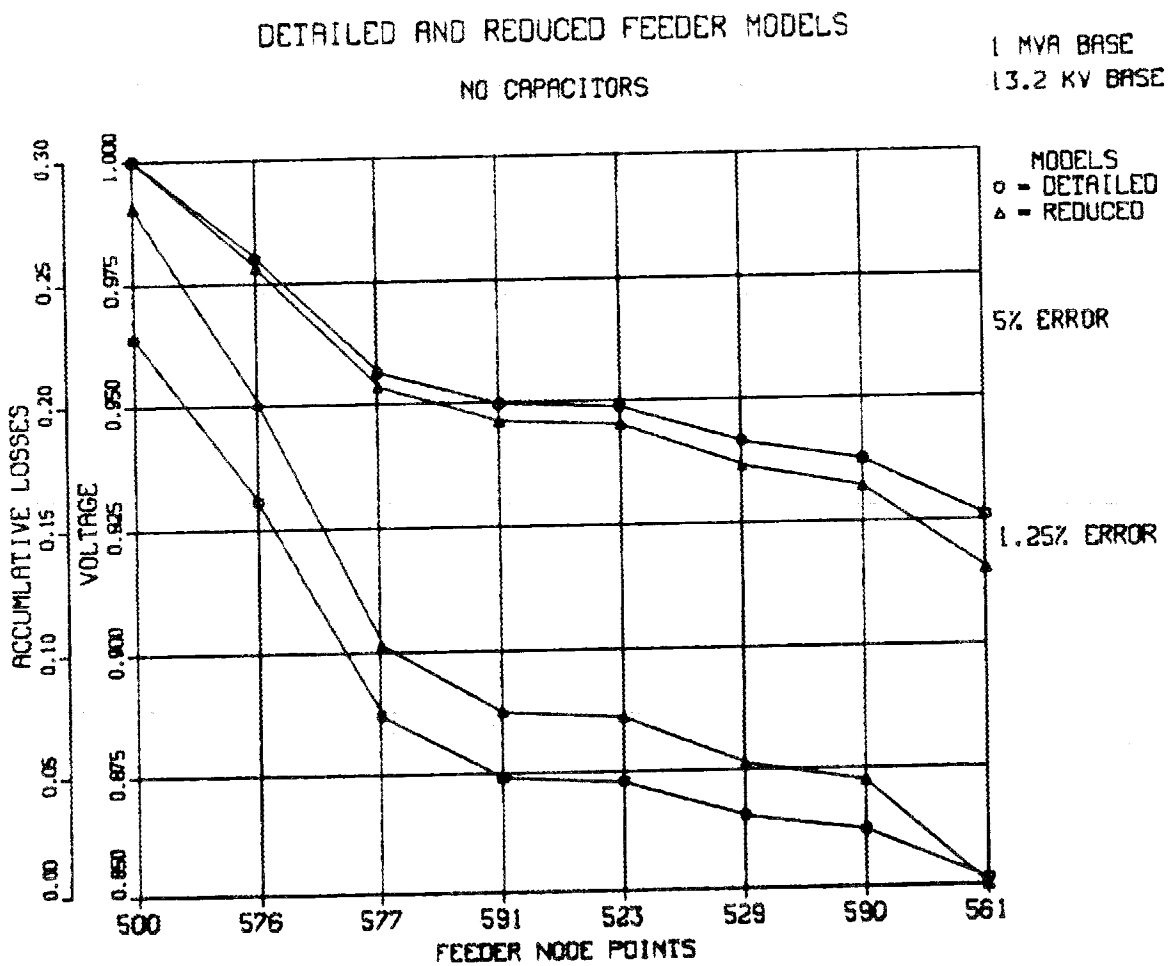
COLOR CODE USED FOR CRT SCREENS

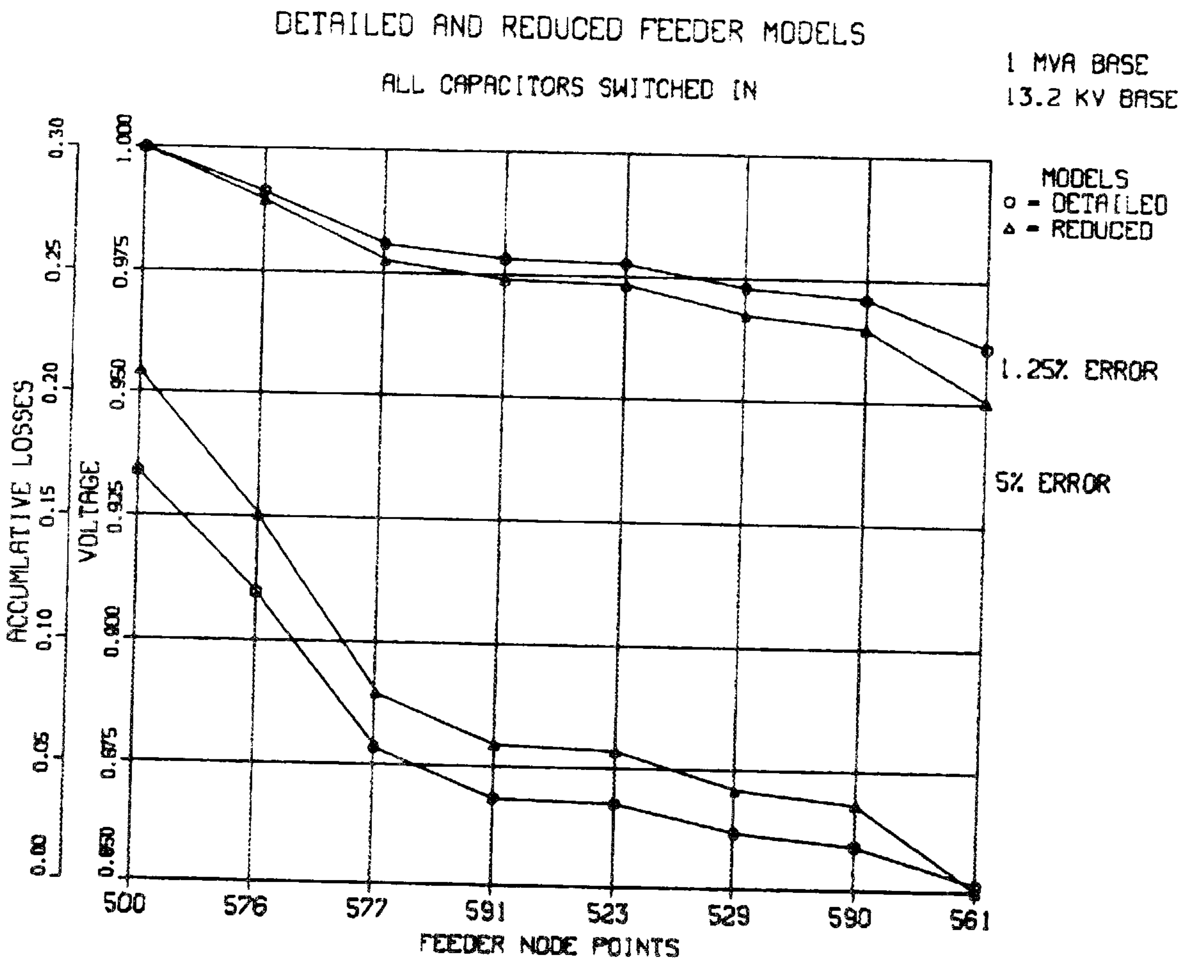
- RED - ENERGIZED PART OF FEEDER
- GREEN - DEENERGIZED PART OF FEEDER
- PURPLE - CAPACITORS AND/OR REGULATORS PRESENTLY UNDER STUDY AND CALCULATED DATA
- YELLOW - REGULATORS, CAPACITORS AND SWITCHES THAT CAN BE CONTROLLED ON THE FEEDER
- WHITE - USED TO LABEL CIRCUIT BREAKER NUMBER, FEEDER NODE NUMBERS & IDENTIFY MONITORED DATA

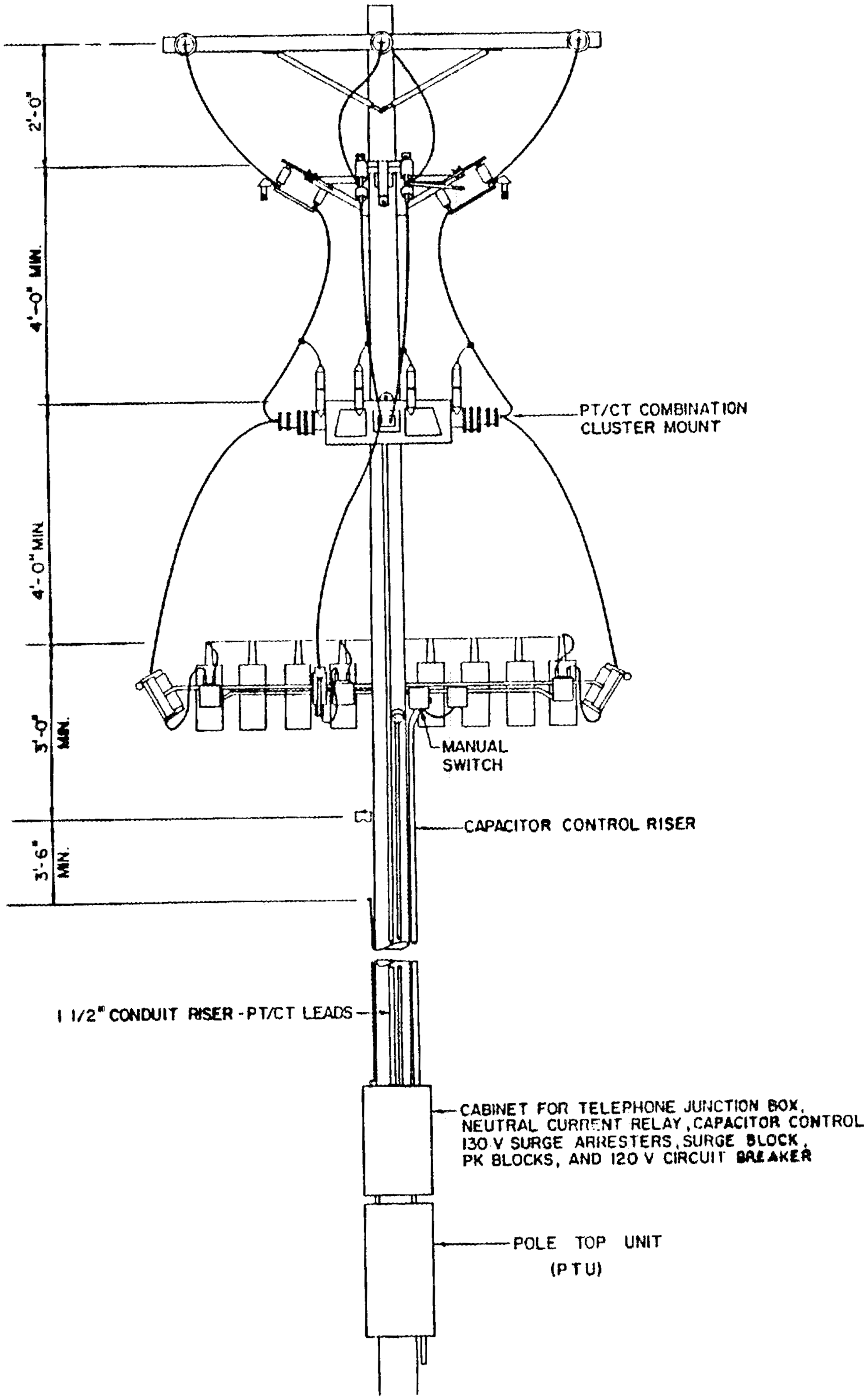
FEEDER MODELING

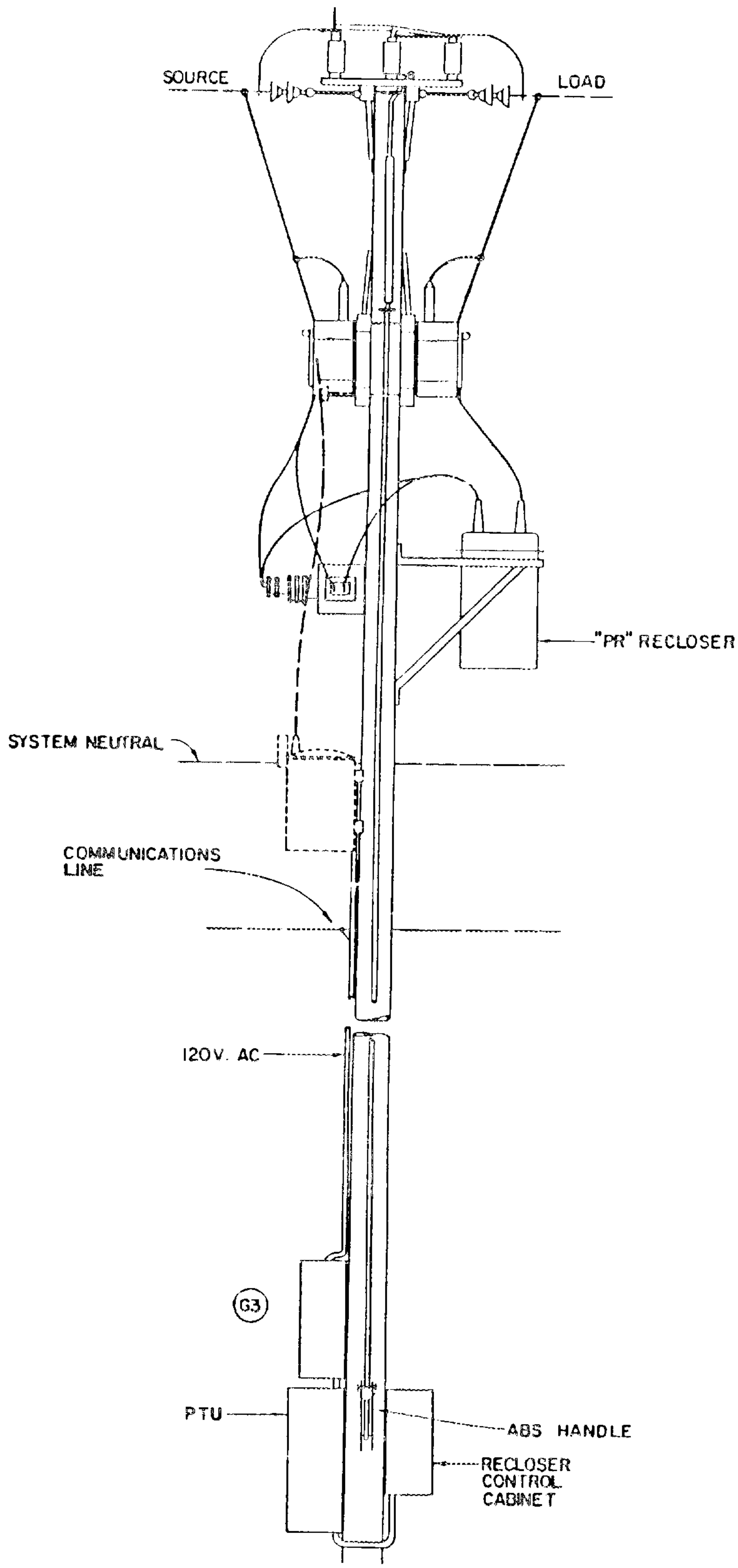
DETAILED MODEL VS. REDUCED MODEL

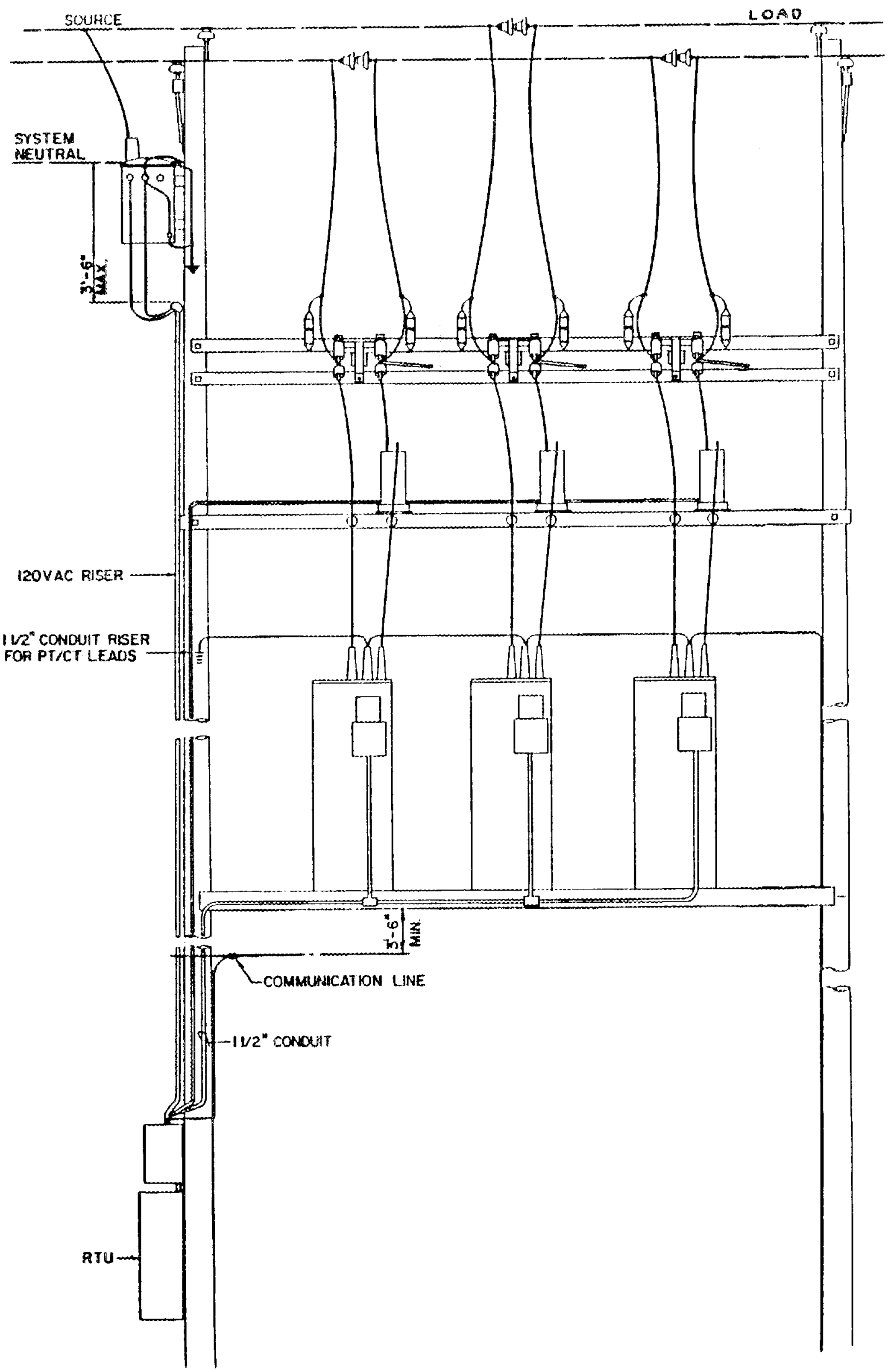
- DETAILED MODEL
  - 56 NODE FEEDER MODEL
  - POWER FLOW ANALYSIS
- REDUCED MODEL
  - 8 NODES & 7 LUMPED LOADS

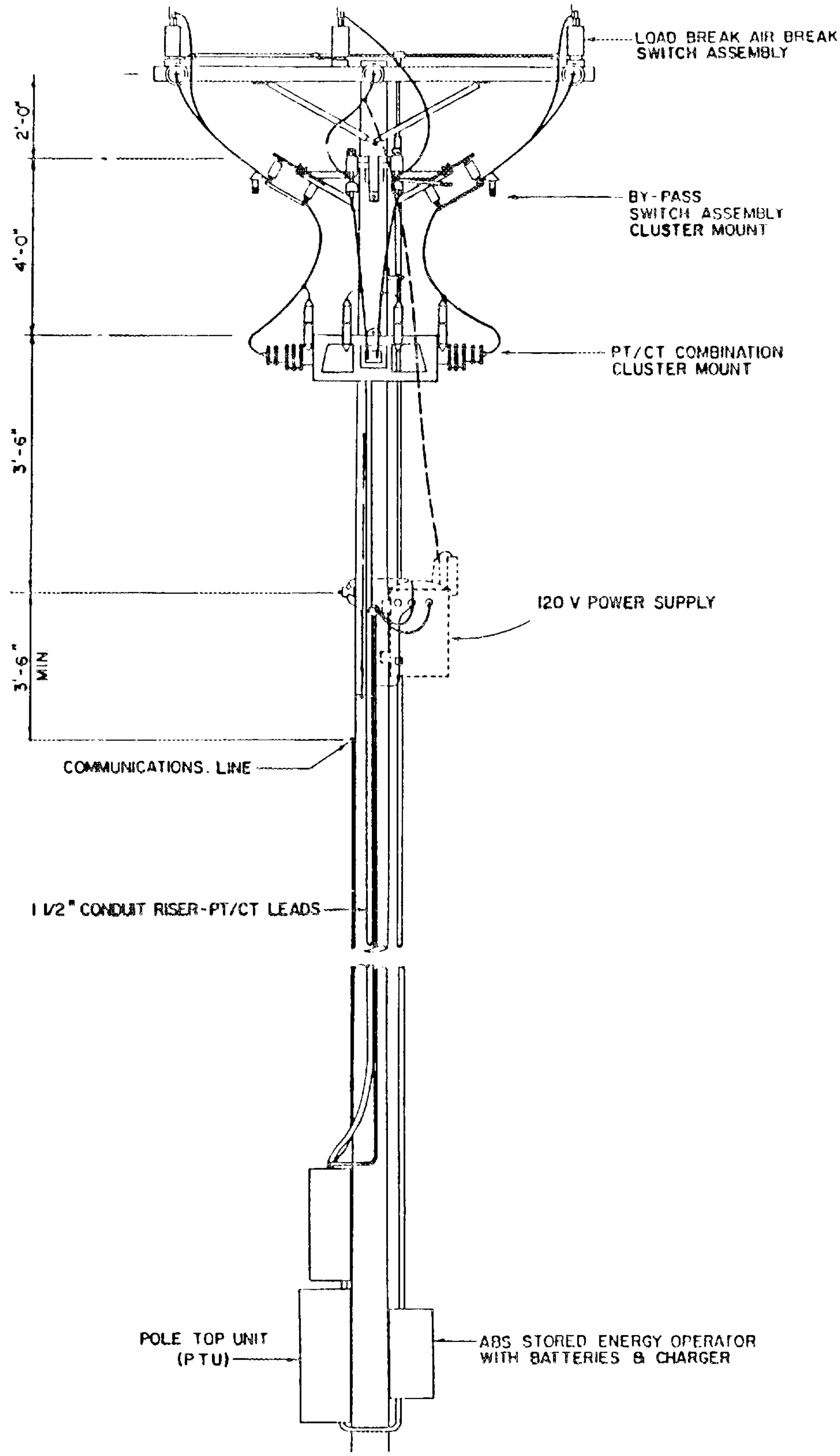

DETAILED AND REDUCED FEEDER MODELS
NO CAPACITORS
1 MVA BASE
13.2 KV BASE
MODELS
o = DETAILED
Δ = REDUCED
5% ERROR
1.25% ERROR
ACCUMLATIVE LOSSES
0.00
0.05
0.10
0.15
0.20
0.25
0.30
VOLTAGE
0.850
0.875
0.900
0.925
0.950
0.975
1.000
500
576
577
591
523
529
590
561
FEEDER NODE POINTS


DETAILED AND REDUCED FEEDER MODELS
ALL CAPACITORS SWITCHED IN
1 MVA BASE
13.2 KV BASE
MODELS
o = DETAILED
Δ = REDUCED
1.25% ERROR
5% ERROR
ACCUMLATIVE LOSSES
0.00
0.05
0.10
0.15
0.20
0.25
0.30
VOLTAGE
0.850
0.875
0.900
0.925
0.950
0.975
1.000
500
576
577
591
523
529
590
561
FEEDER NODE POINTS


2'-0"
4'-0" MIN.
4'-0" MIN
3'-0" MIN.
3'-6" MIN.
PT/CT COMBINATION CLUSTER MOUNT
MANUAL SWITCH
CAPACITOR CONTROL RISER
1 1/2" CONDUIT RISER - PT/CT LEADS
CABINET FOR TELEPHONE JUNCTION BOX, NEUTRAL CURRENT RELAY, CAPACITOR CONTROL 130 V SURGE ARRESTERS, SURGE BLOCK, PK BLOCKS, AND 120 V CIRCUIT BREAKER
POLE TOP UNIT (PTU)


SOURCE
LOAD
"PR" RECLOSER
SYSTEM NEUTRAL
COMMUNICATIONS
LINE
120V. AC
G3
PTU
ABS HANDLE
RECLOSER
CONTROL
CABINET


SOURCE
LOAD
SYSTEM NEUTRAL
3'-6" MAX.
120VAC RISER
1 1/2" CONDUIT RISER FOR PT/CT LEADS
3'-6" MIN.
COMMUNICATION LINE
1 1/2" CONDUIT
RTU


LOAD BREAK AIR BREAK SWITCH ASSEMBLY
BY-PASS SWITCH ASSEMBLY CLUSTER MOUNT
PT/CT COMBINATION CLUSTER MOUNT
120 V POWER SUPPLY
2'-0"
4'-0"
3'-6"
3'-6" MIN
COMMUNICATIONS. LINE
1 1/2" CONDUIT RISER-PT/CT LEADS
POLE TOP UNIT (PTU)
ABS STORED ENERGY OPERATOR WITH BATTERIES & CHARGER

SYSTEM RECONFIGURATION

OVERVIEW

The two major objectives of system reconfiguration are reliability enhancement and capacity utilization improvement. The expected benefit of system reconfiguration is lower energy costs. Improvements to system reliability will be achieved by automating the response time to outages caused by electrical faults and by automating the relief of line overloading conditions to avoid an outage. The increase in system capacity utilization will be achieved by optimizing the network configuration to best serve the changing electrical consumption patterns. To achieve these improvements, remote monitoring and fault detection will be used to reconfigure feeders using remotely controlled line switches.

The evaluation of the system reconfiguration experiment will involve reliability evaluation, capacity utilization evaluation, and overall evaluation. The benefits and costs of implementing the system reconfiguration functions on Athens Utilities Board's (AUB's) distribution system will be estimated to determine if the program objectives were accomplished and to quantify the benefits. The evaluation will include the performance of the AUB distribution system before automation, during the first year of operation, and during the second year of operation. These evaluations will be compared to the tests simulated on the AACE Test System.

MOTIVATING QUESTIONS FOR THE SYSTEM RECONFIGURATION EXPERIMENT

- What are the benefits of on-line reconfiguration of the distribution network?

- How much and what type of hardware is required to support system reconfiguration?

- What are the additional benefits of coordinating system reconfiguration with load control and volt/var control?

- From a second generation perspective, how should system reconfiguration be controlled?

SYSTEM RECONFIGURATION PROJECT TEAM

Jack Lawler

Jim Patton

Bob Stevens

Larry Monteen

SYSTEM RECONFIGURATION PRESENTATION OUTLINE

1. Introduction
2. Experiment objectives
3. Questions to be addressed by the experiment
4. Conclusions

ATHENS AUTOMATION AND CONTROL EXPERIMENT

SYSTEM RECONFIGURATION

Jack Lawler
Jim Patton
Bob Stevens
Larry Monteen

SYSTEM RECONFIGURATION PRESENTATION OUTLINE

1. Introduction

2. Experiment objectives

3. Questions to be addressed by the experiment

4. Conclusions

SYSTEM RECONFIGURATION

1. Introduction

- Definition of system reconfiguration
- System reconfiguration hardware
- System reconfiguration functions
- Control diagram

DEFINITION

System reconfiguration is the automatic monitoring of the distribution network operating condition and the intelligent control of distribution switching elements.

The potential benefits of system reconfiguration include enhanced service reliability and capacity utilization.

SYSTEM RECONFIGURATION HARDWARE

Controllable Switching Elements:

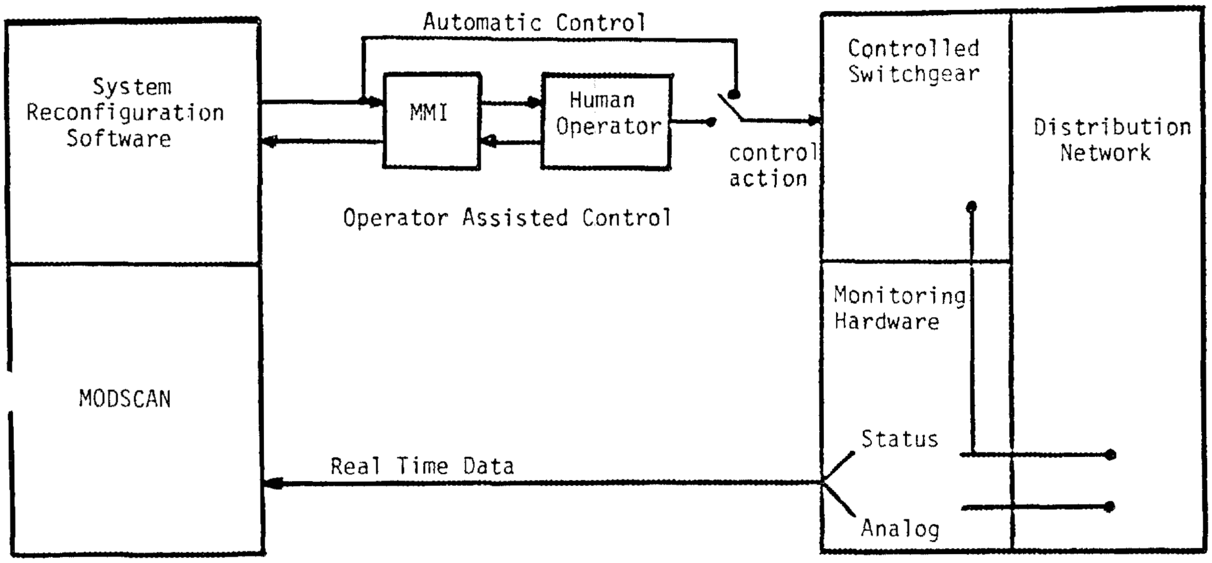
- Feeder breakers
- Power reclosers
- Motor operated load break switches

Monitoring Hardware:

- PTs and CTs for analog values
- Switching element status
- Relay status
- Fault detectors

SYSTEM RECONFIGURATION FUNCTIONS

1. Fault detection
2. Fault location
3. Fault Isolation
4. Service Restoration
5. Cold load pickup
6. Feeder Monitoring
7. Feeder load management
8. Substation load management
9. Adaptive protection



System Reconfiguration Block Diagram

SYSTEM RECONFIGURATION

2. Experiment Objectives

- Service reliability
- Capacity utilization
- Adaptive protection
- Hardware Requirements
- Information transfer

EXPERIMENTAL OBJECTIVES

I. Determine the improvement in distribution system service reliability that can be achieved by automating the detection, location and isolation of faults and subsequent service restoration.

II. Determine the improvement in distribution system capacity utilization with automated cold load pickup, feeder monitoring, feeder load management and substation load management functions.

EXPERIMENTAL OBJECTIVES

III. Determine whether or not adaptive protection is necessary to support on-line system reconfiguration.

IV. Study the amount of automation hardware required to improve distribution system service reliability and capacity utilization.

V. Transfer the experimental results to the electric utility industry.

SYSTEM RECONFIGURATION

3. Questions to be Addressed by the Experiment with Respect To:

    A. Service Reliability

    B. Capacity utilization

    C. Adaptive protection

SYSTEM RECONFIGURATION

3A Questions to be Addressed with Respect to Service Reliability Functions

SR-1 Fault Detection

SR-2 Fault Location

SR-3 Fault Isolation

SR-4 Service Restoration

SR-5 Cold Load Pickup

SR-1 FAULT DETECTION

1.1 What is the differential in fault detection time between present AUB practice (customer calls) and automation?

1.2 How many faults are detected by customers but are missed by automation?

1.3 How many faults occurred that the automation system wasn't designed to detect?

SR-1 FAULT DETECTION

1.4 How many false or inconsistent indications of faults are reported by automation?

1.5 What is the advantage of detecting fault current levels using fault detectors as opposed to monitoring recloser/sectionalizer status?

1.6 Can high impedance faults be detected by automation?

1.7 Will customers begin to rely on the automation and not report trouble?

SR-2 FAULT LOCATION

2.1 What is the difference in time between fault detection and fault location with automation as compared to present AUB practice?

2.2 What is the advantage of extensive fault monitoring for precision fault location as compared to moderate monitoring in terms of the speed of crew response?

2.3 How often does the crew find the fault in the zone indicated by automation?

SR-3 FAULT ISOLATION

3.1 How much time is required to isolate a faulted feeder section by automation as compared to manual isolation?

3.2 What is the benefit of controlled switching and monitoring as compared to monitoring only?

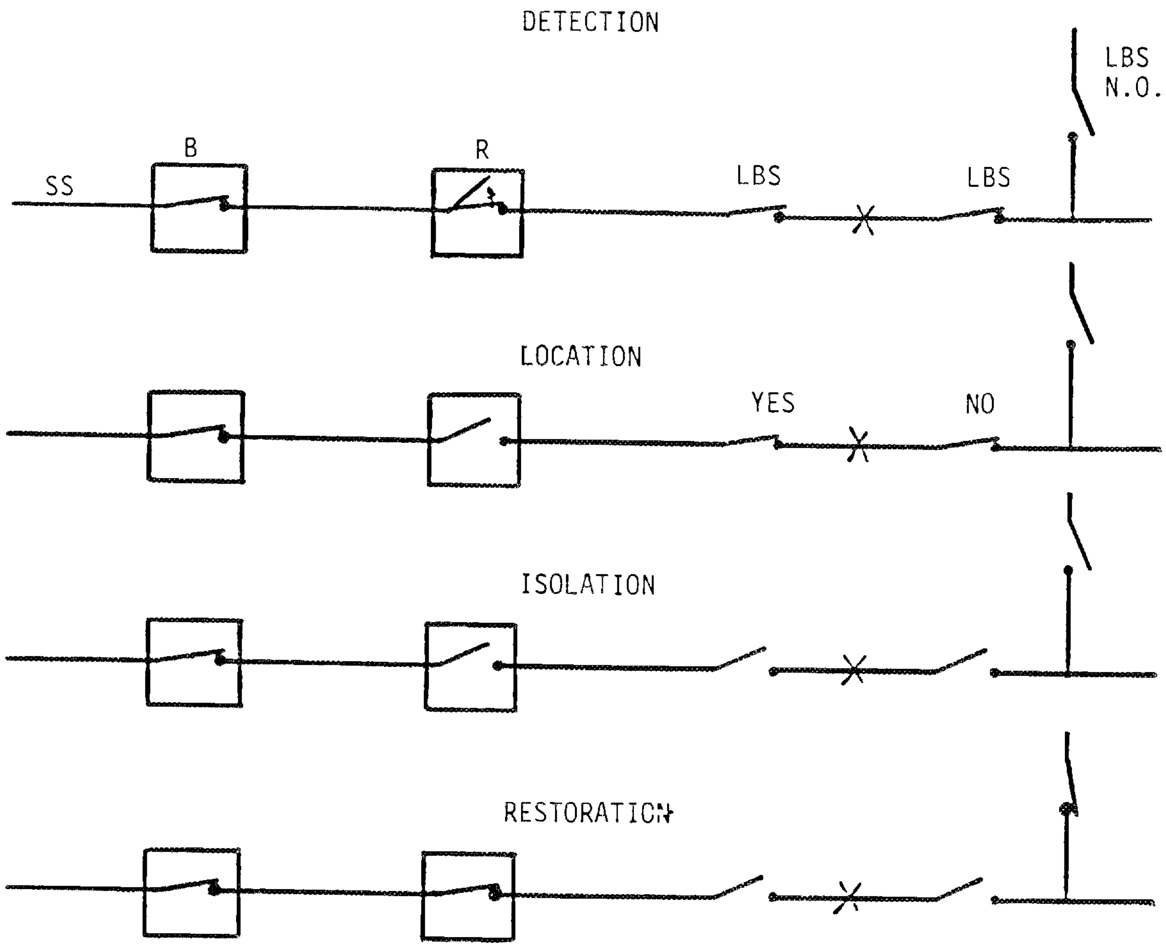
3.3 How many controlled switches should be used?

SR-4 SERVICE RESTORATION

4.1 How often is the proposed restoration unacceptable from a voltage, capacity or protection perspective?

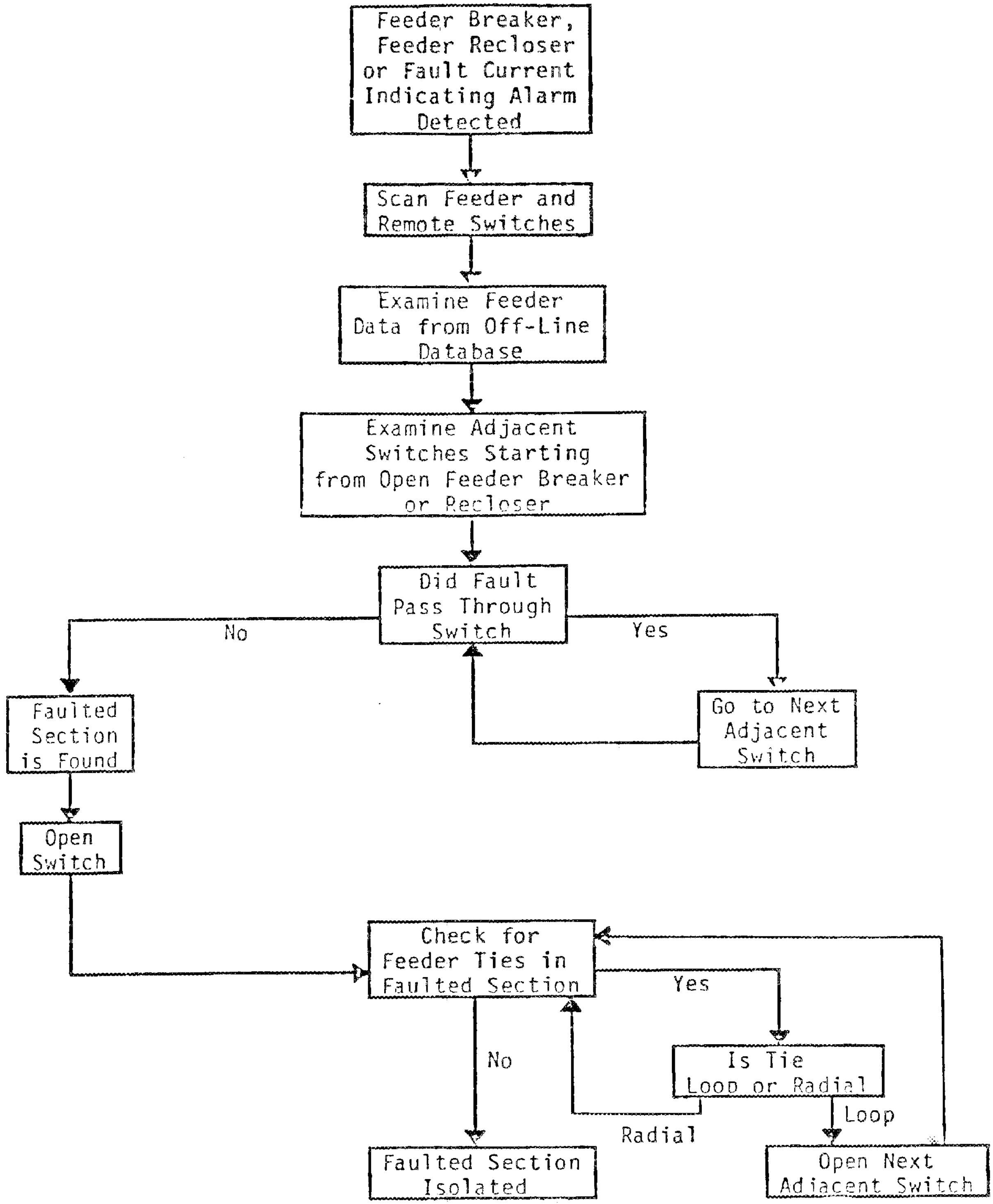
4.2 Can load control and/or volt/var control assist in service restoration?

4.3 Can service be restored from more than one feeder?



FAULT DETECTION, LOCATION, ISOLATION AND SERVICE RESTORATION - EXAMPLE

AUTOMATED FAULT DETECTION, LOCATION AND ISOLATION



SR-5 COLD LOAD PICKUP

5.1 What is the cold load overload as a function of temperature and outage time?

5.2 What percent of outages at AUB require relay adjustment to pickup the load?

5.3 Can cold load effects be reduced by lowering voltage?

5.4 How is the magnitude of overload related to the number of pickup stages?

SR-5 COLD LOAD PICKUP

5.5 What time should elapse between pickup stages?

5.6 Can feeder reconfiguration be used to reduce cold load pickup problems?

SYSTEM RECONFIGURATION

3B Questions to be Answered with Respect to Capacity Utilization Functions

SR-6 Feeder monitoring

SR-7 Feeder load management

SR-8 Substation load management

SR-6 FEEDER MONITORING

6.1 Where should the feeder be monitored?

6.2 What should be monitored?

6.3 What types of feeders should be monitored most closely?

6.4 What is the sensitivity of feeder loads to weather?

6.5 How closely do calculated voltages and flows agree with measured values?

SR-6 FEEDER MONITORING

6.6 Characterize load growth by area and customer type.

6.7 How often should feeder load information be archived?

6.8 What is the effect of load control on peak feeder loading?

6.9 What are the component loss of life consequences of load control?

6.10 Determine the load diversity between feeders with and without load control.

SR-7 FEEDER LOAD MANAGEMENT

7.1 How much can the daily feeder peak load be reduced by feeder load management?

7.2 What frequency of reconfiguration is desirable?

7.3 What impact can feeder load management have on planned feeder expansion/reinforcement?

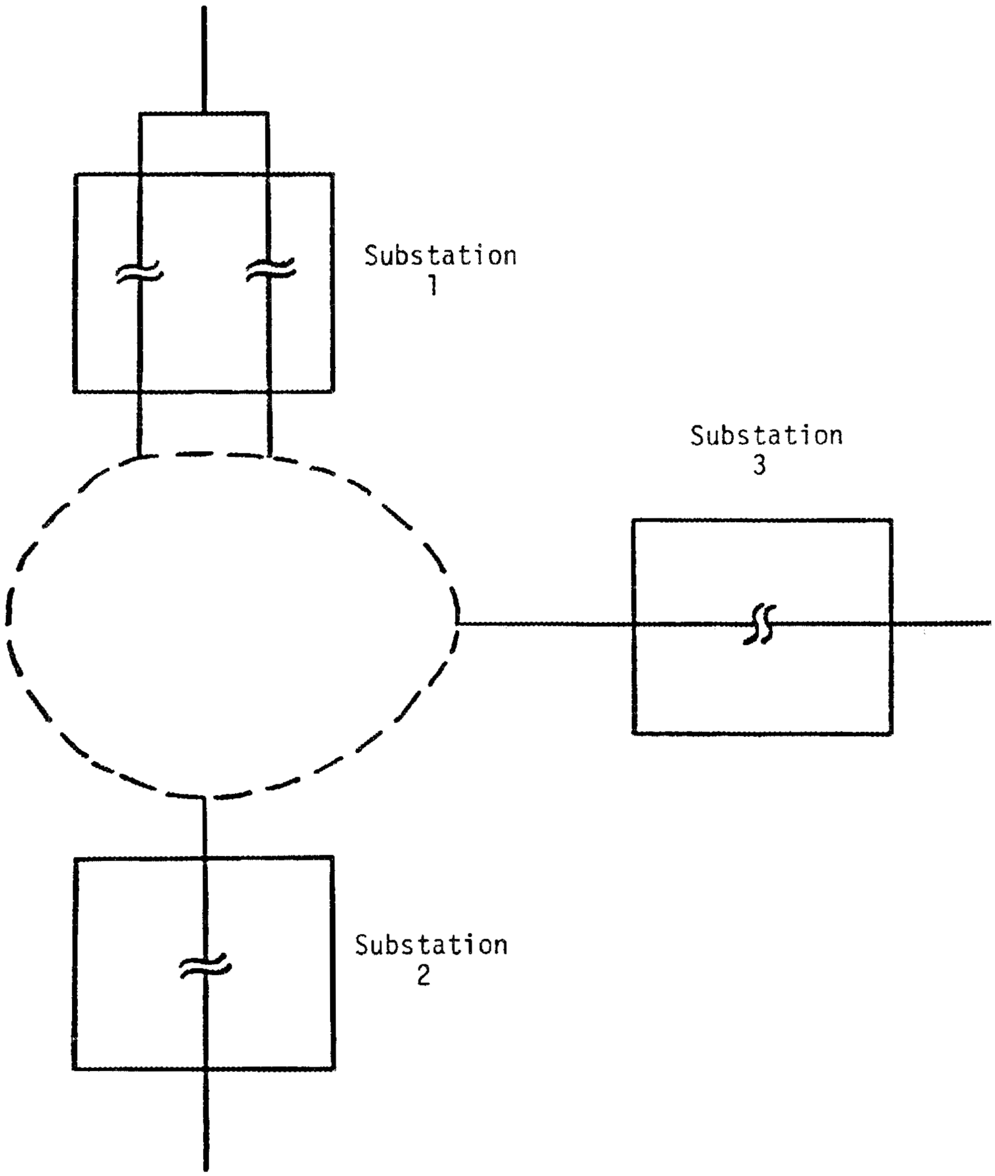
7.4 Can losses be reduced by switching loads from heavily loaded feeders to lightly loaded feeders?

SR-7 FEEDER LOAD MANAGEMENT

7.5 What are the constraints for automatic reconfiguration?

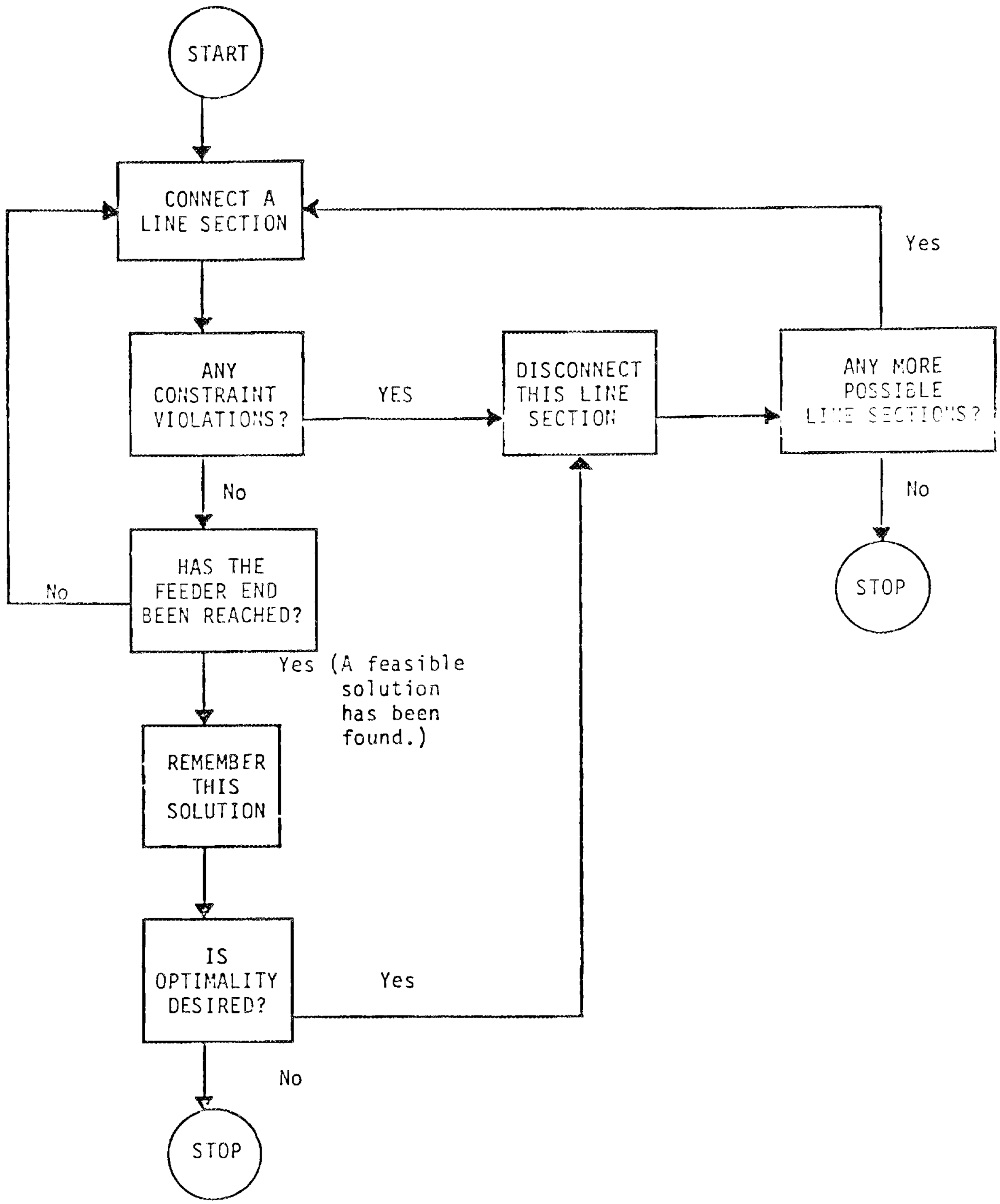
7.6 Can feeder load management reduce planned outage cost?

7.7 What is the cost of maintenance associated with feeder load management?



FIRM AREA CONCEPT

FLOW DIAGRAM FOR BRANCH AND BOUND METHOD
FOR AUTOMATED LOAD RESTORATION AND TRANSFER



SR-8 SUBSTATION LOAD MANAGEMENT

8.1 What are the constraints in initiating load transfers between feeders connected to different substations?

8.2 How much total load can be transferred by interties to provide firm area capacity?

8.3 Can load control be used to complement the firm area concept?

8.4 What is the impact of firm area operation on planned transformer capacity additions ?

SR-8 SUBSTATION LOAD MANAGEMENT

8.5 What frequency of substation-to-substation load transfers is desirable?

8.6 What additional transformer/conductor capacity can be obtained through operation based on dynamic thermal ratings as compared to static load limits?

8.7 Can transformer overloads be anticipated in time to shift loads?

SYSTEM RECONFIGURATION

3C Questions to be Answered with Respect to the Adaptive Protection Function

SR-9 Adaptive protection

SR-9 ADAPTIVE PROTECTION

9.1 What percentage of proposed reconfigurations will not coordinate?

9.2 Will the fault duty on any distribution equipment increase due to reconfiguration?

9.3 Are there times when the system is poorly coordinated due to natural load variation?

SR-9 ADAPTIVE PROTECTION

9.4 What is the time savings of automated versus manual setting of relays?

9.5 Can power recloser settings be adjusted to accomodate any reconfiguration?

9.6 Is adaptive protection required for system reconfiguration?

4. CONCLUSIONS

The objectives of the system reconfiguration experiment are:

1,2. Determine the improvements in distribution system service reliability and capacity utilization that can be achieved through system reconfiguration.

3. Determine whether or not adaptive protection is necessary to support system reconfiguration.

4. Determine the amount and type of automation hardware required.

5. Transfer the experiment findings to the electric utility industry.

The questions raised with respect to each of the 9 system reconfiguration functions will be the basis for the detailed test plan.

LIST OF ATTENDEES

LIST OF ATTENDEES

David L. Barker
Tennessee Valley Authority
1709 S. Lee Highway
Cleveland, TN 37311
(615) 751-8061

Richard L. Berganini
Control Data Corporation
2300 Berkshire Lane, North
PLY011
Plymouth, MN 55441
(612) 553-4425

David Berkowitz
Westinghouse Electric Corp.
P.O. Box 9533
Raleigh, NC 27611
(919) 834-5271

Douglas Birdwell
Consultant
Oak Ridge National Laboratory
P.O. Box X
Building 5500, MS A218
Oak Ridge, TN 37831
(615) 574-5206

Thomas Blessing
Texas Power and Light Co.
P.O. Box 660268
Dallas, TX 75266-0268
(214) 954-5703

Arthur Boecker
City of Austin Elec. Util.
301 W. Avenue
Austin, TX 76653
(512) 397-1632

Eva R. Broadaway
Oak Ridge National Laboratory
P.O. Box X
Building 3500, MS-7
Oak Ridge, TN 37831
(615) 574-6894

James Bruce
Texas Power and Light Co.
P.O. Box 660268
Dallas, TX 75266-0268
(214) 954-5852

James Burke
PTI
1482 Erie Boulevard
Schenectady, NY 12301
(518) 378-1220

David Canon
Dallas Power & Light Co.
1506 Commerce Street
Dallas, TX 75201
(214) 698-7137

Mo Shing Chen
University of Texas at Arlington
UTA Box 19048
Arlington, TX 76019
(817) 273-3882

Wen-Chen Chu
University of Texas at Arlington
UTA Box 19048
Arlington, TX 76018
(817) 273-3882

Kay Clinard
Carolina Power & Light Company
P.O. Box 1551
Raleigh, NC 27602
(919) 836-6793

Thomas Collen
BBC Brown Boveri, Inc.
2435 Pilot Knob Road
P.O. Box 21308
St. Paul, MN 55121
(612) 452-9400

Ernest Dawson
Baltimore Gas & Electric Company
Room 900 Gas & Electric Building
P.O. Box 1475
Baltimore, MD 21203
(301) 234-5732

John Detwiler
BBC Brown Boveri, Inc.
4709 Baum Boulevard
Pittsburgh, PA 15213
(412) 622-6200

Alex Domijan
ESRC, VTA
Arlington, TX 76010
(817) 460-0123

Len Eaton
Sangamo Westom
180 Technology Parkway
Norcross, GA 30092
(404) 441-9006

Wally Echols
City of Austin Electric Utility
P.O. Box 1088
Austin, TX 78767
(512) 397-1469

Reed Feuster
AT&T—Bell Labs
Room 3B-110 WB
Holmdel, NJ 07733
(201) 870-7610

Linda Finley
Houston Power and Light
P.O. Box 1700
Houston, TX 77005
(713) 229-7786

Nick Fortson
Athens Utilities Board
100 Englewood Road
Athens, TN 37303
(615) 745-4501

Charles Gentz
Public Service Electric & Gas
80 Park Place
Newark, NJ 07101
(201) 430-7000

Paul Gnadt
Oak Ridge National Laboratory
P.O. Box X
Building 5500, MS A218
Oak Ridge, TN 37831
(615) 574-0266

Juan Gonzalez
Florida Power & Light Co.
9250 West Flagler Street
Room 5030
Miami, FL 33152
(305) 552-3035

George Gurr
Electric Power Research Institute
P.O. Box 10412
Palo Alto, CA 94303
(415) 855-8958

Larry Hamant
Control Data Corporation
2300 Berkshire Lane, North
PLY011
Plymouth, MN 55441
(612) 553-4859

Robert Harmon
A. B. Chance
210 N. Allen Street
Centralia, MO 65240
(314) 682-8295

Wayne Hilson
Tennessee Valley Authority
109 United Bank Building
Chattanooga, TN 37401
(615) 751-5685

Pat Hu
Oak Ridge National Laboratory
P.O. Box X
Building 4500N, MS G22
Oak Ridge, TN 37831
(615) 574-5284

John Jerrim
Sangamo Westom
180 Technology Parkway
Norcross, GA 30092
(404) 441-9006

John Kazanowski
General Electric Company
607 Tallan Building
Chattanooga, TN 37402
(615) 755-5008

Henry Knight
Dallas Power and Light Company
1506 Commerce Street
Dallas, TX 75201
(214) 698-7170

Roger Knipp
Dallas Power and Light Company
1506 Commerce Street
Dallas, TX 75201
(214) 698-7757

Jack Lawler
Consultant
Oak Ridge National Laboratory
P.O. Box X
Building 5500, MS A218
Oak Ridge, TN 37831
(615) 574-5206

Robert Lee
Pennsylvania Power & Light Co.
1005 Brookside Road
P.O. Box 3328
Wescosville, PA 18106
(215) 398-5150

Whei-Min Lin
University of Texas at Arlington
UTA Box 19048
Arlington, TX 76010
(817) 273-2268

George Lutes
Jet Propulsion Laboratory
4800 Oak Grove Drive
M/S 238/420
Pasadena, CA 91109
(818) 354-6210

Sioe Mak
Chance Load Management Systems
5657 Campus Parkway
Hazelwood, MO 63042
(314) 895-6500

Larry Markel
Electrotek Concepts, Inc.
2570 El Camino, West
Suite 404
Mountain View, CA 94040
(415) 941-2986

Frank Maxwell
Florida Power & Light Co.
4200 W. Flagler
P.O. Box 029311
Miami, FL 33102
(305) 442-5464

Larry McCall
Ontario Hydro
700 University Avenue
Toronto, Ontario, Canada M5G1X6
(416) 592-4781

Michael McCallum
Florida Power & Light Co.
9250 W. Flagler Street
Distribution Engineering Dept.
Miami, FL 33174
(305) 552-4497

Julia McIntyre
Consultant
1364 Parkhill Drive
Huntington, IN 46750
(219) 356-5004

Kevin McKinley
Baltimore Gas & Electric Co.
P.O. Box 1475
Room 303, Front Street Building
Baltimore, MD 21203
(301) 234-7293

Larry Monteen
Athens Utilities Board
100 Englewood Road
Athens, TN 37303
(615) 745-4501

Dennis Nightingale
Jet Propulsion Laboratory
4800 Oak Grove Drive
M/S 126/235
Pasadena, CA 91109
(818) 354-6441

Fred Oberlender
Fred Oberlender & Associates, Inc.
10821 Sanden Drive
Dallas, TX 75238
(214) 343-1946

Jim Patton
Consultant
P.O. Box 3447
Durango, CO 81301
(303) 247-2417

Gustavo Paz
Philadelphia Electric Company
2301 Market Street
Research Division, S10-1
Philadelphia, PA 19101
(215) 841-4865

Steve Purucker
Oak Ridge National Laboratory
P.O. Box X
Building 5500, MS A218
Oak Ridge, TN 37831
(615) 576-5233

Judd Putnam
Dallas Power & Light Company
1506 Commerce Street
Dallas, TX 75201
(214) 698-7139

John Reed
Oak Ridge National Laboratory
P.O. Box X
Building 5500, MS A218
Oak Ridge, TN 37831
(615) 576-5042

Dietrich Roesler
Department of Energy, CE-143
Electric Energy Systems Division
1000 Independence Avenue, S.W.
Washington, DC 20585
(202) 252-1165

William Rom
EBASCO
145 Technology Park
Norcross, GA 76019
(404) 662-2017

Raymond Shoults
University of Texas at Arlington
UTA Box 19048
Arlington, TX 76019
(817) 273-3882

Gordon Sloan
Sulphur Springs Valley Electric
Wilcox, AZ 85634
(602) 384-2221

Bruce Smith
Minimax
2435 Durant Avenue
Berkeley, CA 94704
(415) 548-2548

Ron Smith
Houston Power & Light Company
P.O. Box 1700
Houston, TX 77083
(713) 229-7395

Robert Stevens
Oak Ridge National Laboratory
P.O. Box X
Building 5500, MS A218
Oak Ridge, TN 37831
(615) 574-5003

Robert L. Sullivan
University of Florida
Dept. of Electrical Engineering
Gainesville, FL 32605
(904) 392-4038

Terry Taylor
Dallas Power & Light Company
1506 Commerce Street
Dallas, TX 75201
(214) 698-3668

Frank Tighe, Jr.
S&C Electric Company
6601 N. Ridge Boulevard
Chicago, IL 60626
(312) 338-1000

Brian Trager
McGraw-Edison
Power Systems Division
P.O. Box 2850
Pittsburgh, PA 15230
(412) 777-3377

Ying-Hsten Tsai
University of Texas at Arlington
P.O. Box 19048
Arlington, TX 76019
(817) 273-3847

George Usry
Athens Utilities Board
100 Englewood Road
Athens, TN 37303
(615) 745-4501

Michael Warwick
Bonneville Power Administration
P.O. Box 3621
MS-KES
Portland, OR 97208
(503) 230-5429

Robert Wehmeyer
Texas Electric Service Company
P.O. Box 970
Fort Worth, TX 76101
(817) 336-6362

Barbara Weinstein
AT&T—Bell Labs
WB 3B-107
Crawfords Corner Road
Holmdel, NJ 07733
(201) 870-7598

Randall Wetherington
Oak Ridge National Laboratory
P.O. Box X
Building 3500, MS-17
Oak Ridge, TN 37831
(615) 574-5717

Glynn Williams
Florida Power & Light Company
700 Universe Boulevard
Juno Beach, FL 33408
(305) 863-3712

Del Wilson
Power Technologies, Inc.
P.O. Box 1058
1482 Erie Boulevard
Schenectady, NY 12301-1058
(518) 374-1220

Internal Distribution

1. E. R. Broadaway
2. R. S. Carlsmith
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6. F. C. Maienschein
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External Distribution

47. David L. Barker, Tennessee Valley Authority, 1709 S. Lee Highway, Cleveland, TN 37311
48. Richard L. Berganini, Control Data Corporation, 2300 Berkshire Lane, North, PLY011, Plymouth, MN 55441
49. David Berkowitz, Westinghouse Electric Corp., P.O. Box 9533, Raleigh, NC 27611
50. J. D. Birdwell, Department of Electrical Engineering, The University of Tennessee, Knoxville, TN 37916
51. Thomas Blessing, Texas Power and Light Co., P.O. Box 660268, Dallas, TX 75266-0268
52. Arthur Boecker, City of Austin Elec. Util., 301 W. Avenue, Austin, TX 76653
53. S. D. Braithwait, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
54. James Bruce, Texas Power and Light Co., P.O. Box 660268, Dallas, TX 75266-0268
55. James Burke, PTI, 1482 Erie Boulevard, Schenectady, NY 12301
56. David Canon, Dallas Power & Light Co., 1506 Commerce Street, Dallas, TX 75201
57. Dick Castamore, Tennessee Valley Authority, 1150 Chestnut Street, Tower 2, Chattanooga, TN 37402
58. Mo Shing Chen, University of Texas at Arlington, UTA Box 19048, Arlington, TX 76019
59. Wen-Chen Chu, University of Texas at Arlington, UTA Box 19048, Arlington, TX 76018
60. Kay Clinard, Carolina Power & Light Company, P.O. Box 1551, Raleigh, NC 27602
61. Thomas Collen, BBC Brown Boveri, Inc., 2435 Pilot Knob Road, P.O. Box 21308, St. Paul, MN 55121
62. Ernest Dawson, Baltimore Gas & Electric Company, Room 900 Gas & Electric Building, P.O. Box 1475, Baltimore, MD 21203
63. John Detwiler, BBC Brown Boveri, Inc., 4709 Baum Boulevard, Pittsburgh, PA 15213

64. Alex Domijan, ESRC, VTA, Arlington, TX 76010
65. Len Eaton, Sangamo Westom, 180 Technology Parkway, Norcross, GA 30092
66. R. Eaton III, Department of Energy, CE-143, Office of Energy Storage and Distribution, Electric Energy Systems Division, 1000 Independence Avenue, S.W., Washington, DC 20585
67. Wally Echols, City of Austin Electric Utility, P.O. Box 1088, Austin, TX 78767
68. Alfred Farman, California Utilities Commission, Room 2011, State Building Civic Center, San Francisco, CA 94102
69. Reed Feuster, AT&T — Bell Labs, Room 3B-110 WB, Holmdel, NJ 07733
70. Linda Finley, Houston Power and Light, P.O. Box 1700, Houston, TX 77005
71. Nick Fortson, Athens Utilities Board, 100 Englewood Road, Athens, TN 37303
72. Clark Gellings, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
73. Charles Gentz, Public Service Electric & Gas, 80 Park Place, Newark, NJ 07101
74. S. Malcolm Gillis, Economics and Public Policy, Department of Economics, Duke University, 4875 Duke Station, Durham, NC 27706
75. Juan Gonzalez, Florida Power & Light Co., 9250 West Flagler Street, Room 5030, Miami, FL 33152
76. George Gurr, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
77. Larry Hamant, Control Data Corporation, 2300 Berkshire Lane, North, PLY011, Plymouth, MN 55441
78. Robert Harmon, A. B. Chance, 210 N. Allen Street, Centralia, MO 65240
79. Wayne Hilson, Tennessee Valley Authority, 109 United Bank Building, Chattanooga, TN 37401
80. John Jerrim, Sangamo Westom, 180 Technology Parkway, Norcross, GA 30092
81. Fritz R. Kalhammer, Vice President, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
82. Roger E. Kasperson, Graduate School of Geography, Clark University, Worcester, MA 01610
83. John Kazanowski, General Electric Company, 607 Tallan Building, Chattanooga, TN 37402
84. Tom Kendrew, Electric Power Research Institute, P.O. Box 10412, Palo Alto, CA 94303
85. K. W. Klein, Department of Energy, CE-143, Office of Energy Storage and Distribution, Electric Energy Systems Division, 1000 Independence Avenue, S.W., Washington, DC 20585
86. Henry Knight, Dallas Power and Light Company, 1506 Commerce Street, Dallas, TX 75201
87. Roger Knipp, Dallas Power and Light Company, 1506 Commerce Street, Dallas, TX 75201
88. J. Lancaster, Tennessee Valley Public Power Association, 831 Chestnut Street, Chattanooga, TN 37402
89. J. S. Lawler, Department of Electrical Engineering, The University of Tennessee, Knoxville, TN 37916
90. Robert Lee, Pennsylvania Power & Light Co., 1005 Brookside Road, P.O. Box 3328, Wescosville, PA 18106

91. Martin Lessen, 12 Country Club Road, Rochester, NY 14618
92. Whei-Min Lin, University of Texas at Arlington, UTA Box 19048, Arlington, TX 76010
93. George Lutes, Jet Propulsion Laboratory, 4800 Oak Grove Drive, M/S 238/420, Pasadena, CA 91109
94. Sioe Mak, Chance Load Management Systems, 5657 Campus Parkway, Hazelwood, MO 63042
95. Larry Markel, Electrotek Concepts, Inc., 2570 El Camino, West, Suite 404, Mountain View, CA 94040
96. Frank Maxwell, Florida Power & Light Co., 4200 W. Flagler, P.O. Box 029311, Miami, FL 33102
97. Larry McCall, Ontario Hydro, 700 University Avenue, Toronto, Ontario, Canada M5G1X6
98. Michael McCallum, Florida Power & Light Co., 9250 W. Flagler Street, Distribution Engineering Dept., Miami, FL 33174
99. Julia McIntyre, 1364 Parkhill Drive, Huntington, IN 46750
100. Larry Monteen, Athens Utilities Board, 100 Englewood Road, Athens, TN 37303
101. Brian Newton, Minimax, 2150 Kittredge Avenue, Berkeley, CA 94704
102. Dennis Nightingale, Jet Propulsion Laboratory, 4800 Oak Grove Drive, M/S 126/235, Pasadena, CA 91109
103. Fred Oberlender, Fred Oberlender & Associates, Inc., 10821 Sanden Drive, Dallas, TX 75238
104. Jim Patton, P.O. Box 3447, Durango, CO 81301
105. Gustavo Paz, Philadelphia Electric Company, 2301 Market Street, Research Division, S10-1, Philadelphia, PA 19101
106. Judd Putnam, Dallas Power & Light Company, 1506 Commerce Street, Dallas, TX 75201
107. Dietrich Roesler, Department of Energy, CE-143, Electric Energy Systems Division, 1000 Independence Avenue, S.W., Washington, DC 20585
108. William Rom, EBASCO, 145 Technology Park, Norcross, GA 76019
109. N. D. Sadandan, Tennessee Valley Authority, 1150 Chestnut Street, Tower 2, Chattanooga, TN 37402
110. Raymond Shoults, University of Texas at Arlington, UTA Box 19048, Arlington, TX 76019
111. Joe Skroski, Atlantic Electric, P.O. Box 1264, Atlantic City, NJ 08232
112. Gordon Sloan, Sulphur Springs Valley Electric, Wilcox, AZ 85634
113. Bruce Smith, Minimax, 2435 Durant Avenue, Berkeley, CA 94704
114. Ron Smith, Houston Power & Light Company, P.O. Box 1700, Houston, TX 77083
115. Robert L. Sullivan, University of Florida, Dept. of Electrical Engineering, Gainesville, FL 32605
116. Terry Taylor, Dallas Power & Light Company, 1506 Commerce Street, Dallas, TX 75201
117. Scott Thomas, McGraw-Edison, Power Systems Division, P.O. Box 2850, Pittsburgh, PA 15230
118. Frank Tighe, Jr., S&C Electric Company, 6601 N. Ridge Boulevard, Chicago, IL 60626

119. Brian Trager, Fisher Pierce/Sigma Instruments, 170 Pearl Street, Braintree, MA 02184
120. Ying-Hsten Tsai, University of Texas at Arlington, P.O. Box 19048, Arlington, TX 76019
121. George Usry, Athens Utilities Board, 100 Englewood Road, Athens, TN 37303
122. Michael Warwick, Bonneville Power Administration, P.O. Box 3621, MS-KES, Portland, OR 97208
123. Robert Wehmeyer, Texas Electric Service Company, P.O. Box 970, Fort Worth, TX 76101
124. Barbara Weinstein, AT&T — Bell Labs, WB 3B-107, Crawfords Corner Road, Holmdel, NJ 07733
125. Glynn Williams, Florida Power & Light Company, 700 Universe Boulevard, Juno Beach, FL 33408
126. Del Wilson, Power Technologies, Inc., P.O. Box 1058, 1482 Erie Boulevard, Schenectady, NY 12301-1058
127. Institute for Energy Analysis, ORAU Library
128. Office of the Assistant Manager for Energy Research and Development, DOE-ORO, Oak Ridge, TN 37831

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