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OPTIMAL CONFIGURATION OF DATA COMMUNICATIONS NETWORK FOR A REAL-TIME POWER MANAGEMENT SYSTEM

by

Richard M. Cogan

A Thesis
Presented to the Graduate Committee
of Lehigh University
in Candidacy for the Degree of
Masters of Science
in
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CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering.

4/30/87
(date)

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ABSTRACT

This Thesis is concerned with the data communication between sites of the Power Management System. The Power Management System is used to monitor and coordinate the operation of the Pennsylvania Power & Light (PP&L) electrical power system. The center of the Power Management System is the Power Control Center which monitors and coordinates the operation of generation facilities, the high voltage network transmission and operation of the six Division SCADA Systems. Each Division SCADA System (DSS) monitors and coordinates the operation of the low voltage transmission system in one of the six operating areas (divisions) comprising the PP&L service territory.

A Data Communications Network is proposed to interconnect the seven sites comprising the Power Management System, allowing them to operate as a coordinated unit under the direction of the Power Control Center (PCC). The information exchange between sites, and thus the configuration of the Data Communications Network, is critical to the ability of the Power Management System to effectively coordinate the operation of the electrical network. In this thesis

a determination of an optimal configuration for the Data Communications Network is investigated. In this thesis we have concentrated on four alternatives designated as the STAR, MESH, HUB-STAR and MODIFIED HUB-STAR. Based on our investigation it appears the HUB-STAR configuration would best support objectives in terms of performance, reliability and economics. The principle advantage of the configuration is its superior utilization of the communcations circuits.

This thesis provides an introduction to the Electrical Power System and PP&L Power Management System. A chapter is included which describes the data to be communicated between sites of the Power Management System along with the the associated transfer requirements. The next chapter describes the four configurations investigated, the communication loading scenarios, the queueing theorey based simulation program and support programs employed, and the methodology applied. A chapter follows which presents a discussion of the results of the investigation and a final chapter is conclusions and recommendations.

CHAPTER 1

INTRODUCTION

The purpose of this investigation is to determine the optimal configuration of a Computer Network to support the Real Time Management of the Electrical Power System.

This Introduction is intended to provide a general background on the operation of the Electrical Power System and the relation of communications to that task. The Introduction is organized into four subsections as follows:

1. The Electrical Power System.

2. The computer based systems used to monitor and control the Electrical Power System.

3. The relation of communications to the Electrical Power System.

4. An introduction to the remainder of this thesis.

1.1 ELECTRICAL POWER SYSTEM (EPS)

In its base form, the Electrical Power Systems can be simply defined as an interconnection of various nodes. This type of representation is the same way the Power System is represented in programs for analysis of operation. In this definition, nodes are classified into four major categories:

1. Generators - any node in the electrical network which injects energy into the Power System, (the net power flow is out of the node).

2. Loads - the users of energy, nodes which extract energy from the Power System, (the net power flow is into the node).

3. Busses - nodes at which lines are interconnected at the same voltage level, (power flow into node equals power flow out).

4. Transformers - nodes at which voltage levels are changed, (ideally, power flow into the node equals power flow out).

All types of Power Plants (coal, oil, nuclear, etc.) are obvious examples of Generator nodes. In addition, there are often smaller generators attached to the electrical network, not in the realm of a power plant, which are also classified as generators since the net electrical exchange on this nodes is energy out to the network.

Load nodes, the users of electrical energy, encompass a broad range of possibilities. A load can be anything from a single home to a large manufacturing plant or steel mill. For the sake of simplicity in evaluating the electrical network, small load nodes such as homes are normally grouped together and represented by a single large node. This type of simplification has proven very feasible since the modeling of a single large node can be better characterized than multiple models of single small nodes. Large users of electrical power are more often represented individually for electrical analysis since changes at a single location can have visible impact on the electrical network.

Busses are nodes within the electrical network at which multiple transmission lines are physically linked together, and they are always associated with Generators and Transformers. Busses are important because they can account for the interaction of individual lines which are physically interconnected.

Transformers are the machines used to change the voltage levels of the electricity being transferred on the electrical power system. Transformer nodes are very significant since they represent the coupling of various transmission facilities, including generators, loads and the transmission lines. The following analysis is given to provide a better understanding of the need for transformers on the electric power system.

Various voltage levels are used within the electrical power system to accommodate the varying needs of energy transfers. For large quantities of energy being transferred over long distances high voltage level transmission is used in order to minimize the losses. The reasoning behind this approach is as follows:

1. Power to be Transferred is the product of voltage times the current.

2. In long distance transfers the major loss of power is due to the physical line resistance associated with the transmission lines.

3. The amount of power loss due to line resistance is the result of current squared times the resistance.

4. To minimize the loss due to resistance the current should be minimized.

5. For the transfer of a fixed amount of energy, voltage must be increased in order to minimize the current.

For transfers of lesser amounts of energy over shorter distances lower voltage transmissions are used. The selection of proper voltage levels to be used for power transfers is done based on a number of parameters, the principle ones which are saftey, compatibility, reliability, loss minimization and costs. None of these parameters can be fully considered without consideration of the others. In some instances the optimization of one parameter coincides with optimization of another, but in many instances optimization of one parameter conflicts with another. As an example, for both saftey and compatibility the use of low voltages into individual homes makes sense but in respect to loss minimization this is not the optimal solution. As it turns out for this instance, safety and compatibility are considered very important in relation to minimizing losses, which in this case are small anyway, thus low level voltages are used.

The Nodes of the Electrical Power System are connected by a system of wires, cables and switches. The combination of the wires, cables, switches with transformers and busses is referred to as the transmission system. The wires and cables are the transport mechanism of electricity and come in an assortment of sizes depending on the voltage and current to be transferred. The characteristics of most significance in modeling cables and wires are the resistance (ohms/mile) and the length.

The general category of switches encompasses a variety of devices principally classified as circuit breakers, automatic disconnects and manual disconnects. Switches are necessary for the reliability of the transmission system. Within the transmission system switches allow for reconfiguration to accommodate for the loss of devices within the system and/or changes in electrical characteristics, such as a loss of a generator or a load. An example of using a switch is the instance where a transformer at a substation is taken out of service for maintenance. For this condition outages to customers normally served from that transformer are not considered reasonable. Switches allow for the transmission system to be reconfigured so an alternative transformer can provide electrical service to those customers, and interruption of service is minimized.

Another important aspect of the transmission system is its subdivision into two major parts, Network and Distribution. Network transmission is characterized by the existence of multiple paths between nodes allowing for greater reliability and transfer capability. The Network portion of the transmission system is typically associated with the transfer of large amounts of energy at high (69 kVolts and above) voltage levels. Distribution transmission deals, in general, with lesser amounts of energy and lower voltage transfers (12 kVolts and below). Distribution transmission is characterized by single paths between nodes, often referred to as radial lines. No provision for automatic rerouting of electricity to accommodate for losses is provided.

1.2 MONITOR AND CONTROL OF THE ELECTRICAL POWER SYSTEM

The Electrical Power System can be very complex and a variety of schemes are used for controlling and monitoring it. This section first presents an overview of the control and then of the monitoring.

Control of the EPS can be divided into two main categories according to how control is initiated, automatic or manual. Automatic control is initiated in response to a predefined condition and without human intervention. On the other hand manual control, by definition, requires some human action to take place in order for action to occur. Devices which are normally under automatic control also include provisions for manual control but devices which are normally under manual control most often do not include provision for automatic operation. A Circuit Breaker is an example of a device which can be operated by either automatic or manual means whereas a hand operated disconnect switch is an example of a device which only can be operated manually.

Automatic control on the EPS usually involves relaying and is characterized by application to a small portion or pieces of the electrical system. Automatic control is normally concerned with the protection of some device or a segment of line, without regard to the Power System in general. Some examples of automatic control include overcurrent relay protection operating breakers in order to isolate a transmission lines from conditions of excess current transfer, transformer breaker operating in response to relaying scheme designed to limit oil temperature, and generator control unit modifying steam input based on feedback loops monitoring output power.

Manual control within the EPS requires human initiation, though the actual operation of a device may be mechanized. Manual control is available for virtually all controllable devices within the Power System. This control is normally only exercised for maintenance purposes or to make provisions for exceptional conditions in the power system. An example of manual device control is using hand operated switches to isolate a circuit breaker for maintenance.

The monitoring of the Power System can be subdivided into two categories, real time and historical. The two types of data are not necessarily exclusive in that real time data may also have historical significance. But the handling of the data for the two different purposes is different.

Real time monitoring provides immediate indication of the present state of the electrical system. This information can be fed into computers for analysis and/or presented to operators of the system.

Historical monitoring in the Power System provides a means to review the operation of the system and is used primarily for planning and training purposes. Historical data may be retrieved directly to some storage media such as tape or could be monitored in real time and subsequently stored for future reference.

1.3 RELATION OF COMMUNICATIONS TO THE ELECTRICAL POWER SYSTEM

Communications are critical to all facets of the operation of the Electrical Power System. The better the communications, the better the EPS can be controlled. The following is a partial list of applications of communications in support of the EPS:

- Relay Protection Schemes - Relays are compact analog networks that are connected throughout the Power system to detect intolerable or unwanted conditions within an assigned area. In some applications complex relaying schemes requiring reliable communications between remote locations are necessary.

- Telemetering - Automatic acquisition and transmission of pertinent electrical system data from remote sources.
- Remote Control - Reliable operation of devices in the electrical system from remote locations.
- Data Communications - The information exchange between computers at remote sites.
- Voice - The direct exchange of information between people at remote locations, e.g. the telephone.

As related in the previous section, relay protection schemes are normally associated with automatic control. The implementation of the communications for these schemes can be done in a variety of ways such as Power Line Carrier, fiber optic, microwave or telephone circuits. The choice of the proper method to use is dependent on a number of factors such as availability, reliability and consideration of the device or line that is to be protected. Power Line Carrier makes use of the electrical power lines for communicating. Select frequencies are chosen for communications to indicate normal and trip conditions.

These signals must be distinguished easily from the 60 hertz power signal and its harmonics and coordinated to similar schemes on adjacent power lines. The communication signals are superimposed on one of the transmission lines, normally the ground wire, for communicating information between remote relays. The other methods, fiber optic, microwave and telephone would be used in a similar fashion but with the transport media being different.

Telemetering information is classified into two general categories, status and analog. Status telemetering is simply the indication of a binary condition such as an off / on or a 1 / 0 or an open/close for a single device. Status telemetering communication can also be complex and include, not only simple status but, additional indication such as history of changes between scans for many different telemetered devices from a single source. Analog telemetering requires the transmission of a variable associated with a location within the power system. As with the status the communication can be simple, for only one loaction, or the communication may include a number of locations. The communications methods used for this are telephone and/or microwave.

Remote Control requires a secure communications exchange between the originator and remote site. Normal applications of control require at least two exchanges between originator and remote site before any action will be initiated. The communications method used for this is typically telephone and/or microwave.

Data Communications is accomplished by use of Computer Networks. The support of the EPS demands this information exchange be reliable and secure. An objective of this communication is that it also be robust to support expansion. Many levels of protocol are associated with this communication in order to meet the objectives. The communications method used to implement data communications can be telephone, fiber optic and/or microwave. In any instance the bandwidth of the communications required to support this exchange is normally much greater than for any of the other applications discussed above.

Voice communications are required to support the operation of the EPS to allow operators to exchange information between one another and with field personnel. Though much of the communication between operators can be accomplished with the computer network, voice communication remains more efficient for many applications. Voice communications is also used for backup of critical data exchanges for all the functions described above. Voice is supported principally by telephone and radio.

1.4 THESIS ORGANIZATION

This section describes the organization of the remainder of this Thesis.

Chapter 2 of this Thesis introduces the Pennsylvania Power & Light Power Management System, the computer based system responsible for the Real Time Management of the PP&L Power System. The hierarchy of the Power Management System, along with the objectives of the applications, are described. Chapter 3 describes the Data Communication Requirements associated with the Power Management System. The various types of data transferred are described, classified and characterized. Analysis of Contending Network Configurations is the subject of Chapter 4. Within this chapter objectives of the Data Communications Network are described along with specifics on the data communications loading scenarios which are to be supported. The four contending Network Configurations are presented and described in detail and configuration analysis begun. Under the general heading of configurations analysis the tools used to support the investigation are described, including the queueing theory based simulation program NETQUE. Chapter 5 is a Discussion of the Results of the simulations and investigations as related to the configuration objectives. The analysis of the contending configurations is concluded in this chapter. Chapter 6 is the presentation of the Conclusions and Recommendations of this Thesis.

CHAPTER 2

POWER MANAGEMENT SYSTEM

This chapter of the investigation introduces the Pennsylvania Power & Light (PP&L) Power Management System (PMS), the computer based system responsible for the Real Time Management of the PP&L Power System. The optimization of the Computer Network configuration in the PP&L PMS is the focus of the investigation of this thesis. An overview of the Power Management System is given by first describing the hierarchy and then the application objectives. Particular focus is given in the description to aspects which involve the PMS internal Computer Network, such as configuration of sites.

2.1 PMS ARCHITECTURE

Pennsylvania Power & Light, with its Corporate headquarters in Allentown, is an investor-owned electric utility serving over 1 million customers in a 10,000 square mile area of central-eastern Pennsylvania. See figure 1. The service territory includes a broad range of customer types and characteristics such as rural farmlands, mountain resorts, major industrial areas, small communities, and six major cities served by low tension, underground networks.

The Pennsylvania Power & Light (PP&L) Company's Power Management System (PMS) is a hierarchical system with six Division SCADA System installations which provide supervisory control, data acquisition and monitoring at each of the six division operating offices, and a central Power Control Center (PCC) which provides overall system monitoring, automatic generation control, and direct control of the 500 kV transmission system. Communication is provided between Division SCADA Systems, from each Division SCADA System (DSS) to the Power Control Center, from the PMS to the PP&L Corporate Computer Center (CCC) and from the Power Control Center to the Pennsylvania-New Jersey-Maryland Interconnection (PJM) office in Valley Forge, Pennsylvania. (See Figure 2 for a map of the PJM power pool showing member companies.) The Pennsylvania locations of the PP&L sites mentioned above are as as follows:

- Power Control Center - At the corporate headquarters, downtown Allentown.
- Central DSS - Hazleton.
- Harrisburg DSS - Harrisburg.
- Lancaster DSS - Lancaster.
- Lehigh DSS - Allentown, near intersection of Routes 309 and 22.
- Northern DSS - Scranton.
- Susquehanna DSS - Montoursville.
- Corporate Computer Center - At the corporate headquarters, downtown Allentown.

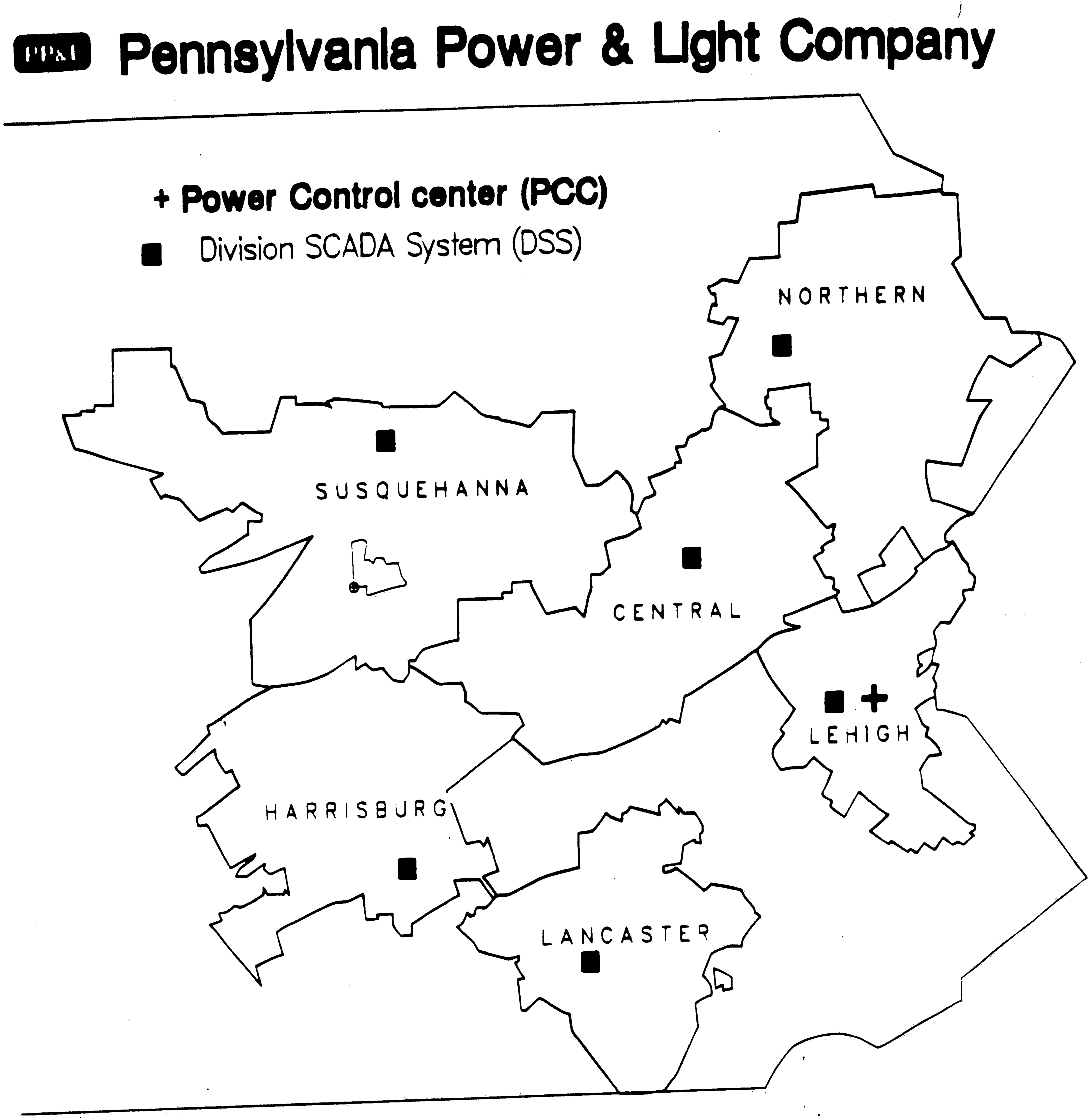

Figure 1.

Pennsylvania Power and Light Service Territory

Divisions and Power Management System Locations Shown

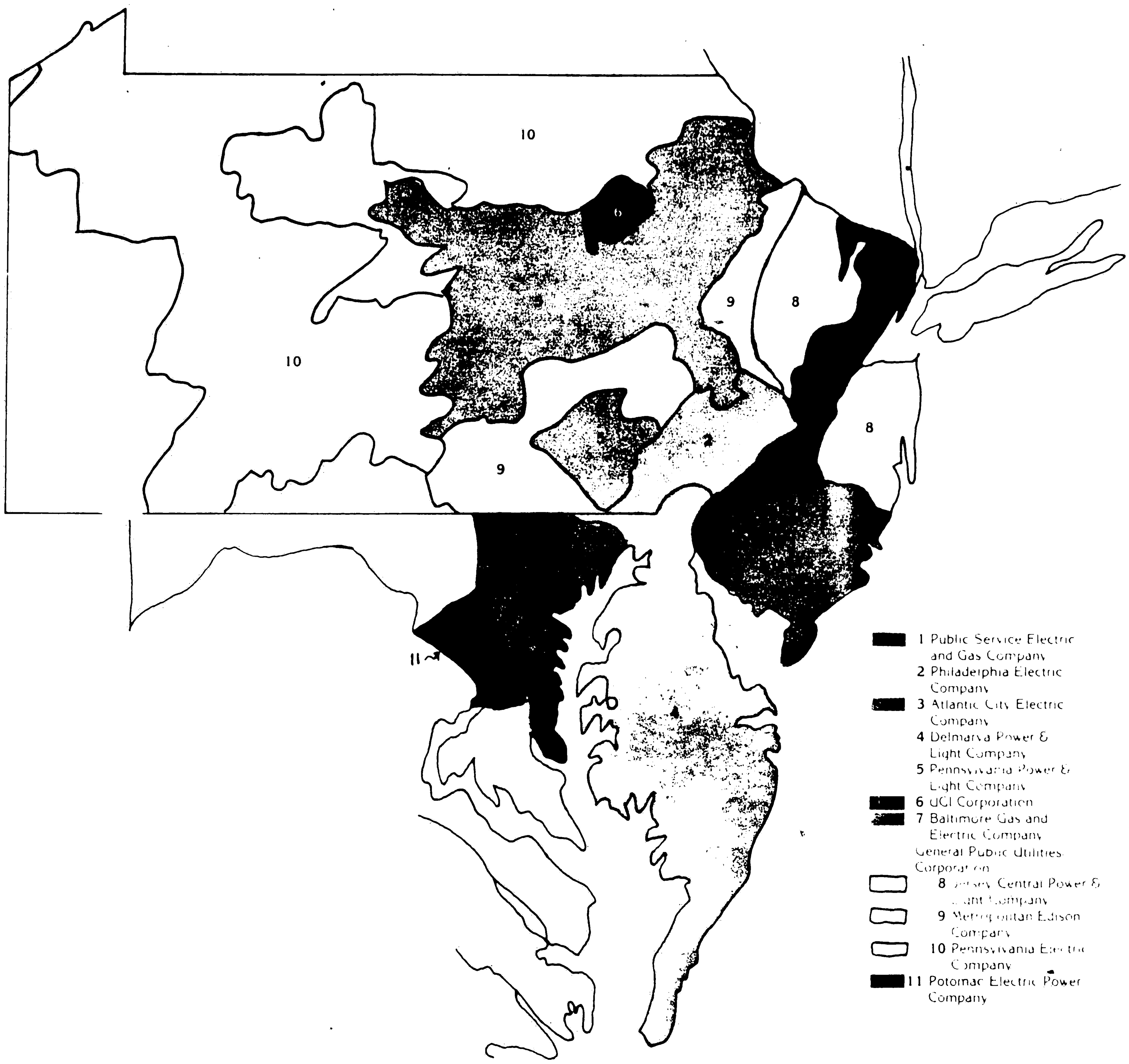

Figure 2.

Pennsylvania-New Jersey-Maryland (PJM) Interconnection

Power Pool Member Companies Shown.

All the PMS sites interface with the electrical network through Remote Terminal Units (RTUs) and Generation Plant Computers. Remote Terminal Units are microprocessor based devices installed at stratagic points in the electrical system, typically at substations, which provide telemetry of quantities and control of remote devices to the PMS. Specialized communications protocols are used in PMS/RTU communications due to the nature of the functionality to be provided and the limited capabilities of the RTUs. Communications with Generation Plant Computers is most often the same as communications with RTUs since from the PMS perspective the same functionality is required.

High availability and reliability are requirements for the Power Management System. This goal is reflected in the configurations of all the systems within the PMS, the PCC, the DSS sites and the Data Communications Network which provides the interconnection of the the PMS sites. At both the PCC and DSS redundancy of key system elements is included in the configuration designs. The computer systems, magnetic memory systems and communications processors all include backups. For other portions of the systems full redundancy is not practical so other steps are taken to address the goals of reliability and availability. Specifics of the configurations and how the systems goals are implemented, are covered in the subsections which follow describing the configurations of each of the sites.

The Data Communications Network (DCN) shares the same goals for availability and reliability as the PMS sites which it interconnects. The implementation configuration for the DCN is the subject of this thesis and as a result will be described in great detail and length starting with the next chapter.

Before proceeding on to the subject of the individual site configurations, a few thoughts about the Local Area Network (LAN), Ethernet, employed at each of the PMS sites should be presented. Ethernet is an element of PMS which is integral to both site configurations, as the principle method of communications, and to the Data Communications Network configuration, since the Communications Network Processors will be Ethernet based. All data transferred internally within a site and all data transferred between sites will transverse Ethernet. With this in mind it is apparent that Ethernet is a key element to the implementation of the PMS as a whole and therefore careful consideration has been given to its reliability.

Ethernet as implemented for the PMS, is coaxial cable based baseband LAN, running at 10 Mb/s. On a system basis the Ethernet can be broken into three critical parts

1. The Ethernet transmission media itself, coaxial cable.

2. The Ethernet transmitter/receiver (transceiver).

3. The Ethernet interface to attached computers.

The coaxial cable itself is passive and the most likely means of failure would be a break in the cable. Considering the PP&L implementation, the risk of a cable failure is considered very low since the PMS sites are secure. This implies no consideration of providing a backup for cable loss should be implemented. The impact of a cable loss, however, is very high implying backup of the Ethernet cable may be appropriate. The resolution of this issue is to implement a single Ethernet, consisting of two sections of coaxial cable joined together by a barrel connector. This implementation would allow a quick means to recover from a cable failure. By disconnecting sections at the barrel connector and adding the proper termination, half the Ethernet could be restored in a short amount of time while work would proceed to caring for the failed cable. This method calls for careful consideration of the termination of the interfaces on the

Ethernet to assure that redundant pieces reside on opposite sections of the LAN.

The second consideration of the Ethernet reliability is the Transceiver element, the device which interfaces to the coaxial cable. Each computer interfacing to the Ethernet has a single independent transceiver. For the PP&L implementation these devices are Digital Equipment Corporation H4000s, which include a level of redundancy in the design and are also designed to avoid failure modes which would bring down the entire Ethernet. The loss of a single transceiver then would be the equivalent of losing a single computer attached to the Ethernet. Since all critical computers will have some means to be backed up, additional provisions for the transceivers is not included in the PMS.

The last element, the computers interface to the Ethernet follows the same logic just given above for the transceivers and no special steps are taken to provide additional backup.

Ethernet is compliant with IEEE Specification 802.3, Local Area Networks - Carrier Sense Multiple Access with Collision Detection.

2.1.1 Power Control Center

The Power Control Center is the logical center of operations for the entire PP&L Power Management System. The PCC, located in downtown Allentown, provides economic dispatch and load frequency control to PP&L's generation units subject to constraints and requirements as determined by the PJM Interconnection. The PCC also provides economic dispatch for PP&L's generation as required to support direct power sales outside of the PJM Interconnection. The PCC has direct supervisory control of the 500 kV transmission system and selected DSS Remote Terminal Units (RTU). Additionally, the PCC coordinates activities of the regional 230kV, 138kV and 69kV transmission systems which are under the direct control of the Division SCADA Systems. The only direct connection from the PP&L PMS to the Pennsylvania-New Jersey-Maryland Interconnection Office is through the PCC.

The Power Control Center configuration is centered around two Digital Equipment Corporation (DEC) 8800 Computer Systems. Each 8800 Computer System includes dual Central Processing Units, 32 MegaBytes of main memory, a BI bus, disk controllers, Ethernet interface, a UNIBUS interface and a UNIBUS located in a CPU expansion cabinet. Each 8800 computer is capable of running all the PCC software applications and interfacing to all external systems. One computer is run as the primary system, monitoring and controlling the real-time power system, while the other acts as a standby computer, prepared to assume the role of the primary should the primary fail. There is no preferred computer system for operation, since both 8800 computers are exact duplicates of each other.

The 8800 computers interface to a common single DEC Star Coupler via the CI bus. The Star Coupler, which has redundancy built into it, allows the two 8800 computers to operate in a cluster arrangement. Clustering means that any Star Coupler attached CPU (up to 8) can access any of the storage devices connected to the Star Coupler. On the PCC Cluster three redundant pairs of 456 MegaByte hard disks a pair of 206 MegaByte removable disk packs and pair of tape drives are connected. Each of the 8800 systems has 3 of the hard disks, one removable disk and a tape drive logically dedicated for use. See Figure 3 for a Power Control Center hardware configuration overview.

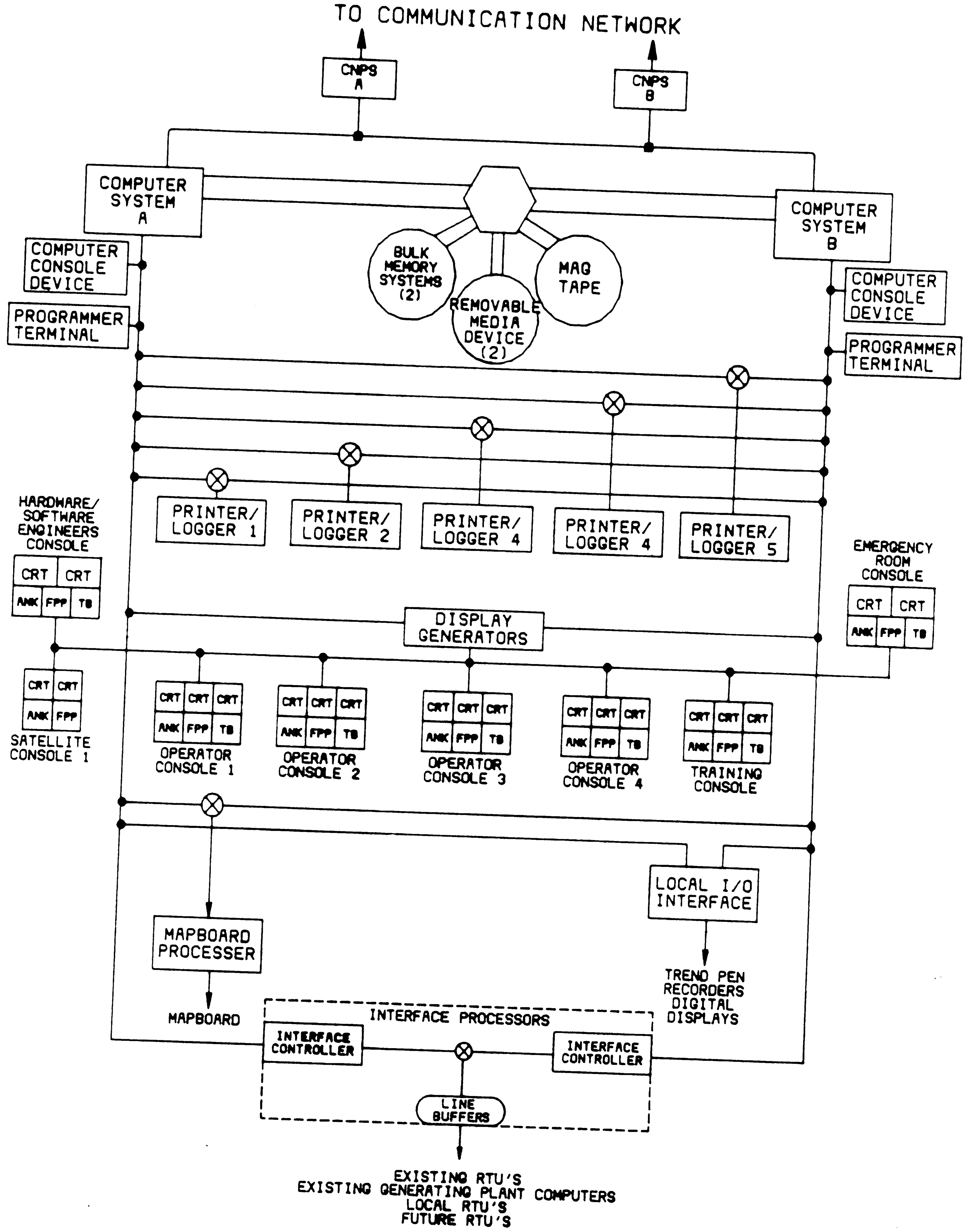

Figure 3.

Power Control Center (PCC)

Hardware Configuration Overview

The PCC includes a non-redundant Communications Interface System (CIS) for communicating with Remotes, (Remote Terminal Units and Generating Plant Computers). The CIS handles the specialized protocol associated with the RTU and Generation Plant Computer communications off-loading that function from the 8800 Computer Systems. The CIS interfaces to the 8800 Computer System through specialized DEC communications processors, DZ11s and KMCs, located on the Unibus. The CIS itself is not redundant, but a level of backup is provided in the interfaces to the Remote phone lines referred to as SCCs, Serial Communication Controllers. For each group of 8 SCCs, known as a bank, 7 can be actively assigned to phone lines and one held as a spare. The spare SCC can take the place any of the other 7 SCCs in the bank should one fail. Note that for the PP&L system up to 3 RTUs may be party-lined on a single phone line so a bank of SCCs may provide the interace for up to 21 RTUs.

The Man Machine Interface system at the PCC is another area which is not redundant. The primary interface at the PCC to the operators is via the operator console. Each console includes 3 CRTs, a keyboard, trackball and a ninety function keypad for specially assigned buttons. Though each individual console is not redundant, great care is taken to assure that the loss of a single device will have minimal impact on the console. For instance, the display generators associated with CRTs at each console are assigned such that the loss of a single generator will result in the loss of no more than one CRT. This is taken one step further to assure that the loss of a single display generator will effect no more than one CRT in the combination of the two primary operator consoles.

Another aspect of the Man Machine Interface at the PCC is the dynamic mapboard. The mapboard provides a pictorial overview of the PP&L high voltage network and, by means of backlighting, provides indications to the operators of transmission outages, overloads, contigencies and substation alarms. This subsystem is implemented by Programmable Logic Controllers and interfaces to the 8800 Computer Systems via the Unibus.

The interface to PJM is fully redundant and provided exclusively at the PCC. The PJM interface, also referred to as the PJM Gateway, is via a modified IBM bi-synch protocol implemented by specialized software residing on a MicroVAX computer. The two MicroVAX computeras are attached to the PCC Ethernet and are accessable from either of the 8800 Computer Systems.

An interface to the Corporate Computer Center IBM Systems Network Architecture (SNA) network is also provided to the PCC. The interface is implemented on an Ethernet based MicroVAX and employs some specialized software in conjunction with standard SNA Gateway interface routines provided by DEC. The interface CCC Gateway is not redundant since it is not critical to support the real time operation of the Power System.

2.1.2 Division SCADA Systems

The Division SCADA System is the second level of the hierarchy, below the PCC, in the Power Management System. Each Division SCADA System is responsible for the operation of the regional 230 kV, 138 kV and 69 kV transmission systems, and the 12 kV distribution system within a limited geographical area (see figure 2 for the division of the PL territory). Additionaly, the DSSs have control over operation of combustion turbine generation used for peaking power and emergency regional power supply within their division.

The number of RTUs associated with a DSS are much greater than those associated with the PCC. This is because the facilities for regional transmission and distribution of electricity are much greater, quantity wise, than the facilities associated with the 500 kV and Generation plants.

The Division SCADA System configuration is centered around two DEC 8300 Computer Systems. Each 8300 Computer System includes dual Central Processing Units, 12 Megabytes of main memory, a BI bus, disk controllers, Ethernet interface, a UNIBUS interface and UNIBUS located in a CPU expansion cabinet. Each 8300 Computer System is capable of running all the DSS software and interfacing to other DSSs, the PCC and the CCC. One computer is run as the primary system, monitoring and controlling the real-time power system, while the other acts as a standby, prepared to assume the role of the primary should the primary fail. As with the PCC, there is no preferred computer system for operation, since the 8300 computers are exactly the same. See Figure 4 for a Division SCADA System hardware configuration overview.

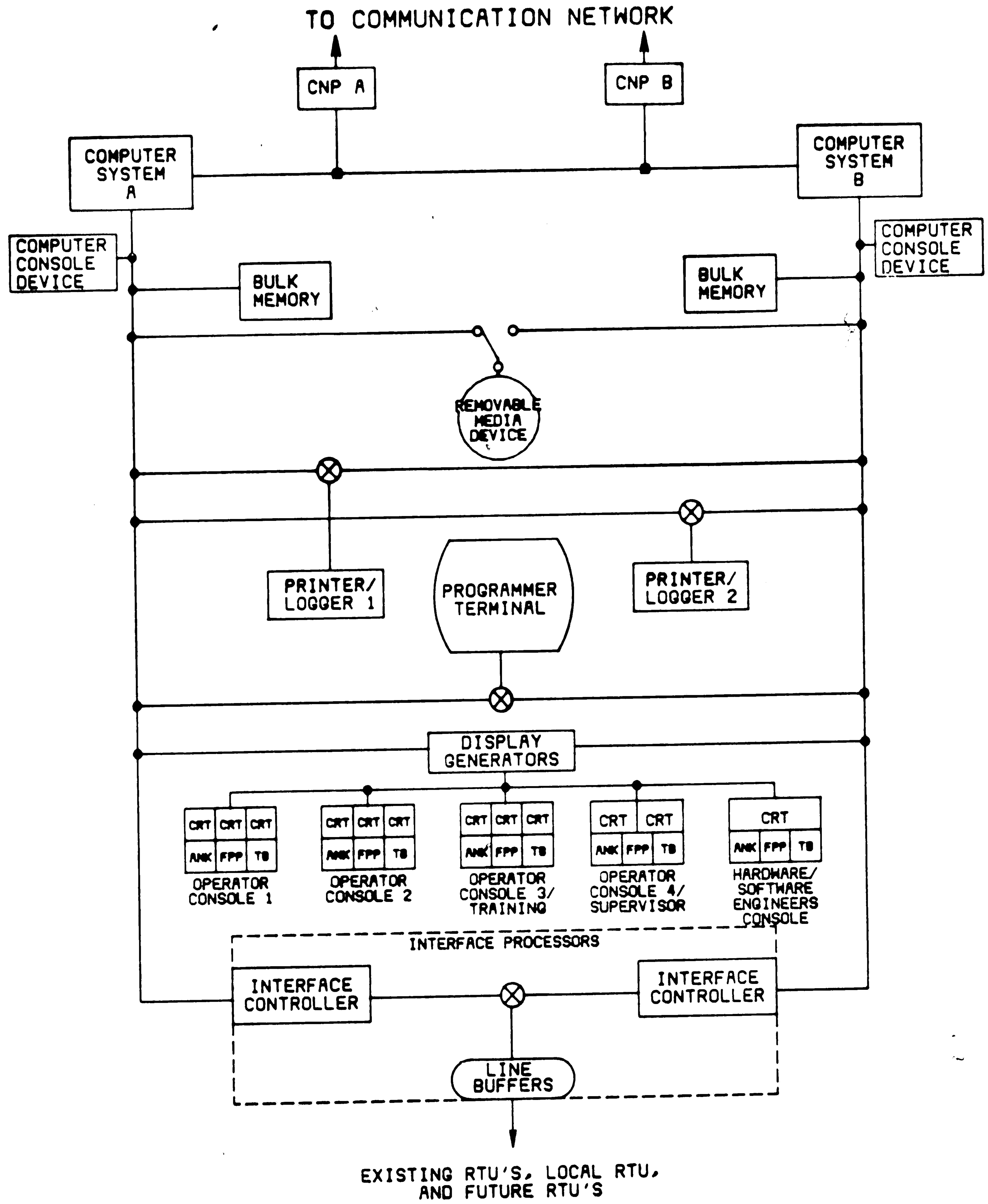

Figure 4.

Division SCADA System (DSS)

Hardware Configuration Overview

Each 8300 Computer System has a dedicated 456 Megabyte hard disk which is switchable between machines by manual switching only. No Star Coupler is provided at the DSSs as is done at the PCC. A single 206 Megabyte removable disk is included at each DSS site and is switched between systems by manual configuration switch located on the unit itself. The 206 Megabyte removable media disk is the single load device for each DSS location.

The Communications Interface System at the DSSs is the same system as implemented at the PCC and is also not redundant. The DEC interfaces into the 8300 are through the UNIBUS and the same devices are used, namely the DZ11 and the KMC.

The Man Machine Interface at the DSSs is the same as the MMI used at the PCC. The number of consoles supported is less but the same implementations as described above are employed.

The mapboards at the DSSs are static and modified to reflect the power system operation by hand.

The interface to the Corporate Computer Center is through the same MicroVAX described for the PCC. This SNA Gateway is physically located on the Ethernet at PCC, but it is logically, directly accessible from all DSSs. Communications between DSSs and the CCC do not go through the 8800 hosts at the PCC but rather, are localized to the the Ethernet at PCC to the PMS/CCC Gateway.

2.1.3 Remote Terminal Units

Remote Terminal Units provide the principle interface to the electrical system for the PMS. The microprocessor based devices are the PMS monitors of the power system and in addition the RTUs also provide the PMS the means to remotely control devices in the electrical system. The functionality provided for the PMS by RTUs, is critical to the ability of the PMS to operate effectively.

The PP&L system currently includes approximately 150 RTUs located throughout all the divisions and another 6 more interfacing directly to the PCC. Installation of RTUs is continues yearly and as it does, the effectiveness of the DSSs and the PMS as a whole is enhanced by the additions.

2.1.4 Electrical Generating Stations

The Electrical Generating Stations in the PP&L System interface to the Power Control Center. Currently in the PP&L System there are 9 principle generation facilities:

1. Brunner Island - 3 Coal fire units/total capacity of 1600 MWatts.

2. Holtwood - Hydroelectric/total capacity of 110 MWatts.

3. Hunlock - 1 Coal fire unit/total capacity of 55 MWatts.

4. Martins Creek - 2 Coal fire units/total capacity of 340 MWatts and 2 Oil fire units/total capacity of 1800 MWatts.

5. Montour - 2 Coal fire units/total capacity of 1700 MWatts.

6. Safe Harbor - Hydroelectric/total capacity of 450 MWatts.

7. Sunbury - 4 Coal fire units/total capacity of 450 MWatts.

8. Susquehanna - 2 Nuclear units/total capacity of 2200 MWatts.

9. Wallenpaupack - Hydroelectric/total capacity of 45 MWatts.

These facilities, with the exception of Wallenpaupack, interface directly with the PCC. The numbers of interfaces represented by these various plants varies with each plant based on internal structure of the plant itself. For instance Martins Creek Steam Electric Station appears as three separate interfaces to the PCC, one for the two coal units which are operated by a single system, and two more interfaces, one for each oil fired unit which are operated independently from the coal units and from one another.

Wallenpaupack interface is unique to the system and is actually directly telemetered to the Northern DSS. PCC controls Wallenpaupack through Northern DSS under normal conditions.

In addition to the Generating Stations listed above there are approximately 40 Combustion Turbine Units under control of the PCC/DSSs. These units range from 5 to 20 MegaWatts and are used principally to provide power quickly, while the larger Stations ramp up to new generation levels. These units can also be used continuously when demand is very high, but are not generally used this way since their operation is typically far more expensive, per KiloWatt, then the larger generating stations.

The communication protocol currently used to the Power Plants is the same as what is used for RTUs.

2.2 APPLICATION OBJECTIVES

Now with an overview of the hierarchy of the PMS and a feel for the configurations, this section proceeds to describe the functions performed by applications within the PMS.

There are five main categories of software in the PP&L Power Management System: the operating system, HABITAT, SCADA, system utilities and PMS applications.

- The operating system in the PMS is VAX/VMS (Virtual Memory System). This software is the foundation of the entire system and manages the operation of the computer and controls the physical aspects of the storage of information.

- HABITAT, is the system support software written by PP&L's prime contractor for the PMS, ESCA located in Bellevue, Washington. This software is layered on top of VMS and controls the logical organization of data and provides an "environment" for the system services and PMS applications in which to run.

- SCADA, Supervisory Control And Data Acquisition is a combination of applications responsible for the gathering of information and issuing of control. This subsystem is described in greater detail below.

- System Utilities are Habitat related applications which perform special services required by many applications. An expanded description of the Utilities is provided in one of the subsections below.

- PMS Applications include special programs which perform specific functions to support Generation and Transmission of electricity. Again, a more detailed description of these functions will be given below.

See Figure 5 for an overview of the Power Management System Software Overview.

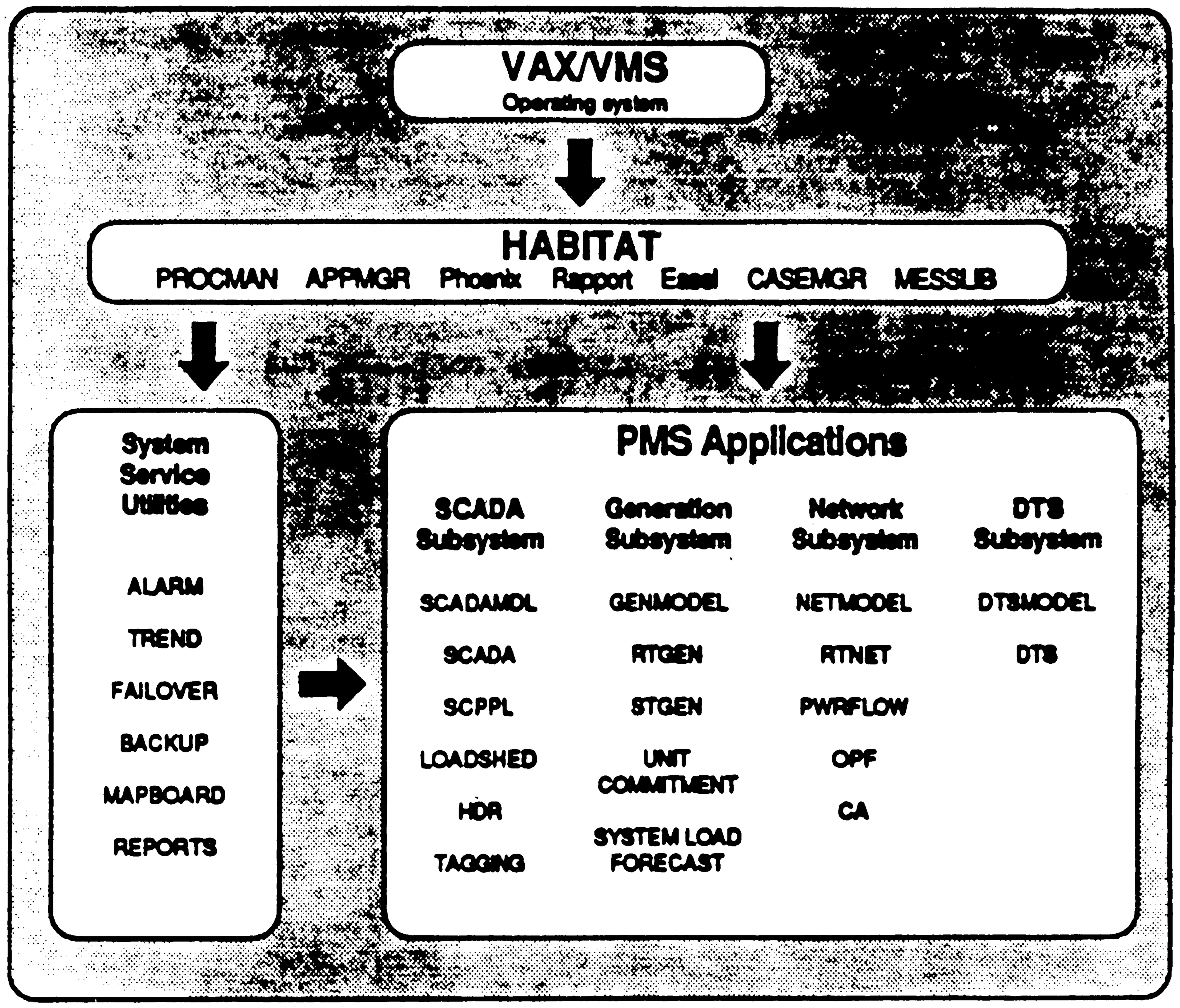

Figure 5.

Power Management System

Software Overview

2.2.1 Supervisory Control And Data Acquisition (SCADA)

SCADA is the bread and butter of the PMS applications and the largest user of the Data Communications Network and for this reason it is called out separately. SCADA is responsible for gathering data and the proper issuing of control instructions and is the principle real-time application used by operators.

The data acquisition function of SCADA retrieves power system data every few seconds. This data can include things such as the status of circuit breakers (status) and the measurements of the power flow somewhere in the system (analog). This data, which represents the current state of the power system, is processed and stored in an online database. Any changes in the way a particluar device is operating is reflected to the operators on their console displays. Operators can also use the SCADA displays to manually enter status for non-telemetered devices.

Retrieved data can be telemetered directly from RTUs and generation plants or may be obtained from other PMS sites or, in the case of PCC, from PJM. SCADA is responsible for gathering all the data and providing the information to the PMS operator. Status data is retrieved at a 2 second rate and analog data is retrieved at a 10 second rate from Remote Terminal Units and Generating Stations. SCADA data exchanged between DSSs and the PCC is also transferred at these same rates and given the data to be transferred, which is detailed in the next Chapter, SCADA is by far the predominant user of the Data Communications Network.

Normal operating states of power system devices are defined in the SCADA database. As SCADA scans the power system, it compares retrieved readings against the defined norms and detects discrepancies. The operator is then notified of any such differences through the Alarm subsystem, which is described later under System Utilities.

Other functions performed under the general heading of SCADA include the following:

- o Control - coordination of the operation of field devices through the RTUs.
- o Voltage Monitoring - compares monitored voltage readings against pre-defined schedules.
- o Capacitor Monitoring - determines the status position of capacitors and compares against the pre-defined schedule.

- Peak Data Capture - monitors specified quantities and tracks the peak reading for that quantity each day.

- Open Phase Detection - monitors three-phase current values for mismatches which could indicate the opening of one or two phases.

- Sudden Load Drop Detection - monitors individual load values checking each for sudden drops in excess of a defined threshold.

- Limit Replacement - allows operator to specify multiple sets of operating limits for telemetered devices. The operator can also specify different actions to be taken for violations for each of the limits.

- Closed-loop Control - allows an operator to specify a MW or MVAR value for a generator to conform to and the module handles coordinating the actual movement of the generator.

- CB Ready for Test - monitors circuit breakers for operation to the "lock-out" condition and then starts a timer which will indicate when the breaker has had sufficient time to recharge and is ready for test.

- Feeder Demand - monitors selected analog quantities once a minute and records the value and time of the highest sample for each quantity, once a day.

- Loadshed - allows operator to automatically drop an amount of load he specifies from the system for emergency conditions. This module determines the proper devices to be operated to meet the specified amount and actually operates the devices themselves through the RTUs.

- Historical Data Recording - record snapshots of critical SCADA data to give operators and engineers a means of recreating the power system status at a given point in time.

- Tagging - allows operators to place protective tags on devices and parallels the physical tagging done in the field. Operations which are blocked in the field along with the tag are also blocked at the PMS sites.

2.2.2 System Utilities

System Utilities are programs which provide functionality which can be used by many different PMS applications. The following are the utilities included in the PP&L PMS system, with a brief descriptions of each.

2.2.2.1 Alarm -

An alarm is defined as the notification from an application to the operator of new events requiring his attention. The notification can be simply a change in color of a device on a display up to generation of a tone requiring acknowledgement. All alarms are stored in an alarm summary display and generate an entry into a system log.

The purpose of the Alarm Utility is to provide the operator notification services, maintain summary information to assist the operator in investigating the current system state and direct the operator's attention to the pertinent displays in the PMS Application that will give him more detailed information.

2.2.2.2 Failover -

The Failover Utility is responsible for maintaining operation of the site even when a computer or other critical hardware fails or malfunctions. If the primary computer fails or is disabled for some reason, the Failover Utility automatically switches PMS online operations to the standby computer. It also switches control of peripheral devices such as consoles and printers.

2.2.2.3 Backup -

The Backup Utility allows other applications and the operator to transfer data between computers. Backup interfaces with every other application and is used whenever data must be transferred to another computer's database. The Backup Utility constantly copies critical data on an exception basis from the primary computer to the standby computer so that, if the primary computer fails, the standby computer will be as updated as possible when it assumes primary functions.

2.2.2.4 Reports -

The Reports utility supports the definition, generation, and archiving of reports. A report can be generated using any application database as the source of data.

Reports maintains a database of report characteristics, such as interval of creation, data sampling period, etc. Reports samples the specified database at periodic intervals, performs calculations on the data to present it in the desired form, formats the report for a console display and/or printer, and archives the completed reports. Sampled source data can be manually modified to produce an updated report.

2.2.2.5 Trend -

The Trend Utility can be used to keep track of periodic changes in selected numeric values in the system. Trend can sample numeric data from any PMS database, then plot the sampled values on chart recorders or present them on console displays.

2.2.3 Advanced Power System Applications

The Advanced Power System Applications can be broken down into three major subcategories: Generation, Electrical Network and Data Training Simulator. Each of these categories is described in the following subsections.

2.2.3.1 Generation -

The Generation programs are used at the PCC to monitor, analyze and control electrical system generation. The Generation Subsystem includes one real-time application and several study applications and one database which decribes the generation components such as plant controllers, generating units, fuels and operating areas.

The objective of the Real Time Generation application is to economically schedule and control generation and to provide generation operators the necessary tools for monitoring and controlling the Generation Subsystem. The Real Time Generation application consists of a number of parts providing specific functionality. The various parts of the Real Time Generation subsystem work from a central database.

The Automatic Generation Control (AGC) is the central portion of the the Real Time Generation Application. AGC retrieves power system data from SCADA and based upon this data, dispatches generation to meet demand while minimizing costs and observing all generation constraints. At the conclusion of each execution AGC issues command signals through SCADA to the generation units to control their MW output.

The Economic Dispatch (ED) portion of Automatic Generation Control studies all the dispatchable units in the PMS opeating area and, given the present load, cost of fuels and generation constrasints, determines the most economical allocation of generation to meet the demand for power.

The Transaction Scheduling function of Real Time Generation allows the operator to schedule sales and purchases of power with neighboring utilities.

The External Unit Scheduling function creates a model of external operating areas and uses the model to estimate the probable operating levels of units in those areas. The model this function creates is also used in the Electrical Network application's State Estimator to determine the state of the external system.

-Real Time Generation's Reserve Monitor function calculates and monitors the reserve generation capability available in the system. The operator can either schedule reserve requirements or use predefined default requirements.

Real Time Generation's Loss Model Update function maintains information about the losses in the electrical system, such as the power lost for every MW generated.

Study Generation is the portion of the generation subsystem which allows operators and engineers to conduct studies of Economic Dispatch and Transaction Evaluation. The study mode allows operators to modify unit parameters and to add potential transactions, to observe their effects without impacting the Real Time system.

Another Study function included in the Generation Subsystem is Unit Commitment (UC). The primary purpose of UC is to determine the commitment schedule for each generating unit. UC uses Economic Dispatch to determine the most economical way to turn units on and off to meet the anticipated generation and reserve requirements over a period of time. A typical use of this program is to determine fuel quantity requirements and to examine the benefits of purchasing power from neighboring utilities.

System Load Forecast (SLF) provides forecasts of load for other PMS applications. SLF uses weather forecasts for the future as well as actual historical load data.

2.2.3.2 Electrical Network -

The applications of the Electrical Network Subsystem are used at the PCC to monitor and analyze the steady-state performance of the power system. The Electrical Network Subsystem includes real-time and study applications along with a single master database which contains the definition of the Network model parameters including resistance of lines and attributes of specific pieces of equipment.

The Real Time Network application is intended to maintain a complete description of the electrical network' operating state as it exists in real-time and to provide the information to other related applications. Topology Processor is one portion of the Real Time Network application which uses status data from SCADA to determine how components in the system are currently connected. The result of this analysis, a bus model, is then available for other portions of the subsystem.

The State Estimator uses the bus model results, along with real-time measurements from SCADA to calculate the electrical state of the network. With a sufficient amount of data, the State Estimator is able to calculate values for non-telemetered devices and also perform consistancy checks on the telemetered data to detect bad readings.

The State Monitor program checks electrical components for rating violations and abnormal output.

Numerous study applications are included in the Electrical Network Subsystem to allow the operators and engineers to evaluate the network. The Powerflow application is the basic analytic tool and is used to analyze the steady-state behavior of the power network and provides a complete description of the voltages and flows in all components. Powerflow can be run using actual data from SCADA, hypothetical data provided by the engineer or historical data. This application allows for the study of effects of outages or system reconfigurations.

Optimal Powerflow is a study application used to recommend controller moves for alleviating violations and/or optimizing objectives. Optimized objectives could be cost or other experimental considerations. The outputs from Real-Time Network programs or Powerflow can be used as inputs to this program.

Contingency Analysis is an application which is used to examine the possible effects of selected contingencies on the system operating conditions. Contingency Analysis is run each time the Real-Time Network application completes execution, and the operators are notified automatically of any real-time contigencies discovered.

2.2.3.3 Dispatcher Training Simulator -

The last piece of the Advanced Power System Applications is the Dispatcher Training Simulator which is used to create a realistic environment in which operators can practice system operations wihtout jeopardizing the online system. The principle objective of the DTS is to increase the operator's knowledge of the behavior of the power system and its responses to his control actions.

Similar to other applications the Dispatcher Training Simulator has an associated database which defines the organization and behavior of the prime movers and relays for the electrical system. In addition, pointers are included to the Generation and Electrical Network databases for information included within.

The Dispatcher Training Simulator allows the instructor or user to simulate events on the power system and provide a realistic response to the effects such action would have. Thus many abnormal events could be simulated to prepare operators for those eventualities.

CHAPTER 3

DATA COMMUNICATION REQUIREMENTS

This Chapter describes the Data Communication Requirements of the Power Management System. The various types of data transferred within the PMS are described, classified and the characteristics identified.

3.1 INFORMATION EXCHANGE WITHIN THE PMS

The timely and reliable exchange of information on the state of the electrical power system is critical to the effective operation of the Power Management System. The real-time applications described in the last Chapter can only be as good as the information they use, thus the communication of information is critical to the operation of the entire PMS.

Communication to Remote Terminal Units from individual PMS sites is important in the operation of each of the sites as independent entities. Communication between the PMS sites, the DSSs and the PCC, is critical to the operation of the PMS and the PP&L Electrical System as a whole. The DSSs provide critical information to the Power Control Center on the low voltage network and distribution loads. In turn the PCC offers the individual Division SCADA Systems the a single source of coordination, necessary to maximize the efficiency of the entire system.

On the Power Management Systems Data Communications Network the principle traffic is SCADA data. Data retrieved locally at the PMS sites is transferred from SCADA via the DCN to all other locations which desire that information. The principle flow of SCADA data is from the DSSs to the PCC, but there are components of SCADA data which go the oppsite way, PCC to DSSs. In addition there is SCADA data which is transferred directly between Division sites.

There is also data other than SCADA transmitted on the DCN between the PMS sites. This information is less frequent and in most instances is asynchronous. Descriptions of the specifics are included later in this

Chapter.

3.2 DATA CLASSIFICATION

The data transferred over the PMS Data Communications Network can be segregated into three classes defined as follows:

- o Class 1 - Real-time short scan data.
- o Class 2 - Critical scan data.
- o Class 3 - Informational data.

Class 1 or Real-time short scan data originates from the SCADA application and represents the principle load on the Data Communications Network. Class 1 data from SCADA is principally comprised of Status and Analog data representing conditions in the electrical network. Information includes telemetered values, retrieved from RTUs, as well as non-telemetered values such as operator entered or calculated. Both the telemetered and non-telemetered values are sent from the originating site at a high rate based on the scan rate of the telemetered data. For Status, data is retrieved from RTUs and thus sent on the DCN, every 2 seconds. For analogs, data is retrieved from the RTUs during each 10 second interval and transmitted over the DCN at the same rate.

Class 1 identifies data which will require special consideration for transmission from source site. Specifically, Class 1 data shall have preference for transmission from the source site such that it will always be sent before all other data when contention exists in the Data Communications Network.

Class 2 data also identifies data which requires special handling consideration. Class 2 is characterized as information which is critical and should not be lost no matter how long it may take to transfer. The implication of this data class, is that the originating applications must take extra steps to insure proper delivery and to also accommodate for temporary losses in communication. This application involvement is necessary because the DECnet protocol guarantees packets sent and recieved will be correct and re-assembled in the proper order, but does not guarantee delivery. To expand on why this is the case, consider the condition where two nodes are communicating. Initially node 1 is sending information to node 2 which is receiving the data successfully and everything is fine. Now assume node 2 fails during this process, node

1 is not able to determine how much data was received by node 2 before communications failed because DECnet uses an acknowledgement scheme which allows multiple outstanding packets. Thus any number of packets sent may still be outstanding.

Another consideration of application involvement in handling Class 2 data is that DECnet reports status of transmission from DECnet to DECnet between machines, but not the successful transfer of data to end applications. Thus, if true end-to-end acknowledgement is desired, the applications must take the steps necessary to confirm exchanges with the cooperating application at the other site.

Class 3 data is informational in nature and does not require special handling. This data is considered non-critical to the operation of the PP&L Electrical Power System.

3.2.1 Real Time Data

Real Time Data is a subset of SCADA application originated data. In particular, the status and analog information obtained every 2 seconds and 10 seconds, respectively, is the Real Time Data. This information provides the monitoring of the vital signs of the electrical power system and its timely reporting is critical to the "real-time" operation of the power system.

There are two principle alternatives by which Real-Time SCADA Data can be reported to remote databases, in full or by exception. Reporting in full means that all possible status and analog values available from SCADA are reported each and every scan cycle. Reporting by exception means that only changes to the currently agreed upon value are reported between the remote databases. The following paragraphs discuss in more detail the two reporting alternatives.

Full Reporting is the more straight forward of the two methods identified for reporting SCADA data. Since all data is reported each scan cycle, database integrity is easily maintained between remote sites. The potential for remote databases getting out of synchronism is minimal and would normally be cleared in the following scan cycle. Another advantage of this method is that address bits need not be added for every quantity since all data can is sent each scan cycle it can be sent in the same order and identified by relative position. Thus, for full reporting each analog value is 32 bits and each status value is 16 bits, noting that each value has a number of flags associated with it concerning quality of data. Some type of communications between sites is necessary to assure the remote databases agree on the positioning of data, but this is not a complicated problem. The principle disadvantages of this method are:

1. Very ineffective use of the communications bandwidth.

2. Ineffective use of CPU resources at both the originating and receiving sites since all data must be processed by both each scan cycle.

Reporting SCADA data by exception is a more complicated in some ways than Full Data Reporting. Database integrity is not free and explicit steps must be taken by the SCADA application at the sending and receiving sites to ensure integrity is maintained. Another disadvantage of this method is that all data must carry a unique identifier to distinguish it from all other data. This is necessary since only changes are exchanged and they are always random. For the PP&L system 16 bit identifiers (or addresses) are associated with both status and analog values in the SCADA database for exception reporting. Thus SCADA analog values would be 48 bits (16 for address + 32 information) and status values would be 32 bits (16 for address + 16 information). But exception reporting has advantages full data reporting does not have, namely, it makes much more efficient use of the communications bandwidth and is less costly in terms of CPU resource.

The advantage of Report By Exception is apparent for periods of low electrical system activity where there is little data changing. The load imposed on the Data Communications Network is low and the resource requirements on the CPU is also low. In contrast, the full reporting method would communicate all the values each scan and the load on both the Data Communications Network and the CPUs would be steady and relatively high. During Periods of high electrical system activity is when you would expect report by exception to falter and full data reporting performance become preferred. Much time and effort was spent in evaluating the performance of the two methods for such conditions and it was discoverd that the expected was in fact not true for the PP&L System. Evaluation of the tests uncovered why this was true. In addition to the SCADA data telemetered from the RTUs there is a large portion of the SCADA databases on the PP&L system allocated for calculated and manually entered data. For exception reporting the amount of manually entered data transmitted during any single scan period is minimal since operators can only make a minimal number of entries (1 or 2) in a 10 second period. On the other hand, for Full Data Reporting, these values are communicated in every communications cycle since they can be changed. The end result was that even under conditions of high electrical system load, exception reporting provided benefits in CPU and Communications utilization which supported the selection of this method for reporting SCADA data. The following paragraphs provide more detail on how SCADA reporting is actually done for the PP&L Power Management System.

SCADA allocates a buffer for analog data sufficient in size to handle a single entry for each analog value in the database which may be transmitted. If a new analog value is identified from the RTU scan before the buffer of analog values is sent to another site, SCADA will overwrite the first value since, for analog values, the most recent value available is important rather than a history of all the transitions.

For Status information originating from SCADA the buffer for transmission is sized to handle up to six entries for each scanned value. This is done because, unlike analog points, there is significance in the transient readings of Status points. As an example, if a status is read indicating a breaker has gone from closed to open and before it is sent to another site another status comes in indicating the device has now gone from open to close, all that information is important to the receiver of the data. If the receiver does not receive the transients he would get an indication that a device he believed was closed went from open to close, and he would question the integrity of hiçs own database.

One point to make about the exception reporting method described above is that in order to insure the integrity of remote databases periodic scans are done which include all data, regardless of change or no change. This normally occurs after a Failure at a site or site configuration change, but it can also be triggered by some other event or by an operator when the integrity of a database is in question.

3.2.2 Control

Control is a special function performed by the SCADA application. Control includes the operation of transmission system devices as well as generators on the behalf of Generation applications. By convention, control is always actually implemented by the local site, but it can be done at the direction or request of a remote site. The remote site control requires the SCADA applicatons on the remote sites to communicate in order for control to be implemented. The transfer over the Data Communications Network of this information is time critical and requires a strict end-to-end acknowledgement scheme between SCADAs. SCADA actually prioritizes control actions above the exchange of real-time data and handles all the necessary application level protocol associated with the operation.

3.2.3 Accounting Data

Accounting data is a general term given to information periodically (regularly) exchanged over the DCN which is used for after the fact billing, modeling or review of operations. This information is not necessary for operating the real time network but does have definite value and application after the fact.

1. Critical - data which would be included in Class 2 as identified above. The primary example would be Megawatt Hour readings which are used in determining the billing between PP&L and other utilities. This information is not necessary in operating the system on a minute-by-minute basis, but it is very crucial to the operation of the company as a whole.

2. Non-critical - data which is useful, but is not strictly necessary. This information would be included in Class 3 as identified above. An example of this data would be information obtained from Distribution Substations used by the PP&L Planning Department to perform long range planning. If a portion of this data is lost for a period of time, such as a week, there is no impact to the operation of the company.

3.2.4 Informational Data

Informational data is exchanged in response to an operator request or initiation and is thus not periodic. This information all falls under Class 3 data. The information is available to support the operation of the system, but has not been determined to be normally required to support the operation of the power system.

1. Displays - the display exchange capability of the PMS allows an operator at any site to request a "snap shot" of any display available at any other site. Where the term "snap shot" indicates that a single picture is sent without linkages to the databases which support them and in fact the display is simply a static representation of the display as it was when the exchange took place.

2. Text messages - The text message exchange capability allows operators within various sites within the PMS send notes to one another. The operator at the originating site prepares a message then designates where it should be sent and a copy is forwarded to the specified locations. This is similar in concept to electronic mail but is less sophisticated because the operator's computer environment and man machine interface is not geared to support all the functionality available from other products.

3.3 DATA TRANSFER REQUIREMENTS (PERIODICITY AND QUANTITIES)

This section identifies the various exchanges to take place over the Data Communications Network. These data exchanges not only include the Division SCADA Systems and the Power Control Center, but also the Corporate Computer Center exchanges with the DSSs since this communication traffic will also be present. This section is divided into three subsections covering the sources of data, namely, DSS, PCC and CCC. Please note the subsection for the DSS source data is presented in the context of traffic for a single Division and the assumption is made that all Divisions will be equivalent and the actual load imposed by all DSSs will be six times what is identified here. The quantities of data to be exchanged from the largest division were used in order to generate the most conservative results, (the highest communications load). Though it is not strictly true that DSS are equivalent, analysis of the actual detailed exchanges expected for each of the Divisions indicates the differences in communication load are minor and the assumption is reasonable.

Within each of the source site subsections, names are given to each entry along with a description of the data to be exchanged including the identification of the applications involved. Also included in the descriptions is the following information:

o Periodicity of the exchanges

o Amount of data to be exchanged

o Class of the exchange

o Maximum transfer time.

The periodicity of exchanges identifies how often exchanges are aniticipated to take place and the amount of data to be exchanged is a quantitative estimate of the data to be transferred. The concept of Class was discussed earlier in the Chapter and is not repeated here. The last item, Maximum transfer time, is included as a target for the most time any particular transfer should take to complete. This value is critical for estimating the actual required bandwidth necessary to support the Data Communications Network.

3.3.1 DSS Source Data Entering The DCN

The following information represents the ultimate communications load anticipated on the DCN from a single Division SCADA System. This traffic consists of three parts; communication with the PCC, communication with other DSSs, and communication to the Corporate Computer Center via the Gateway located on the Ethernet at the PCC Site.

3.3.1.1 DSS To PCC Data -

DSS STATUS - Indication of binary state of telemetered devices from Remote Terminal Units.

- Originates from the DSS SCADA application and goes to PCC SCADA.
- Changes of status are transmitted every 2 seconds.
- Class 1 data
- Maximum transfer time of 2 seconds.
- DSS STATUS consists of the following:

Telemetered Data	175 pts.
Non-Telemetered Data-3 pts./telemetered	525 pts.
Calculated- assume 40% of calc. are xmitted	800 pts.

Note: Since exception reporting is used the non-telemetered values need not be accounted for in normal operation. Non-telemetered are only sent for integrity scans.

DSS STATUS = 1000 points

DSS ANALOG PART 1 - A variable associated with a measurement of a value at a specific location as telemetered from an RTU.

- Originates from the DSS SCADA application and goes to PCC SCADA.
- Changes of telemetered analog values above a defined threshold are transmitted every 10 seconds.
- Class 1 data
- Maximum transfer time of 10 seconds.
- DSS ANALOG PART 1 consists of the following:

Telemetered Data- 3 pts(Watt,Var,Amp)/dev	525 pts.
1 pt./bus (Volt)	60 pts.
Non-Telemetered Data- 700 values estimated	700 pts.
Calculated- The initial assumed 33% of calc are transmission data. For the ultimate 25% was used since the bulk of new points are associated with distribution data.	2425 pts.

Note: Non-Telemetered values need not be considered.

DSS ANALOG PART 1 = 3000 points

DSS ANALOG PART 2 - Calculated variables associated with the amounts of load available for shedding in case of system emergency. For each DSS there are three quantities sent to the PCC for Loadshed. The quantities are the total available load for shed in the High Priority, Low Priority and Manual categories. For the actual value to be used for the DCN loading analysis 6 pts. are included to account for the case immediately after loads have been shed and the amounts shed and amounts still available are sent.

- Data calculated by the Loadshed program is forwarded to the SCADA application. From the DCN perspective, the data originates from the DSS SCADA application and goes to PCC SCADA.

- Changes of the loadshed value are transmitted within 10 seconds of change and if they change constantly they would be sent every 10 seconds.

- Class 1 data

- Maximum transfer time of 10 seconds.

- DSS ANALOG PART 2 consists of the following:

  Loadshed Data 6 pts.

  DSS ANALOG PART 2 = 6 points

DSS ACCUMULATORS - Analog values retrieved once an hour from RTUs which indicate the amount of power which has flowed through the line.

- Data originates from the DSS SCADA application and is sent to the PCC MegaWatt Hour application.
- All values are transmitted once an hour.
- Class 2 data.
- Maximum transfer time of 180 seconds.
- DSS ACCUMULATORS consist of the following:

  Telemetered Data- Based on the highest division load identified for a single division (Lehigh). 300 pts.

  DSS ACCUMULATORS = 300 points

DSS TEXTUAL PART 1 - Forms sent from the DSS to the PCC concerning Work Requests, Switching Orders and Permits. These forms deal with the coordination of the Power System Operation with crews in the field. Contacts with the field personnel are always through the site with direct juristictional responsibilities and the transmission of the information between sites is done for convenience and for coordinating overall system operation.

- Exchange originates from the Tagging Application at DSS and is exchanged with the PCC version of the same program.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 90 seconds.

- DSS TEXTUAL PART 1 is estimated to be 3 CRT pages in size at 62 Kbits/page.

  DSS TEXTUAL PART 1 = 186,000 bits

DSS TEXTUAL PART 2 - Reports sent from the DSS to the PCC including the Daily Operating Report.

- Exchange originates from the DETM (Display Exchange/Text Messages) application at DSS and goes to the DETM application at the PCC where it can be presented to the operators.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 30 seconds.

- DSS TEXTUAL PART 2 is estimated to be 1 CRT page in size.

  DSS TEXTUAL PART 2 = 62,000 bits

DSS DISPLAYS - **Any display on the DSS sent to the PCC** upon request by the PCC. Imbedded along with the actual display exchanges are the requests for the displays from PCC by a DSS which are small in size and neglected for this study.

- Exchange originates from the DETM (Display Exchange/Text Messages) application at DSS and goes to the DETM application at the PCC where it can be presented to the operators.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 30 seconds.

- DSS DISPLAYS is estimated to be 1 CRT page in size.

  DSS DISPLAYS = 62,000 bits

3.3.1.2 DSS To DSS Data -

INTERDIV STATUS - Indication of binary state of telemetered devices from Remote Terminal Units.

- Originates from the DSS SCADA application and goes to DSS SCADA at other sites.

- Changes of status are transmitted every 2 seconds.

- Class 1 data

- Maximum transfer time of 2 seconds.

- INTERDIV STATUS consists of the following:

  Telemetered Data- Up to 75% of virtual data identified for a DSS is assumed to be for Interdivision Data received from other DSSs. 600 pts.

  INTERDIV STATUS = 600 points

INTERDIV ÁNALOG - A variable associated with a measurement of a value at a specific location as telemetered from an RTU.

- Originates from the DSS SCADA application on source site and goes to other DSS SCADA at the destination sites.

- Changes of telemetered analog values above a defined threshold are transmitted every 10 seconds.

- Class 1 data

- Maximum transfer time of 10 seconds.

- INTERDIV ANALOG consists of the following:

  Telemetered Data - Up to 66% of virtual data at a DSS is assumed to be for Interdivision Data from other DSSs. 800 pts.

  INTERDIV ANALOG = 800 points

INTERDIV TEXTUAL PART 1 - Forms sent from the DSS to the other DSSs concerning Work Requests, Switching Orders and Permits. These forms deal with the coordination of the Power System Operation with crews in the field. Contacts with the field personnel are always through the site with direct juristictional responsibilities and the transmission of the information between sites is done for convenience and for coordinating overall system operation.

- Exchange originates from the Tagging Application at DSS and is exchanged with the other DSS sites version of the same program.
- Exchanges are irregular and estimated to occur 10 times per hour.
- Class 3 data.
- Maximum transfer time of 90 seconds.
- INTERDIV TEXTUAL PART 1 is estimated to be 3 CRT pages in size at 62 Kbits/page.

  INTERDIV TEXTUAL PART 1 = 186,000 bits

INTERDIV TEXTUAL PART 2 - Reports sent from the **DSS** to other DSSs including the Daily Operating Report and Weather.

- Exchange originates from the DETM (Display Exchange/Text Messages) application at DSS and goes to the DETM application at the other DSSs where it can be presented to the operators.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 30 seconds.

- INTERDIV TEXTUAL PART 2 is estimated to be 1 CRT page in size.

  INTERDIV TEXTUAL PART 2 = 62,000 bits

INTERDIV DISPLAYS - Any display on the DSS sent to another DSS upon request by the remote DSS. Imbedded along with the actual display exchanges are the requests for the displays from remote DSS by a DSS which are small in size and neglected for this study.

- Exchange originates from the DETM (Display Exchange/Text Messages) application at DSS and goes to the DETM application at the remote DSS where it can be presented to the operators.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 30 seconds.

- INTERDIV DISPLAYS is estimated to be 1 CRT page in size.

  INTERDIV DISPLAYS = 62,000 bits

3.3.1.3 DSS To CCC Data -

DS/CC STATUS - Indication of binary state of telemetered devices from Remote Terminal Units.

- Data from the DSS SCADA application goes to the CIA application at the CCC. CIA filters status changes to account for momentary changes in status then reports the information to the Customer Interruption Analysis program on the Corporate Computer Center (CCC).

- Changes of status are transmitted once a minute after filtering.

- Class 2 data

- Maximum transfer time of 30 seconds.

- DS/CC STATUS consists of the following:

  Telemetered Data - Assumed 50% of status points from largest division (Lehigh) 2000 pts.

  DS/CC STATUS = 2000 points

DS/CC ANALOG PART 1 - A variable associated with a measurement of a value at a specific location as telemetered from an RTU. Included in this category is environmental data retrieved from RTUs at Power Generating Stations and Oil data retrieved for Combustion Turbine Units.

- Originates from the DSS SCADA application and goes to Environmental and Oil applications at the CCC.
- Periodic samplings of telemetered analog values are transmitted every 5 minutes.
- Class 2 data
- Maximum transfer time of 120 seconds.
- DS/CC ANALOG PART 1 consists of the following:

  Telemetered Data - Environmental and Oil. 1000 pts.

  DS/CC ANALOG PART 1 = 1000 points

DS/CC ANALOG PART 2 - Data on the Electrical Distribution System monitored by Remote Terminal Units. This information is used by System Planning to evaluate the load on various circuits and perform forecasting and long range planning.

- Data is sampled from the DSS SCADA application every minute and a 15 minute averaged demand determined and stored.

- Three times a day all the stored data is transmitted to the CCC from a DSS.

- Class 2 data

- Maximum transfer time of 90 seconds.

- DS/CC ANALOG PART 2 consists of the following:

  Telemetered Distribution data - assumed
  3 amp readings per feeder circuit and
  a volt point for every 2 feeders. 1500 pts.

  DS/CC ANALOG PART 2 = 1500 points

DS/CC TEXTUAL - Reports sent between the DSS and CCC for general company wide communication. Currently the only specific exchanges included in this category are sending Daily Operating Reports and Weather Forecast from DSS to CCC but provisions are included for additional exchanges in both directions.

- Exchange originates from the DETM (Display Exchange/Text Messages) application at DSS and goes to a new application on the CCC which will handle the distribution of the information to appropriate CCC users.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 30 seconds.

- DS/CC TEXTUAL is estimated to be 1 CRT page in size.

  DS/CC TEXTUAL = 62,000 bits

3.3.2 PCC Source Data Entering The DCN

The following information represents the ultimate communications load anticipated from the PCC onto the Data Communications Network. This information is broken into two categories; communication with DSSs and communication to the CCC. The communication to the Division SCADA Systems is represented by the load to a single site. To expand for the entire Data Communications Network, the quantities represented could be multiplied by a factor of 6 to account for all DSSs.

The PCC to CCC exchanges are localized to the PCC Ethernet portion of the Data Communications Network and are included in this investigation for completeness.

3.3.2.1 PCC To DSS Data (Destination is a single DSS) -

PCC STATUS - Indication of binary state of telemetered devices from Remote Terminal Units and/or Generation Plants.

- Originates from the PCC SCADA application and goes to DSS SCADA applications.
- Changes of status are transmitted every 2 seconds.
- Class 1 data
- Maximum transfer time of 2 seconds.
- PCC STATUS consists of the following:

Telemetered Data	200 pts.

DSS STATUS = 200 points

PCC ANALOG PART 1 - Results from the PCC State Estimator and Security Analysis Programs.

- Originates from the PCC SCADA application and goes to DSS SCADA.
- Results are sent each time the PCC applications complete runs, approximately 5 minutes.
- Class 1 data
- Maximum transfer time of 30 seconds.
- PCC ANALOG PART 1 consists of the following:

  State Estimator & Security Analysis Results 200 pts.

  PCC ANALOG PART 1 = 200 points

PCC ANALOG PART 2 - Variable associated with a measurement of a value at a specifiic location as telemetered from an RTU or Generation Plant.

- Originates from the PCC SCADA application and is sent to the DSS SCADA application at the destination sites.

- Changes are transmitted within 10 seconds of detection and if values change constantly they would be sent every 10 seconds.

- Class 1 data

- Maximum transfer time of 10 seconds.

- PCC ANALOG PART 2 consists of the following:

Telemetered Data	200 pts.

ANALOG PART 2 = 6 points

PCC TEXTUAL PART 1 - Forms sent from the PCC to the DSSs concerning Work Requests, Switching Orders and Permits. These forms deal with the coordination of the Power System Operation with crews in the field. Contacts with the field personnel are always through the site with direct juristictional responsibilities and the transmission of the information between sites is done for convenience and for coordinating overall system operation.

- Exchange originates from the Tagging Application at PCC and is exchanged with the DSS version of the same program.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 30 seconds.

- PCC TEXTUAL PART 1 is estimated to be 3 CRT pages in size at 62 Kbits/page.

  PCC TEXTUAL PART 1 = 186,000 bits

PCC TEXTUAL PART 2 - Reports sent from the PCC to the DSS including the Daily Operating Report and Weather.

- Exchange originates from the DETM (Display Exchange/Text Messages) application at PCC and goes to the DSS application at the DSS where it can be presented to the operators.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 30 seconds.

- PCC TEXTUAL PART 2 is estimated to be 1 CRT page in size.

  PCC TEXTUAL PART 2 = 62,000 bits

PCC DISPLAYS - Any display on the PCC sent to the DSS upon request by the DSS. Imbedded along with the actual display exchanges are the requests for the displays from DSS by a PCC which are small in size and neglected for this study.

- Exchange originates from the DETM (Display Exchange/Text Messages) application at PCC and goes to the DETM application at the DSS where it can be presented to the operators.

- Exchanges are irregular and estimated to occur 10 times per hour.

- Class 3 data.

- Maximum transfer time of 30 seconds.

- PCC DISPLAYS is estimated to be 1 CRT page in size.

  PCC DISPLAYS = 62,000 bits

3.3.2.2 PCC To CCC Data -

PC/CC ANALOG - A variable associated with a measurement of a value at a specific location as telemetered from an RTU. Included in this category is environmental data retrieved from RTUs at Power Generating Stations and Oil data retreived for Combustion Turbine Units. Provisions are included for the addition of additional Plant data in the future.

- Originates from the PCC SCADA application and goes to Environmental and Oil applications at the CCC.
- Periodic samplings of telemetered analog values are transmitted every 5 minutes.
- Class 2 data
- Maximum transfer time of 120 seconds.
- PC/CC ANALOG consists of the following:

  Telemetered Data - Environmental and Oil. 3000 pts.

  PC/CC ANALOG = 3000 points

PC/CC TEXTUAL PART 1 - Results from AC Power Flows to be included with the CCC Study applications.

- Exchange originates from the Electrical Network Analysis programs from the PCC and goes to Network Analysis applications on the CCC to be used by the Planners for doing System Analysis.

- Only selected results are sent as determined by the PCC operator so transfers are infrequent and estimated to be approximately every 2 hours.

- Class 3 data.

- Maximum transfer time of 600 seconds.

- PC/CC TEXTUAL PART 1 is estimated to be 36,000 words of data.

  PC/CC TEXTUAL PART 1 = 36,000 words

PC/CC TEXTUAL PART 2 - Reports sent between the PCC and CCC for general company wide communication. Currently the only specific exchanges included in this category are sending Daily Operating Reports and Weather Forecast from PCC to CCC but provisions are included for additional exchanges in both directions.

- Exchange originates from the DETM (Display Exchange/Text Messages) application at PCC and goes to a new application on the CCC which will handle the distribution of the information to appropriate CCC users.
- Exchanges are irregular and estimated to occur 10 times per hour.
- Class 3 data.
- Maximum transfer time of 60 seconds.
- PC/CC TEXTUAL PART 2 is estimated to be 1 CRT page in size.

 PC/CC TEXTUAL PART 2 = 62,000 bits

3.3.3 CCC Source Data Entering The DCN

The following information represents the ultimate communications load anticipated on the Data Communications Network resulting from transfers from the Corporate Computer Center to the DSSs and PCC. Please note that the PCC destined traffic will be localized to the Ethernet at PCC where the Gateway to the CCC is located but the information is included in this investigation for the sake of completeness.

3.3.3.1 CCC To DSS Data (single DSS) -

CC/DS TEXTUAL - Reports sent between the CCC and DSS including outputs from the CCC Customer Interruption Analysis program. The CIA information would include outage summaries and alert messages.

- Exchange originates from the CIA application at the CCC and is destined for the DETM (Display Exchange/Text Messages) application at DSS which is responsible for notifying and presenting information to the operators.
- Exchanges are irregular and estimated to occur 6 times per hour.
- Class 3 data.
- Maximum transfer time of 30 seconds.
- CC/DS TEXTUAL is estimated to be 1 CRT page in size.

  CC/DS TEXTUAL = 62,000 bits

3.3.3.2 CCC To PCC Data -

CCC ANALOG - A variable associated with cost to operate various Power Plants. The data represents a Curve which is used at the PCC to determine actual and projected operating costs associated with each generating unit.

- Originates from the CCC Generation applications and goes to PCC Generation Applications to be used for Unit Commitment and Optimal Power Flow.

- Cost Curves are changed infrequently, in the range of once a month, but for the sake of communications load it is estimated to occur every 4 hours.

- Class 3 data

- Maximum transfer time of 300 seconds.

- CCC ANALOG consists of the following:

Cost Curve Data	8000 pts.

CCC ANALOG = 8000 points

CC/PC TEXTUAL - Category for miscellaneous exchanges from the CCC to PCC.

- Exchange origination is not yet defined.
- Assumed to be operator initiated and to occur every 20 minutes.
- Class 3 data.
- Maximum transfer time of 30 seconds.
- CC/PC TEXTUAL is estimated to be 62,000 bits, one CRT page.

  CC/PC TEXTUAL = 62,000 bits

CHAPTER 4

ANALYSIS OF CONTENDING NETWORK CONFIGURATIONS

This Chapter of the thesis presents the configuration objectives to be met by the Data Communications Network, the alternatives considered, the analysis method and the analysis of the investigation of those configurations.

4.1 CONFIGURATION OBJECTIVES

The objective of investigating the Data Communications Network configuration is to determine the most reliable, best performing and economic configuration available to support the Power Management System needs. A more descriptive discussion of the objectives is as follows:

- **Reliability** - The configuration is to be robust such that it can survive the loss of any single line or communications device with minimal impact to operation of the Power Management System.

- Best Performing - Effective utilization of the communications lines comprising the DCN. Inclusion of under utilized circuits or idle spares is not desirable.

- Economic - The most cost effective solution, which does not imply the cheapest, but rather the configuration which reasonably meets the first two objectives at the most reasonable cost.

4.2 CONTENDING ALTERNATIVES

Four distinct network designs were considered for the Data Communications Network in this investigation. The four are a STAR, MESH, HUB-STAR and MODIFIED HUB-STAR. Originally many more options were considered, but after careful examination of the alternatives and consideration of the limitations of DECnet, it was determined these other network designs reduced to networks similar to those included in this investigation.

The limitation imposed by DECnet on the configurations is the lack of support for load sharing on multiple circuits between two nodes. DECnet only supports the use of a single active path between two nodes at any one time and use of secondary paths is only done when the first path fails. No load balancing is available (splitting the load between two paths) and DECnet does no dynamic routing based on loading. According to DEC the ability of DECnet to support load balancing, (active support of two lines simultaneously between two nodes), is not intended in the near future, so inclusion of multiple active circuits between nodes was not considered desirable for the configuration options considered.

During the initial review of alternative configurations another simplifying assumption was made in that automatic line (communication circuit) switching would not be performed. This assumption was made because it is felt the complexity involved in providing such a scheme for automatic operation is not justified. As a result, alternative configurations were eliminated which included spare channels available for automatic switching to accommodate physical reconfiguration of the network.

All the configurations included in this investigation are designed using common hardware and have some common characteristics. The Communications Network Processor (CNP) is the primary communications device used to connect all the PMS internal sites. In the implementation of the DCN the CNP is the DEC Router, a PDP 11/24 computer serving as a communications server. The Router is capable of supporting up to eight 56K bps communications links to remote sites using DECnet and communicates to local hosts at each site via Ethernet. Two Routers are included at each site in order to allow communications to continue when any single Router fails. The assignment of communication circuits to Routers is done in such a way that communications between any sites is still available for any single communication failure such as loss of a communications circuit, Router or Digital Data Set.

Digital Data Sets are used for interfacing the Router with the 56K bps digital circuits to be used for the DCN. The Digital Data Sets (referred to as Data Sets) connect to the Dataphone Digital Service (DDS) network and includes both the Channel Service Unit and Data Service Units.

Another common factor in each of the configurations considered is the interconnection of the PMS to PJM and the CCC via Gateways. A gateway is defined as a communications processor which allows nodes which communicate by unlike protocols to communicate with one another transparently. For the PMS internal DCN, which is DECnet based, the gateways allow for communication with PJM and the CCC which each use different protocols. The PJM Gateway is implemented on redundant MicroVAXes attached to the PCC Local Area Network. Communications to the PJM system is by binary synchronous communications, also referred to as Bisynch protocol. For CCC, a single DECnet/SNA Gateway is provided on the PCC Local Area Network to allow communications to take place with the IBM based Corporate Computer Center. Both these interconnects were included in the Study for informational purposes and not to specifically address configuration issues concerning their implementation. For Data Communications Network loading analysis, the traffic between the DSSs and CCC is included as part of the communications load. Communication between the PMS and PJM is handled through the PCC, so this traffic is localized to the PCC Ethernet.

As a result of the initial elimination process four designs were identified to warrant further analysis and of those three were to be included in the DCN loading runs. The configurations which made it through the first analysis have been labeled the STAR, the HUB-STAR, and the MODIFIED HUB-STAR as referenced above. These configurations are described in the following subsections.

While reading the descriptions of the configurations it will be useful to refer to the diagrams labeled "Network Configurations" included in each subsection. Also worth note in the descriptions that follow is the fact that focus is given to communications processors and sites where a site is assumed to be but a single host node. This assumption is made since the hosts at a site are redundant machines which one is intended to operate as one as primary and the other as a standby at any point in time. Thus, even though there are two physical nodes located at each site, they are thought of as a single node carrying the site name in context of communications. In the actual implementation of the Data Communications Network, the communications software layered above DECnet, handles the logical translation of sites into physical nodes.

4.2.1 STAR

The STAR network is the simplest of the network designs considered. It consists of 12 communication circuits, connecting the 6 DSSs to the PCC. Each of the Division sites (DSS) is connected to the Central site (PCC) by two direct 56K bps lines. One of the two circuits between a DSS and the PCC would be actively used at one time and the second circuit would be a hot spare. See Figure 6 for an overview of the STAR configuration.

At a DSS the two communication lines to the PCC are connected through two Digital Data Sets to two separate Routers. In turn, at the PCC, the other end of the two communications lines are routed through two Digital Data Sets to two separate Routers as well. This arrangement provides a backup for DSS-PCC communications for the case of a single communications failure such as a line, a Digital Data Set or a Router.

At the PCC the connections to the divisions are made through two Routers with six lines connected to each. The assignments of lines to Routers is such that no two lines from a single division are connected to the same PCC Router. This ensures that a single failure of a Router at PCC will not result in loss of communications to any division.

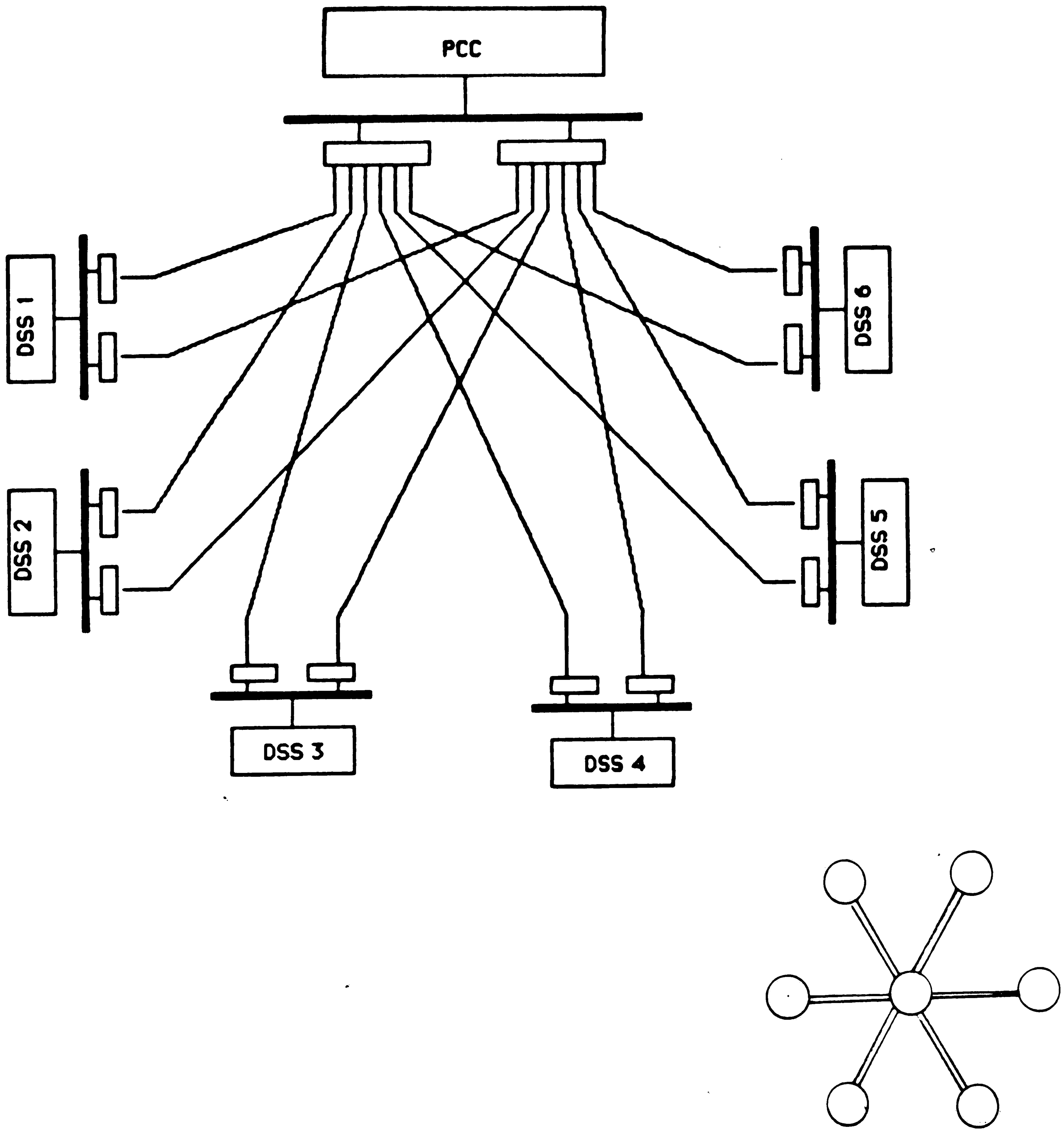

Figure 6.

Data Communications Network

STAR Configuration

The STAR network has the advantage of simplicity; it is conceptually and physically the simplest network design. However, the design has 6 communications lines and six or seven Routers which are idle most of the time. Since the lines are basically idle, their is a great inefficiency in the use of the facilities and the quality of the unused lines is not being well tested. A problem with having lines unused and not well tested is that the idle line could fail without detection until attempts are made to use it. This condition raises the potential for having both lines failed simultaneously, which is obviously undesirable. In addition, the 6 spare communications lines are very long in some instances and potentially can be much more costly than some of the other configurations. Idle Routers do not present the same problem as idle communications lines because it is possible to monitor the health of those devices from one of the hosts on the Ethernet Local Area Network. But detection of idle line interface card problems is difficult, even with the sophisticated diagnostic software available.

4.2.2 MESH

A MESH configuration was considered for the sake of completeness. The MESH network is a fully connected mesh and is characterized by each site being connected directly with each other site. For the case of the PP&L Data Communication Network such a configuration would require 21 communications circuits to fully connect the seven PMS sites. Note that for a fully connected Mesh network N(N-1)/2 full duplex links are required where N is defined as the number of nodes (or sites for this instance). The MESH configuration is shown in Figure 7.

The full MESH network has many advantages related to the fact that traffic between any two sites is restricted to take place on the links directly connecting those sites. Another advantage is that recovery of a failed link, Digital Data Set or Router is simplified, since many alternatives paths are available.

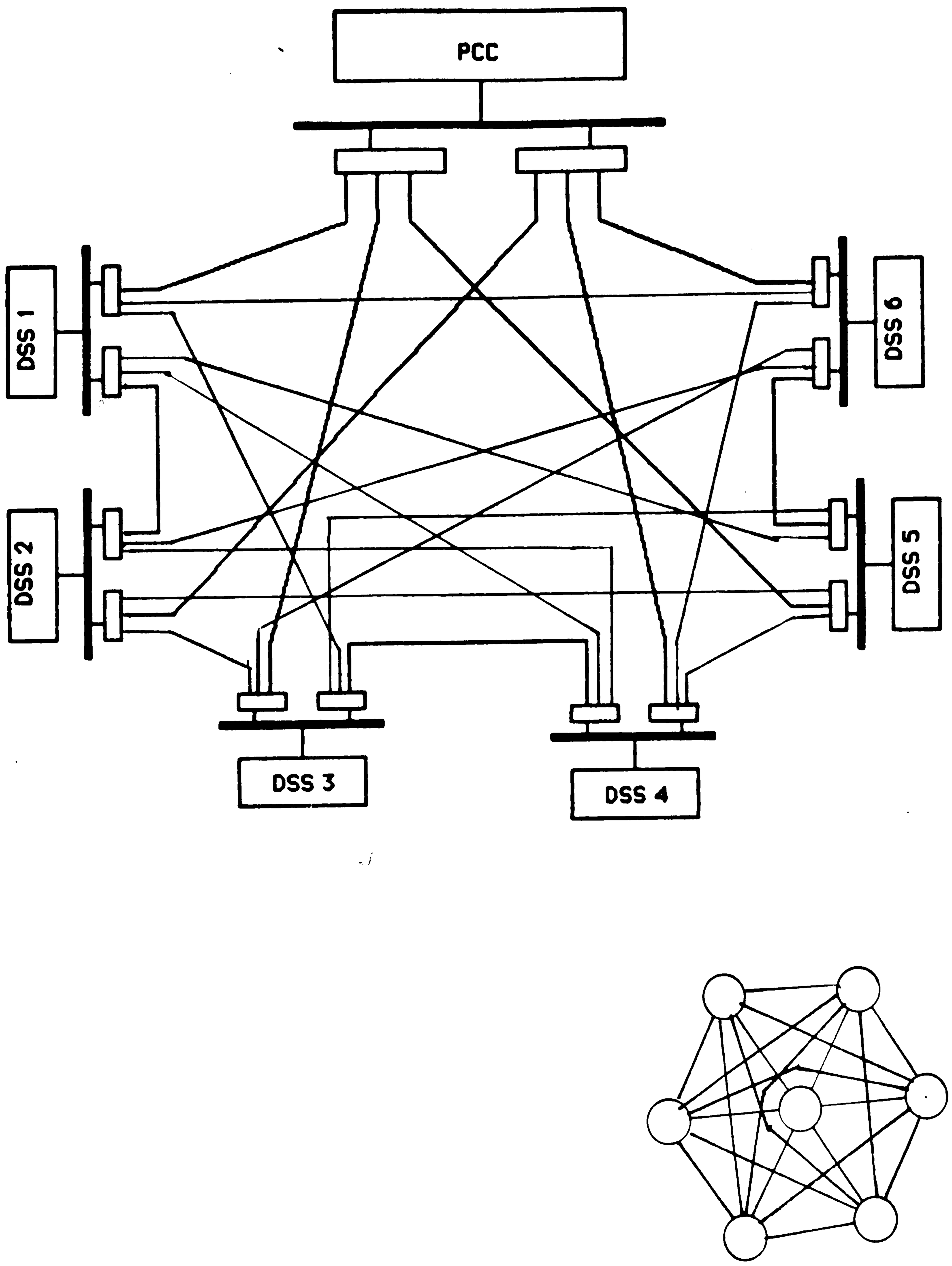

Figure 7.

Data Communications Network

MESH Configuration

The principle disadvantage of this configuration is the associated cost. Analysis of DSS to DSS traffic indicates only small amounts of data actual flow between any particular two divisions. Given this, the numerous circuits included in this network to provide full connectivity between divisions are negligibly loaded and certainly do not justify the cost.

As a result of the above analysis, detailed loading studies of this configuration were not pursued.

4.2.3 HUB-STAR

The HUB-STAR network is the simplest version of a mesh network that is feasible for the PMS configuration. It consists of 12 communication circuits with each DSS being connected through two Routers and 56K bps lines to two other DSS's, and to the PCC. Conceptually this configuration appears to be a single STAR with the PCC at the center connecting to each 6 DSSs' and a hub surrounding the STAR connecting all the DSSs together. (See Figure 8.) The assignment of channels to Routers would be made such that no single failure would result in the loss of all three lines. Thus, each DSS has three lines connected to it; two to its DSS neighbors, and one to the PCC. The PCC has six lines connected to two Routers, one line for each DSS. The assignment of lines to Routers at the PCC will be done in such a way that no DSS and either of its connected neighbors would be assigned to the same device. As a result a loss of a PCC Router would result in the loss of direct communication to 3 non-adjacent divisions. DSS traffic from these divisions would then be re-routed via neighboring DSSs to the PCC.

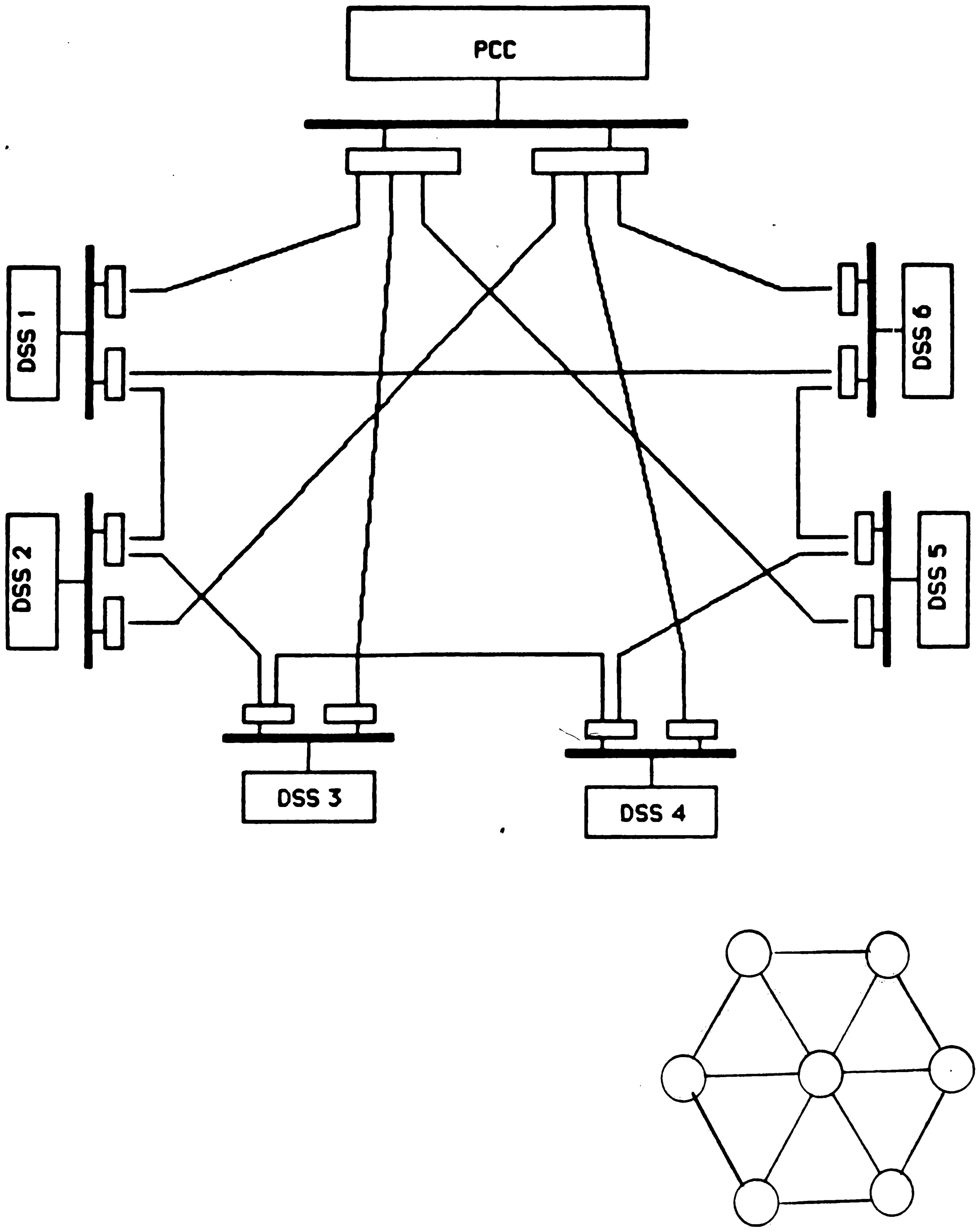

Figure 8.

Data Communications Network

HUB-STAR Configuration

The HUB-STAR design has the advantage that all DSS-DSS traffic can be removed from the line that goes to the PCC, lowering the load on the PCC-DSS lines. This, in comparison to the STAR, makes the network more noise immune (increasing its overall reliability) by providing greater bandwidth for the DSS-PCC transmissions. At the same time, use is made of the DSS-DSS lines, thus checking the integrity of these lines continuously. Backup for communication related failures is provided by lines that are doing useful work and as a result the money spent on communications lines has a higher return in service.

A disadvantage of the HUB-STAR configuration is that the setup of DECnet parameters such as routing cost will be more complicated than the other alternatives. Careful consideration must be given to the routing of information, especially for failure scenarios. But this disadvantage is minor and would only be required to be designed once.

4.2.4 MODIFIED HUB-STAR

The MODIFIED HUB-STAR is a version of the HUB-STAR that does not fully connect a DSS to its neighbors. In this net, the DSS's are interconnected in pairs. Each DSS has two 56K bps lines connected to it, one to a neighbor DSS and the other one to the PCC. The PCC connections are the same as in the HUB-STAR. Conceptually this configuration just calls for removing every other DSS-DSS link from the HUB-STAR. MODIFIED HUB-STAR configuration is shown in Figure 9.

The MODIFIED HUB-STAR has the advantage that it offers redundancy capabilities nearly equivalent to those offered by the HUB-STAR, with 25% fewer communications lines necessary, only nine as opposed to twelve for the other configurations.

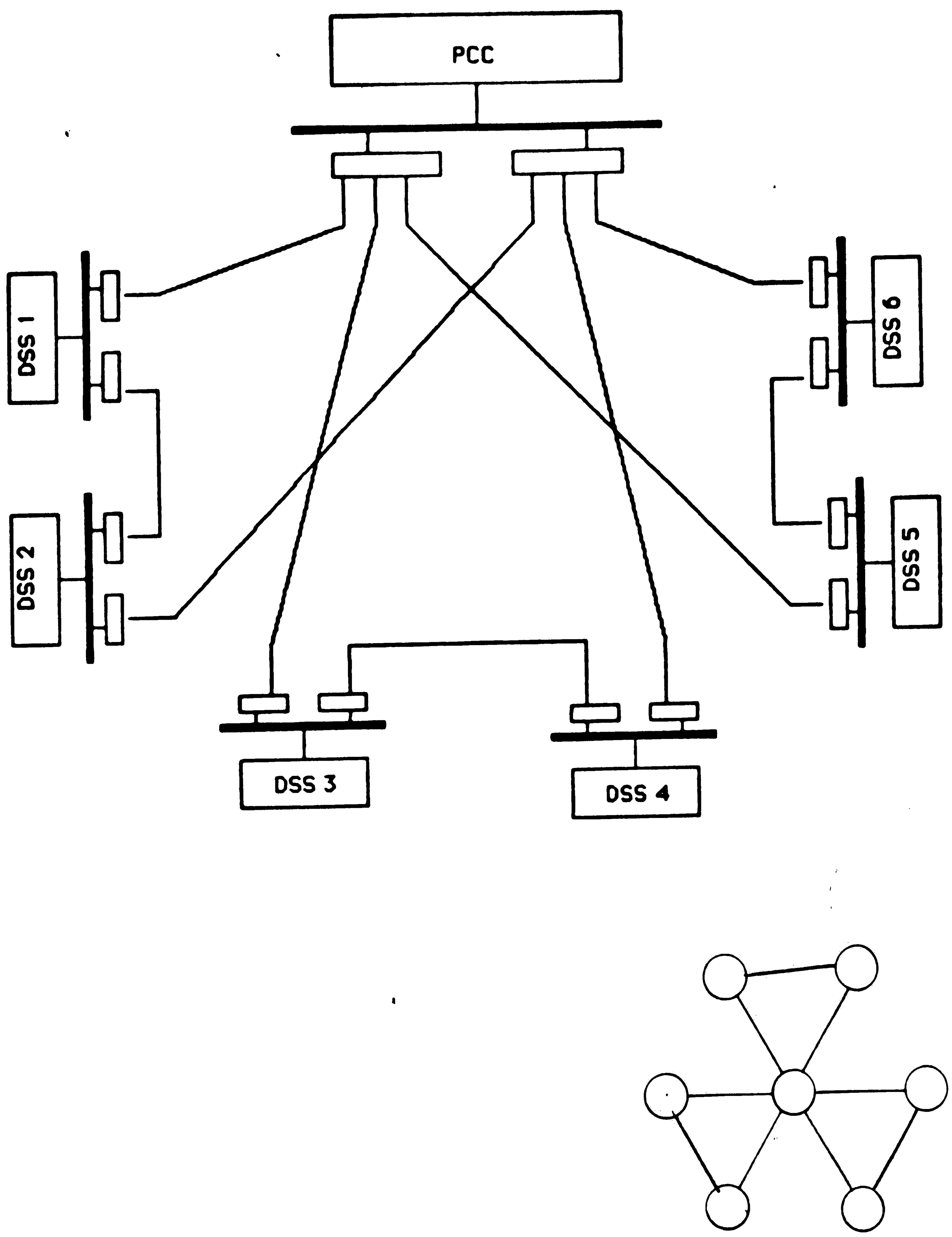

Figure 9.

Data Communications Network

MODIFIED HUB-STAR Configuration

The disadvantage of the MODIFIED HUB-STAR network is its inability to remove all DSS-DSS traffic from the DSS-PCC lines. Since the traffic flowing between the DSSs has been determined to be relatively independent of the particular sites, the DSS-DSS links in this configuration can only channel about 20% of the total DSS-DSS traffic. As a result the configuration yields loads only slightly better than with the STAR configuration without providing the full backup capability associated with the hot spares.

4.3 CONFIGURATION ANALYSIS

In the previous Section of this Chapter a number of alternative configurations for the Data Communications Network were presented. Of these a number were identified as meriting further evaluation. This Section describes the analysis performed on these alternatives.

This Section of the thesis presents the methodology employed to evaluate the alternative configurations for the Data Communications Network. Subsections are included on the methods, data representation, tools, assumptions and modeling. Analysis for the various configurations was done against the requirements of the Power Management System and the configurations were also compared directly to one another.

4.3.1 Methods

The method for evaluating the alternative configurations was to perform computer simulations of the communication loading on the Data Communications Network. Numerous loading runs were made for each configuration and included simulations for the following:

- o Configurations

  - Normal full configuration

  - Failure scenarios for single contigency failures.

    1. Loss of a single DSS-DSS communication circuit

    2. Loss of a single DSS-PCC communication circuit

    3. Loss of a DSS Router, the one including a DSS-DSS and the DSS-PCC interfaces for the HUB-STAR.

    4. Loss of a PCC Router, which includes the loss of 3 DSS-PCC interfaces for the HUB-STAR.

o Loading Conditions

- Normal activity - expected normal operating level, the state the electrical system is in most of the time.

- High activity - expected increased level of activity which the electrical system experiences for periods of about an hour twice a day.

- Peak activity - activity associated with a high level of electrical system changes over a short period of time.

- Baseload - accounting for the integrity scan required for the operation of SCADA as described in the previous Chapter.

o Classes of Data

- All data that may be expected to be transferred.

- Realtime only, or Class 1 data.

- Background only, combination of Class 2 and Class 3 data.

Loading runs were made for each configuration above, in all possible combinations, then the results were compiled and tested for accuracy and consistency. Random hand calculations were performed as part of the accuracy check. Loading values were calculated based on the actual data to be sent on the DCN then a factor was added to account for overheads of DECnet and checked against the simulation generated numbers for reasonability. The consistency check involved comparing results for the various runs and checking actual simulation results against expected results. As an example of this type of check, the separate runs made for the Realtime and Background data for certain conditions were combined and checked against the results for the combination run.

The simulations run for the loading analysis are based on Queueing Theory and for the use of DECnet in particular. The following subsections present a brief description of Queueing Theory, discuss data representation for the simulation, the tools for running the simulation, assumptions made, and the modeling employed.

4.3.1.1 Queueing Theory -

Queueing Theory is used to perform delay analysis for communication networks. Queueing systems are used to model the receipt of packets into nodes and the delays encountered before those packets are retransmitted. These delays are associated with the amount of time required to service each packet as it arrives. The servicing of the packets includes the error checking and the routing of the packet to the proper location. Thus queueing theory accounts for the receipt of data packets from multiple input ports on a node and the routing or shuffling of those packets to the multiple output ports on the node. It should be noted that the relationship of input to output is not necessarily one-to-one and in fact it usually is not. Data coming from various input ports, typically leave on common output ports, and Queueing Theory accounts for the interaction of the various buffering involved.

Queueing system based analysis yields probabilistic results for the delay times of sending data from a source node to receipt of the data at the destination node. Also the analysis will provide results for the expected queue lengths for nodes which allows the network designer to account for the proper amounts of buffer space.

Detailed treatments of Queueing Theory are available in much of the literature on computer communications and are not presented in any additional detail in this paper.

4.3.2 Data Representation

Chapter 3, Communication Requirements, identifies the base of the data which is to be sent via the Data Communications Network. As noted earlier, a major portion of this data, SCADA, is to be reported on an exception basis so some steps were necessary to address this condition. Exception reporting results in having a DCN load which is in direct proportion to the electrical system activity. To account for this relationship a number of electrical system activity levels were defined. These levels are STEADYLOAD, HIGHLOAD, PEAKLOAD and BASELOAD and each is described in detail in the subsections to follow with emphasis in the descriptions given to the effects of the Data Communications Network.

The Data Communications Network modeling must be done based on the load at the sending site; thus, for each performance scenarios a separate data load was generated.

Each of the loading scenarios described below was run separately for Foreground (Realtime), Background (non-Realtime) and All data, the combination of the first two. Each category of run was made to determine maximum coincident (peak) and maximum average loads. The maximum coincident load can be envisioned as every possible transfer taking place simultaneously, and maximum average load as all transfers occurring over an extended period of time. The modeling of these items is discussed in the section on Modeling.

4.3.2.1 STEADYLOAD -

STEADYLOAD is the lowest load state defined for the PMS and PP&L electrical system. This is the state at which the system is expected to be running most of the time. In regards to the DCN the following factors in the load state definition are the most important:

- o 1 Status point change/30 seconds
- o 50% Analog points changes/scan (10 seconds)
- o All DCN background traffic is active

4.3.2.2 HIGHLOAD -

HIGHLOAD is a system state in which system activity is considerably increased, but which the system can reasonably be expected to reach relatively often (couple of times daily). This load state is one that the system would be expected to be operating in for long periods of time. In regards to the DCN the following factors from the load state definition are the most important:

- 10 Status point changes/2 seconds
- 75% Analog points changes/scan (10 seconds)
- All DCN background traffic is active

4.3.2.3 PEAKLOAD -

PEAKLOAD is defined to be the highest anticipated activity level of the electrical system. This state can be envisioned as the combination of two sub-states which will be called PEAKLOAD1 and PEAKLOAD2.

PEAKLOAD1 is defined as the first 16 seconds of the PEAKLOAD activity state. During this period the electrical system is changing rapidly and the PMS runs at an extremely high rate of alarm generation, which is not sustained. This high rate of alarm generation affects the

DCN by dumping a very large short-term load onto it. The alarms generated during this 16 second period come from a combination of status state or analog value changes, but for the DCN loading analysis, all values were assumed to be due to status changes, causing the load on the DCN to be maximized for this period. This assumption maximizes results because, coincident with the alarms, it is assumed that 90% of the analog values under scan change significantly enough to be reported. Therefore, assuming alarms are all status eliminates potential overlap between the reporting of analog alarms and analog changes and thus maximizes the combined number of analog and status points that are reported. This assumption is intentionally in error but it is reasonable to do so since it errs on the side of conservatism. In regards to the DCN load the significant factors effecting the loading are as follows:

- o 250 Status point changes/2 seconds (for a total of 2000 in 16 sec.)

- o 90% Analog points changes/scan (10 seconds)

- o Some applications, and thus some of the DCN background transfers are suspended during this period.

PEAKLOAD2 is the remainder of the PEAKLOAD activity state and accounts for the period after the first 16 seconds. At this time the rate of alarm generation drops off dramatically (along with the causes of the alarms), and the load on the DCN stabilizes for the 10 minute duration of the load scenario. PEAKLOAD2 models this nine minute, forty-four second "tail". In regards to the DCN load the following items from the load state definition are significant:

- 20 Status point changes/2 seconds
- 90% Analog points changes/scan (10 seconds)
- Some applications, and thus some of the DCN background traffic, is suspended during this period.

  the Work Statement.

4.3.2.4 BASELOAD -

BASELOAD is not a load scenario in the context of the other scenarios described above, but rather, it is the representation of all data that can possibly be sent by the PMS on the network. This load can be envisioned as Full Data Reporting by SCADA using the data sizes defined for Report By Exception. It is an unlikely scenario which involves EVERY data point in the SCADA system changing every time the SCADA system scans the data points, coincident with all the possible background transmissions simultaneously taking place. An important feature of Baseload is that the Realtime portion of this load, by itself, represents the load imposed on the DCN when an integrity scan takes place. A summary of the loading on the DCN are as follows:

- o All Status points reported each scan (2 seconds)
- o All Analog points reported each scan (10 seconds)
- o All Background traffic active

4.3.3 Tools For Configuration Analysis

This section describes the tools or programs used to support the DCN Study and describes how these tools were used.

4.3.3.1 Queueing Theorey Simulation Program (NETQUE) -

NETQUE is a FORTRAN program, developed by DEC, that models the loading of a DECnet computer network. A DECnet network is composed of nodes, which are computers, connected by physical lines. NETQUE uses queuing theory, modeling a DECnet node (for example, a DSS system) as queues of messages, connected with a given size physical communications line. The program maintains the queues, applying wait time in queues to messages, and dequeuing messages as line loading (from previous messages, and performance at the far end of the line) and wait times allow.

Within a given node, many sources for messages can exist, and messages from these sources are added to the NETQUE outgoing queue as quickly as they are generated. If this adding of messages overwhelms the capacity of the line, the user of the program is notified of that fact, and processing for all nodes in the network stops. (It would no longer be meaningful to model other nodes, as the loading they would experience from possible messages would be impossible to predict.) NETQUE gives error messages for each of these lines calculated to exceed 99.9 percent loading. The values given for these overloaded lines are NETQUE estimates which are normally not consistent with other data, probably due to buffer overflows in the program. If the required bandwidth for a number of messages does not exceed the available bandwidth on a line, the program goes on to calculate the loading for the entire network, applying the mechanism above node by node. If messages transfer through a node (route-through), they are removed from one queue, a delay time is applied to them that is based on the amount of traffic on the node and the processing time for the node, and the messages are placed in the appropriate outgoing queue for their destination.

The output from the NETQUE program consists of several statistical measures on the communication line loading and message delay times. For the purposes of this study, two of these outputs were considered significant; percentage of line utilization between nodes, and queue sizes at nodes.

The input to NETQUE consists of two major sections. First is a description of the DECnet network by node and line, in a format that allows specification of physical transmission line delays, wait time in queues, node processing times, line bandwidth, line error rates, and other factors that impact the physical part of the network. Second is a description of the data to be transmitted through the network, which includes origin and destination, data rates, and line costs (a measure of relative expense to the computer of using a line, NOT the dollar cost of using it).

Due to the volume of the actual input to and output from NETQUE, it has not been included in this paper. If the actual files are desired, they are available on tape from the author.

4.3.3.2 NETQUE Limitations -

NETQUE's primary limitation, from the standpoint of this application, is that it assumes the load on the network is a steady state one. Because of this assumption it is not possible to enter time-variant data into NETQUE directly, so modeling a network that moves from one load state to another is not easily done. To overcome the modeling limitation of NETQUE, the Network was modelled for short discrete periods rather than a single continuous one. Each of the periods related to a load scenario, as described earlier in this chapter, were modelled for both the maximum coincident load and the maximum average load conditions based on the input data.

Another NETQUE limitation is that communication line speeds are limited to 56,000 bits per second (56K bps). This was not regarded as a problem since the study was targeted at using 56 kbs lines.

NETQUE's final limitation is that it models only Phase III of DECnet, not Phase IV, which is the current version and the version PP&L will initially implement. The prime difference between versions III and IV of DECnet affecting DCN data throughput is in the area of flow control, how nodes signal to one another that more data can be accepted by a node. According to the DEC communications specialist involved in the early stages of the Study, Phase IV of DECnet uses a more efficient algorithm which allows slightly higher throughput (depending on the situation, up to 10% higher). As this estimation errs on the side of conservatism, it is not considered detrimental.

4.3.3.3 Secondary Tools

Secondary tools in the context of this report are all other programs used in performing the DCN loading study. All of these tools exist to support NETQUE and descriptions of each of them are included in this section.

4.3.3.3.1 NETQUEFE -

The input NETQUE expects for data descriptions is not compatible with the format in which data was originally compiled for this investigation, and the format of input data to NETQUE is not meaningful to understanding and managing the data for users. Due to the incompatability of the input data formats, and since a portion of this investigation involved subsets of the data, and because managing large numbers of subsets of data was regarded as undesirable, a small program was written to convert data easily and quickly. This tool, called NETQUEFE, allowed easy selection of subsets of data from a master data set, in a format meaningful to the author or reader, to be formatted for input into NETQUE.

4.3.3.3.2 DOITALL -

This command procedure automates the process of establishing the input files for NETQUE when using NETQUEFE. In each directory where input data for NETQUE is being created, a NETQUEFE command file exists which contains all the answers to the prompts from NETQUEFE.EXE. By running DOITALL.COM the input data files are created for the categories of data you specify, either Realtime, Background, Both or All three categories. To modify the inputs to NETQUEFE.EXE you simply edit the NETQUEFE.COM files in the subdirectory required.

4.3.3.3.3 EXNETQUE -

This command procedure steps the user through the process of running input files to NETQUE. The program steps through all input files in the directories specified and prompts the user to type both the input and output file names to be used. In cases where an output file corresponding to an input file already exists (based on naming conventions specified in NETQUEFE documentation), the program asks the user if he wishes to replace the output file by running the corresponding input file. If the user responds no to the question the next input file is found and the process continues. When the user answers yes to replacing the existing output file the program prompts the user for the input and output file names and, after completion of NETQUE, purges the output file.

4.3.3.3.4 LOOKDATA -

This command procedure steps the user through the output files and automatically enters EDT (a standard VAX/VMS editor) and searches for the "Line Delay Results" which is where the data on Effective Utilization of Bandwidth is given. When the user completes looking at an output file he simply enters the command QUIT and the command procedure automatically enters into EDT for the next output file.

4.3.3.3.5 ELS -

This program is actually a part of NETQUE and provides a table of Effective Bandwidth related to Error Rates and Packet Sizes based on parameters specified by the user. This tool was useful for the first pass at determining packet sizes for the DCN and is envisioned to be a very beneficial support tool for future operation of the DCN as well.

4.3.4 Assumptions

In the process of this investigation, assumptions were made in a number of areas concerning the Data Communications Network. These assumptions deal primarily with the simulation and modeling of the DCN and are listed below:

1. Communications line bandwidth was taken as 56K bps for all lines and all lines were assumed to be synchronous and full duplex.

2. Communications line error rates were taken to be 1 bit in 1,000,000 (1 bit in one million). Information available from Bell of Pennsylvania indicates that this line error rate is conservative and their experience with error rates on 56 K bps digital

circuits has been better than 1 bit in ten million. Initial experience of PP&L with these digital circuits has supported the claims.

3. Processing time for a data packet was taken to be 0.002 seconds. This is the amount of elapsed time DECnet consumes, over and above what is required to generate the packet. DEC claims that this is an accurate figure for VAX 11/780's, and is high for the higher speed processors such as the 8300's and 8800's being used in the PMS.

4. DECnet is assumed to be operating as task-to-task communications.

5. Packet generation time (over and above DECnet) and the effects of the ESCA implemented Communication Software layers are not explicitly accounted for by NETQUE. But it is felt the conservative assumption made above, relating to processing time, is large enough to to account for this oversite.

6. Line delay times (time required for a data packet to get through the communications lines from one site to another) were uniformly set at 0.015 seconds. This number was estimated based on the PP&L configuration and includes delay time for the traversing of the

physical line as well as the time for the signals to travel through the comm devices such as the data sets and the Communications Network Processors (CNP) or Routers.

7. Headers and other overheads associated with the transfer of data by DECnet are modelled by NETQUE.

8. NETQUE assumes that there is sufficient CPU power available on all nodes to handle the communications processing. According to Communications Consultants from DEC Router throughput is estimated at approximately 500K bps and thus it would not be a limiting factor for the PP&L Data Communications Network. Also, DEC supports up to eight 56KBaud links to a single Router and the maximum number of ports used in any of the evaluated configurations is six.

9. All DSS's were considered to be equivalent systems; that is, no DSS contributed any more load to the DCN than any other. This assumption is reasonable based on analysis by the author which indicated that the DSS to DSS interdivision data and the DSS to PCC data is primarily Electrical Network data and was common with all DSS sites. The DSS to PCC data varied from Division to Division because of differences in the actual data being scanned at each location but, for

the sake of the Study, the loading from the largest DSS was used. The use of this load for all DSS to PCC links represents a conservative load scenario (highest load).

10. The data sizes, in bits per point, assumed for SCADA data are as follows:

    PMS DATA BETWEEN PCC, DSSs and CCC

    Analog = 48 Status = 32 Accum = 32

    DATA BETWEEN PCC and PJM

    Full Reporting (only) Analog = 20 Status = 8

    These values include quality flags associated with data and the individual point identifications as well. A detailed discussion of the data sizes and methods used by SCADA is included in the section on Data Representation.

11. The sizing for the other transfers going over the DCN are as follows:

    Textual 62,000 bits per page.

    Display 62,000 bits per page.

These numbers do not include overheads but do assume every bit associated with a CRT screen for a display and a textual message will be sent. The cumulative result is an overall conservative estimate of the load imposed on the DCN for these types of transfers.

12. The maximum packet size assumed for the study was 512 bytes, a standard DECnet packet size. This size was determined based on performance needs. The first consideration was the effect of the packet size given the error rate of the transmission lines. Using ELS as a tool the value of 512 bytes was determined to be near optimum. Another consideration which prevented selecting a larger size was that Background data must be sized to be interruptable by Foreground data when necessary.

13. NETQUEFE rounds up the size of all data transfers to an even packet boundary and provides the input to NETQUE in the form of message rates. As an example of the rounding, a transfer of 50 bytes, including data and all associated overheads is modelled as a 512 byte transfer by NETQUEFE. The result of this rounding is a conservative estimate of DCN load.

14. All loads were calculated for two conditions, maximum coincident load and maximum average loads. Maximum coincident load reflects the highest instantaneous load that would occur based on the data presented in Chapter 3. To model this, the periodicity of all the data was set equal to the allowable period for transfer, resulting in a model representing a constant transmission of all data at the highest possible rate. Maximum average load represents the highest AVERAGE load that would occur based on the data from gathered for the applications. This load was modelled by sending all data at the periodicity specified for applications, resulting in the highest average loading value to be expected.

15. No type of data compression was assumed for any of the transfers. The potential does exist for using some techniques that could dramatically lower the loading for transfers such as displays and files but to use these methods would result in additional CPU load and added delays in the transfer of the data from application to application between sites. The Study does not attempt to address the trade-offs between CPU load and DCN load but makes the assumption no compression techniques are used and the DCN load is maximized.

16. Application level protocol which may be implemented in data exchanges is not accounted for in the loading analysis. This category could include a number of items such as data poll/request methods, end to end message acknowledgements, message structures and error handling. The effect of this assumption should be minimal since the protocol to be implemented should be a very small percentage of the total information exchange between the applications. This is particularly true in the instances identified in the loading runs which focused on maximum data transfers.

17. The link to the PJM system from the PCC was modelled in the loading analysis as a DECnet connection since NETQUE does not recognize other types of networks. The reason for including the PJM link was to get a general feel for the bandwidth that may be required for this link.

18. The link to the CCC from the PMS was modelled in the loading analysis as a DECnet connection since NETQUE does not recognize other types of networks. The reason for including the CCC link was to account for data transfers from the PMS to CCC which have an impact on the DCN loading. Also, inclusion of the CCC link will give a general feel for the bandwidth that

will be required for this link.

19. In general, where an assumption regarding line loading needed to be made, it was made to err on the side of increased loading. This way, all result figures in this report can be looked upon as Not-To-Exceed figures; the figures seen in actual use of the network should not exceed these numbers as long as the data being transferred is consistent with those numbers used in this Study.

4.3.5 Modeling

The model of the PL Data Communications Network used for NETQUE reflects the operation of DECnet software in the PMS and does not attempt to model the Application Programs using the DCN. The focus of the NETQUE analysis is therefor limited to the communications transport mechanism rather than on the overall Systems performance.

The PL Data Communications Network is modelled on two levels to be entered into the NETQUE program. The first level is the physical representation of the DCN which includes the nodes and the lines connecting them. Physically, all the sites included in the PMS are represented as nodes. Each of the configurations described in the previous section were represented in their entirety for inclusion in the simulations. In addition to the full configurations previously described, derivatives of the HUB-STAR and MODIFIED HUB-STAR are also included to represent scenarios for single line or device failures.

The second level of modeling is the representation of the software and related delays associated with the communications. The earlier section on Assumptions discusses the inputs for this level of the modeling.

Numerous performance runs were made with NETQUE for various load scenarios, data sizes, data types and configurations. Actual loading runs were made for all combinations from the list below when using a single entry from each item on the list to identify an individual run:

- o Runs were made to determine both Maximum Peak and Average loads.
- o Runs were made for both Initial quantities of data for applications and the ultimate Quantities expected.
- o Runs were made for Foreground (realtime) and Background separately as well as for Both, the combination of Foreground and Background.

- Runs were made for each Network Configuration: STAR; HUB-STAR; and MODIFIED HUB-STAR.

- Runs were made for normal Network Configurations plus for failure scenarios for the loss of a DSS-PCC link, DSS-DSS line (HUB-STAR and MODIFIED HUB-STAR only) and loss of a Router.

It should be recognized that the results from many of the possible runs are in fact the same since all conditions do not create unique situations. As an example, for the STAR configuration load runs for failure scenarios of a single DSS-PCC line failure is no different than the Normal load since the DSS-PCC lines are redundant in this configuration. Also, it should be noted that not all combinations apply. As an example for the STAR configuration the failure of a DSS-DSS line does not make sense since there are none of these lines in the normal configuration.

CHAPTER 5

DISCUSSION OF RESULTS

This chapter presents the results and an analysis of the loading studies described in Chapter 4.

5.1 NETWORK CONFIGURATIONS PERFORMANCE

This section presents analysis of the performance of the two configurations which were included in detailed computer simulations, namely the STAR and the HUB-STAR. The performance analysis includes not only discussion of the numerical results of the loading runs but other considerations associated with each of the configurations as well.

In the context of pure communications line loading, the STAR and HUB-STAR both performed adequately, and were able to support the load required for the Data Communications Network. For Normal network configuration, those with no failures, the HUB-STAR yields clearly superior performance. This is expected since this configuration utilizes all 12 communication lines with the inclusion of the DSS-DSS lines in addition to the PCC-DSS lines. For single failure contigency configurations, a single device or line failure, the STAR configuration exhibits better loading results then the HUB-STAR. The reason for this is the STAR is effectively unchanged by a single failure and the load is the same as the normal, whereas the HUB-STAR reroutes traffic after a failure and increases the loading on some communication circuits above the normal load.

Looking beyond the strict numbers generated in the loading analysis and considering other characteristics of the configurations, the HUB-STAR clearly offers many more advantages over the STAR network. A summary of the advantages of the HUB-STAR configuration is as follows:

- Much better distribution of load over the communications circuits as a whole. The HUB-STAR actively uses all 12 communication lines whereas the STAR only uses half.

- Greater immunity to communication circuit noise resulting in better circuit utilization. In the normal configuration the loading of the DSS-PCC circuits is less in the HUB-STAR than with the STAR, thus the impact of noise on the communication circuit, and the effective loss of available bandwidth, is less on the HUB-STAR.

- Less hardware and software required since physical switching of circuits is not necessary. This assumes a scheme would be introduced into the design of the DCN which would force periodic use of the spare communication circuit to test integrity.

- Fuller connectivity between sites, each site connects to three other sites instead of a single site as would be the case for a DSS in the STAR.

- Greater immunity for the PMS to a PCC site disaster. If a disaster occurs at the PCC, other PMS intersite communications could continue, and the functionality of the PCC could potentially be migrated to a DSS site.

An item considered when reviewing the specific results for all the configurations was the conservative assumptions made in performing the loading runs. The results of the loading runs were done for worst case scenarios and the quantities reflected for loads were expected to be high when verified against actual numbers during DCN testing.

The following sections present analysis of the STAR and HUB-STAR configurations.

5.1.1 STAR

An advantage of the STAR configuration is its simplicity. The loading results for recovery scenarios for a lost DSS-PCC line or a Router in the STAR configuration are simply a duplication of the results for the normal loading cases. This is because the STAR configuration assumes that all DSS-PCC lines and Routers are redundant. Under this assumption the loss of a single line or Router is virtually unnoticeable since a duplicate of the lost line or Router will take the place of the failed element. Because of this arrangement the STAR configuration exhibits the best performance for the failure of a DSS-PCC line. This advantage is based on the assumption that the routing for the two lines linking a particular DSS to the PCC are diversely routed and that outages effecting one line would not have a direct effect on the other line. If this assumption is not true, and outages of both lines are directly related, then the prime advantage of having dual lines between the PCC and DSSs is lost.

The disadvantages of the STAR configuration are related to the fact that all communications between all sites is concentrated through a central location, the Power Control Center site. This arrangement causes all intersite communications, at a minimum, to go through a PCC Router. This routing of all PMS exchanges presents a couple of problems. The first problem is that the entire communications of the PMS becomes reliant on the single site and a disaster at that site results in the loss of the DCN. A second problem with this configuration is that the loading on the lines linking the DSSs and the PCC is much higher than with the alternative HUB-STAR configuration. This is a concern because the DSS to PCC lines are the most heavily loaded in all configurations and the additional burden of carrying non DSS-PCC traffic will cause the lines to overload much sooner than they would if they were strictly carrying DSS-PCC and DSS-CCC traffic. Examples of this condition are evident in the NETQUE results when comparing the two configurations.

Another disadvantage with the STAR configuration is the inefficient utilization of communications lines. Of the twelve communications lines linking the DSSs and the PCC only six are in use at any point in time and the other six are idle. Besides being very inefficient, the existence of idle lines as spares has pitfalls as well. Consider that a DSS is communicating to the PCC over line 1 of the redundant pair and line 2, the spare fails. The DSS and PCC at this point are not aware a problem exists with the spare line and thus take no action to correct the problem with line 2. If sometime later line 1 or one of the Routers connected to line 1 fails, a spare is not currently available and communications between both sites are lost. Steps could potentially be taken to address this shortcoming, such as to force switching of communications between lines periodically or providing for switching of communication lines between Routers, but the solutions would increase the complexity of the communications system and would have impact on the DCN and PMS performance.

In reviewing the entries for the STAR Network it was observed that there are a few cases where the loading on circuits for "All Data" exceeds the 100% limit. The Realtime portion of the load itself does not exceed 100% in any cases, thus the result of the overloads of All Data is the transmission of the Background data will be delayed. The effect of delaying the Background data would be minor since the load conditions for which this applies is for a maximum coincident peak and assumes a number of events occurring concurrently.

The Baseload runs for the STAR configuration do have instances where the Realtime portion of the data exceeds the 100 percent level. The implication of this condition is that the background data transmission will be delayed in excess of one full scan cycle (10 seconds for analog), but since the Baseload is really an integrity scan, the load would be expected to immediately drop to a manageable level the next scan cycle and the impact, overall, will be minor.

For the Maximum Average Load results for all entries for the STAR configuration are below 100 percent, with the exception of a duplication of the results for the Realtime data in the Baseload scenario.

The same analysis as given for the coincident case applies here.

5.1.2 HUB-STAR

The HUB-STAR configuration's use of full connections between DSS's in addition to the DSS-PCC connections offers a great advantage over the other configurations. The advantage is realized because, by proper definition of the DECnet parameters, costing in particular, all interdivision traffic (DSS-DSS) is handled exclusively on DSS-DSS lines. As a result the traffic on the DSS-PCC lines is limited to DSS-PCC and DSS-CCC traffic which is lower volume than what is transmitted over the same links in the other configuration, the STAR. As discussed earlier, these DSS-PCC lines are the most heavily loaded so the distribution of part of the load to the rest of the DCN is a big advantage.

Another advantage of the HUB-STAR configuration is efficient use of all the communications lines. Unlike the STAR network, all lines in the HUB-STAR network are used all the time thus the need for separate services for monitoring health of unused lines is eliminated. The HUB-STAR configuration exhibits better performance for the Normal loads as mentioned earlier.

Reviewing the entries for the HUB-STAR network in the Normal configuration shows that the loading for all cases can be managed, with the exception of Baseload. As described earlier the Baseload is equated to an integrity scan occurring simultaneously with all Background activity. The load figures represented by Baseload are considered transient since it is defined as a single scan or event which does not continuously repeat. For the case of the Ultimate quantities the Realtime portion of the load exceeds 100% which means that completion of the integrity scan will take longer than a single scan period, (10 seconds for SCADA), and that Background data will be delayed until the integrity scan is complete. As with the STAR network, this is not a concern since the integrity scans are not expected to occur frequently, and the load would be expected to return to reasonable levels immediately upon completion.

The backing up of lines in the HUB-STAR configuration is provided by lines which are active. The loss of a DSS-DSS line is functionally backed up by the remainder of the DSS-DSS lines. Therefore, when a DSS-DSS line fails data between divisions is rerouted strictly through the remaining DSS-DSS lines. This is again is an advantage, because it represents a more efficient use of the available lines while not increasing the load on the heaviest loaded lines, DSS-PCC. In the Results for the loss of a DSS-DSS line the numbers are very similar to those for the Normal case, with the exception that the DSS-DSS line load increases. The level of the increase is small and easily managed by the HUB-STAR configuration.

For the loss of the DSS-PCC line, the data which is normally routed over this link will be re-routed by DECnet through an adjacent division. The actual physical routing will be via the DSS-DSS line to a neighboring division and then to the PCC by way of the neighboring divisions DSS-PCC line. A disadvantage of this routing method for back-up is that a DSS-PCC line is now carrying twice the normal load.

For the loss of a DSS-PCC communication line and the loss of a DSS Router, which is assumed to be the one with the combination of a DSS-PCC and DSS-DSS lines, loading results are similar. In the Steady State, High Activity and Baseload activity states, the loading on the DSS-PCC line can exceed 100% for the transfer of All Data. In the instance of Steady State and High Activity, where the Realtime portion is well less than 100% the impact is that Background data transfers may be delayed. Base Case evaluation is similar to other discussions of the scenario presented before with the difference in this instance being that the integrity scan will take longer.

The results for the Maximimum Average loads did not uncover any areas of concern which were not flagged by Maximum Coincident load results.

5.2 RELIABILITY

The reliability of the Data Communications Network is a function of the reliability of the parts that make it up. Thus, in order to address the issue of DCN reliability we will examine the components which make up the DCN and discuss each individually. It should be noted that most discussions presented here are qualitative and not quantitative. The prime reason for this is because reliability figures are unavailable from the manufacturers, because they consider the information sensitive or because the item in question is so new that no meaningful figures yet exist. So in lieu of numerical data a verbal discussion will be given.

The DCN hardware encompasses the devices which are used to link the communications lines between sites to the hosts at each location. The hosts are connected to the Router via Ethernet. Ethernet is Local Area Network based on interconnecting devices over a coaxial cable. Since Ethernet is passive the reliability is extremely high and for the sake of discussion of DCN reliability can be ignored. The same device which is used for the Ethernet connection for the host is used to provide the Ethernet connection for the Routers, namely, H4000 transceiver. This device is in very wide spread distribution throughout DECs user base and it has been extremely reliable according to DEC. In support of DEC's claim, a selected group of users were asked about their experience using the device, and their response was reliability has been excellent. The Router itself, or DECSA box as it is also referred to by DEC, is a packaged PDP 11/24 computer. The PDP series of machines has been a mainstay in DECs line of computers for well over a decade and historically these machines have exhibited excellent reliability. This is according to DEC and is supported by numerous publications in the industry.

The device which interfaces the Router to the Digital communication line is a Digital Data Set. PP&L research on these devices revealed that of four brands available on the market, 3 were made by a single manufacturer, Teleprocessing. The fourth unit was just announced by Paradyne and replaced the Teleprocessing unit which they too had marketed up to that point. Again reliability figures were not available for this equipment, but indications from the manufacturer, and the retailers, was that the device was extremely reliable. Independent verification of this fact was not specifically obtainable, but given the wide spread distribution of the device and the lack of any publicity in the trade magazines to contradict the manufacturers claim, the statement on reliability seems very reasonable. Also, initial experience of PP&L in using the devices has been extremely good.

The physical communication circuit is the next portion of the link between sites. AT&T and Bell of Pa., needless to say, would not commit to any numbers for availability of 56Kbps digital circuits, but gave a "ballpark" figures of about 99%. In comparison to existing telephone circuits used in the existing PP&L PMS this figure is high but not totally unreasonable when given some consideration. We often consider a line unavailable, though AT&T or Bell may not, when excessive noise is present. Digital circuits use phase shift keying modulation to transmit data and by its very nature this type of transmission is less sensitive to noise than normal voice grade circuits. Another consideration on the circuits themselves, is that the equipment AT&T, Bell or any other carrier, uses on these circuits provides a level of error detection and correction independent of what is done with the data at the end points. As a result the digital line would be expected to be available, in PP&L terms, more often than existing circuits. Also for these types of circuits switching is also normally included by the carrier, again independent of the users. As independent verification of digital circuit performance, the communications consultant from DEC verified that his experience with digital circuits, though limited, supports AT&T's claims. Furthermore, he stated that his observations of digital circuits were they were either very clean or failed, but never noisy. Indication from PP&L's initial experiences with these circuits substantiate the claims.

The other portion of the Data Communications Network to consider when talking about reliability is the software. As stated earlier the DCN software is designed with the intent of using DECnet. DECnet is a proven communications package from DEC that has existed on thousands of installations around the world for many years. DECnet is currently in Version 4 and DEC support and performance of the product have been historically exceptional.

In addition to DECnet there is another portion of DCN software, the layer being provided by ESCA, PP&L's prime contractor for their PMS Replacement. This software has completed initial testing and is felt to perform as well as, if not better than, any of the other software running on the PL system.

In reference to the reliability of the configurations, it is expected that the STAR configuration would be the least reliable for either of two reasons. The first possible reason is due to the inclusion of unused communications lines in the configuration. As stated earlier, if a spare line should fail the probability of it going unnoticed for some period of time is high, and as a result the spare line may not be available when needed. The second potential reason for the less reliable performance of the STAR is for the condition where additional hardware is added to provide switching to address the problem of having idle spare lines. The addition of the hardware would add to the probability of failure as well as to the complexity of the entire scheme.

Between the HUB-STAR and MODIFIED HUB-STAR the same amount of hardware, excluding the communication circuits, would be used. The HUB-STAR has greater connectivity between sites in the DCN and because of its superior distribution of communication load, it has definite performance advantages. The result is the HUB-STAR would be more reliable than any of the other configurations considered.

5.3 LINE COSTS

At the time of the preparation of this Investigation the details of the physical implementation of the DCN were being defined. Since that time PP&L has been working with Bell of Pennsylvania on meeting the PMS communications needs. For the sake of analysis in this investigation estimates provided by AT&T were used, under the assumption that costs would be similar to those provided by Bell of Pa. Though it is recognized that the numbers presented here for costs are estimates it is believed that they are representative of the actual costs and, at the very least, present a feel for relative costs.

If the Data Communications Network were to be installed for PP&L by AT&T, it would require leasing the necessary lines and equipment from AT&T long distance for inter-LATA connections, and from local Bell operating companies for connections within the bounds of the LATAs. Estimates of the current costs to connect any DSS with any other DSS and the PCC are given in Appendix A. By simply adding up the costs identified in the matrix and adding the extra items identified in the notes below the matrix, an estimate of the monthly line costs for any configuration can be calculated. Cost associated with installation of the each of the networks is not included in this report since these costs will be one time costs and they are difficult to estimate without additional physical details.

The following are estimates of the cost for each of the configurations examined in the DCN Study. The connections between DSS's in the HUB-STAR configuration are based on the physical proximity of sites and represent the actual physical arrangement which would be expected to be implemented.

STAR CONFIGURATION = \$ 11,627 /month

HUB-STAR CONFIGURATION = \$ 12,375 /month

As indicated above the costs for the STAR and HUB-STAR are comparable to one another so neither offers a decisive economic incentive.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations of the DCN Study.

6.1 CONFIGURATION RECOMMENDATION

The recommended configuration for implementation of the Data Communications Network for the PP&L Power Management is the HUB-STAR as described in this document. This configuration best meets the design objectives of reliability and performance between systems as set forth in Chapter 1. The cost of implementing this network was the higher of the two alternatives evaluated in detail , but the magnitude of the cost difference was not felt to be significant in comparison to the functionality provided.

The actual interconnection of PMS sites should as described below:

NODE/NODE

PCC/Central

PCC/Harrisburg

PCC/Lancaster

PCC/Lehigh

PCC/Northern

PCC/Susquehanna

Central/Lehigh

Lehigh/Lanc.

Lanc./Harr.

Harr./Susq.

Susq./North.

North./Central

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APPENDIX A

DATA COMMUNICATIONS NETWORK LEASED CIRCUIT COSTS

The following is the circuit cost for all the possible connections between all DSSs and PCC. These costs are based on information from AT&T in March, 1985.

FROM \ TO	PCC	CENT	HARR	LANC	LEHI	NORT	SUSQ
PCC		$ 819	$ 932	$1089	$ 620	$ 848	$1348
CENT	$ 819		$1131	$1288	$ 819	$1047	$1547
HARR	$ 932	$1131		$ 777	$ 932	$1160	$1036
LANC	$1089	$1288	$ 777		$1089	$1317	$1193
LEHI	$ 620	$ 819	$ 932	$1089		$ 848	$1348
NORT	$ 848	$1047	$1160	$1317	$ 848		$1576
SUSQ	$1348	$1547	$1036	$1193	$1348	$1576	

In addition to the above costs there is a charge of $125/month for the carrier's equipment at each of the three AT&T hubs, Allentown, Harrisburg and Scranton.

Charges for equipment required at each of the nodes is not included.

The following are estimates of the cost for each of the configurations examined in the DCN Study.

STAR CONFIGURATION

FROM	TO	LN COST/MONTH	COMMENTS
PCC	CENT	$ 1,638	Includes the cost of 2 lns
	HARR	$ 1,864	Includes the cost of 2 lns
	LANC	$ 2,178	Includes the cost of 2 lns
	LEHI	$ 1,240	Includes the cost of 2 lns
	NORT	$ 1,696	Includes the cost of 2 lns
	SUSQ	$ 2,696	Includes the cost of 2 lns
		$ 375	AT&T equip charge $125/hub for Harrisburg, Allentown and Scranton.
TOTAL/MONTH		$ 11,627	

HUBSTAR CONFIGURATION

FROM	TO	LN COST/MONTH	COMMENTS
PCC	CENT	$ 819	Spoke connection
	HARR	$ 932	Spoke connection
	LANC	$ 1,089	Spoke connection
	LEHI	$ 620	Spoke connection
	NORT	$ 848	Spoke connection
	SUSQ	$ 1,348	Spoke connection
CENT	LEHI	$ 819	Rim connection
LEHI	LANC	$ 1,089	Rim connection
LANC	HARR	$ 777	Rim connection
HARR	SUSQ	$ 1,036	Rim connection
SUSQ	NORT	$ 1,576	Rim connection
NORT	CENT	$ 1,047	Rim connection
		$ 375	AT&T equip charge $125/hub for Harrisburg, Allentown and Scranton.
TOTAL/MONTH		$ 12,375	

VITA

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The author resides in Schnecksville, Pennsylvania, with his wife, the former MaryKay J. Shivy, and his two sons Michael and Justin.