CableLabs

Outage Reduction Task Force
Plant Powering Subcommittee

Chapter III - Plant Powering in Cable TV Systems

By H. Mark Bowers, CableSoft Engineering Services
(Other subcommittee members: David Eng, CableLabs; Del Heller, Viacom Engineering; and Tom Osterman, Alpha Technologies)

Cable Television Laboratories Inc.
1050 Walnut St., Suite 500
Boulder, Colo. 80302
Phone: (303) 939-8500
FAX: (303) 939-9189

Printed Date: August 26, 1992

Outage Reduction

III - Plant Powering in Cable TV Systems

III - Plant Powering in Cable TV Systems

1.0 Introduction

Given the theme of reducing plant-related outages and thereby improving overall plant reliability, one must ask the question: "What new or improved methods can be applied to overall cable plant powering techniques, which will reduce exposure to plant outages from loss of commercial power source(s)?" The CableLabs plant powering subcommittee's approach to this question created research and investigation ultimately along three separate but related fronts:

1) Possible (new) plant powering architectures that would significantly reduce exposure to loss of commercial power, compared with current design techniques. This approach primarily focused on "hardened trunk techniques," although it will be shown that it is possible to achieve improvements with current powering topologies as well.

2) The cable operator developing a closer interface with, and understanding of, commercial power grid design and power distribution principles. In other words, can we better understand and work closely with the local electric utility(ies) to improve plant powering reliability (with a corresponding increase in commercial power reliability)?

3) Better understanding and application of modern standby power supply technology to existing or improved cable power grid designs, toward the optimization of total plant powering. What are present standby powering technologies and limitations? How can maintenance be optimized in these applications? (Here, we must consider that a lack of optimal maintenance is considered to be a primary contributor to past standby applications often resulting in less than optimal results.)

The remainder of this discourse seeks to provide an overview of what has been learned to date in these research and information gathering efforts. Some work remains in the area of standby powering, and has been given over to a separate committee on that subject.

2.0 Cable Plant Powering Architectures

Most cable plant powering designs utilize similar processes. The designer seeks to create a power layout for trunk and feeder systems. Typical goals are the provision of adequate load voltages to each active device with uniform current distribution through the plant, all while seeking to maintain a fairly moderate to heavy load on the power supply itself.

2.1 Typical Cable Plant Powering Techniques

The major problem with cable plant powering is that the cable system is optimized for distribution of RF (voltage) signals, not AC (power). The 75-ohm coaxial cable system is not designed nor optimized for the purpose of AC power distribution. Past and future techniques must ultimately deal with this very basic issue. Present methods of powering the trunk and feeder have served the industry fairly well, but can create reliability problems because of the power supply cascade in conjunction with the reliability of commercial power. Coaxial cable sizes used for RF distribution, the frequency of placement and type of RF electronics, and the operator's design technique and percentage loading of main AC supplies all combine to create some rather healthy power supply cascades. The term "power supply cascade" as used here describes the same effect encountered with cascades of amplifiers. For example, if a signal leaving the headend or hub site has to travel through 12 different power supply areas to reach a customer's home, then the power supply cascade is 12. The fact that trunk and feeder are powered simultaneously from the same power supply intensifies this cascading problem.

Modern AC supplies should be loaded at close to 100 percent of rated value for proper operational efficiency. If significantly underloaded (less than 75 percent), the supply's efficiency will fall off dramatically. At best, you end up paying for power that is dissipated as heat. At worst, you'll experience premature failure of supplies in your system. If your design dictates only 5 to 6 amperes at a given location, install a smaller amperage supply to maintain proper efficiency. Many power supply manufacturers now offer graduated values from 3 to 15 amperes. You can choose the size of supply that best meets your design needs. The true optimal value for supply loading has to do with the type of load powered (linear or switchmode supplies), and whether the AC supply is standby or normal. Supplies powering a load that is predominantly switchmode should be loaded to a lesser extent. Standby loading will impact total powering time on the batteries installed, which must be considered as well.

General power supply loading recommendations are as follows:

Load Type	Standby supply	Normal Supply
Linear	90%	100%
Switchmode	85%	90%

Table 1 on the next page shows system reliability calculations and uses a base model cable TV system with a cascade of 25 trunk amplifiers and varies the number of power supplies in cascade and the reliability of the commercial power. The resultant chart depicts power supply cascade numbers vs. commercial power reliability, seeking to determine supply cascade and commercial power reliability limitations. Data (answers) shown are outages/month for the worst-case subscriber. In other words, given some typical level of commercial power reliability, is a cascade of 25 power supplies acceptable? If not, to what must the cascade be reduced? If the cascade cannot be significantly reduced, what level of commercial power reliability is needed for that cascade of 25?

System component reliability used to calculate outage rates in Table 1 was determined by the CableLabs Outage Reduction Task Force to be the expected failure rates of the various types of equipment based on vendor recommendations and field experience. For example, the committee has determined that seven percent for amplifiers is the reliability that should be experienced with today's equipment.

The numbers shown in Table 1 on page 6 represent outages/month experienced by a subscriber in the sample system. (Again, these numbers represent all parameters at committee-suggested levels, except commercial power reliability and power supply cascades.) Commercial power reliability percentages are yearly numbers. Six-tenths of an outage per month is deemed the maximum acceptable level, hence the results in Table 1 are shaded where combinations of commercial power reliability and power supply cascade levels were at or below acceptable levels.

Power Supply Cascade Level

% power fail/year	20	15	10	8	7	6	5	4	3	2	1
100	2.13	1.69	1.26	1.08	1.0	.91	.82	.73	.65	.56	.47
90	1.96	1.57	1.17	1.02	.94	.86	.78	.70	.62	.54	.46
80	1.79	1.44	1.09	.95	.88	.81	.74	.67	.60	.53	.46
70	1.63	1.32	1.01	.88	.82	.76	.70	.63	.57	.51	.45
60	1.46	1.19	.92	.82	.76	.71	.66	.60	.55	.49	.44
50	1.30	1.07	.84	.75	.71	.66	.61	.57	.52	.48	.43
40	1.13	.95	.76	.68	.65	.61	.57	.54	.50	.46	.42
30	.97	.82	.68	.62	.59	.56	.53	.50	.47	.44	.42
20	.80	.70	.59	.55	.53	.51	.49	.47	.45	.43	.41
10	.63	.57	.51	.49	.47	.46	.45	.44	.42	.41	.40
0	.47	.45	.43	.42	.42	.41	.41	.40	.40	.39	.39

Cascade of 25 trunks + 1 bridger + 2 line extenders

Table 1 - Power Sensitivity Chart (Outages/Month for Worst-Case Customer)

Table 1 brings us to some basic conclusions. For commercial power loss rates that are deemed "average" at this juncture (typically 30 percent per year), power supply cascades of around seven or less are mandatory to meet consistent system reliability requirements. Conversely (and as one example), if a system's power supply cascades average approximately 10, commercial power reliability must be no more than 20 percent total downtime per year or the system will not be able to meet necessary reliability requirements. Standby powering at specific or all locations is always an option to lower the effective commercial power loss rate close to zero, but this brings new considerations to bear.

A general rule of thumb from this also emerges. This is, if the "trunk-to-power-supply ratio" is four or more, supply cascades are probably acceptable if there are no more than 25 amplifiers in cascade. In other words, as an initial determination of whether power supply cascades are reasonable, take the number of trunk stations in the system and divide by the number of power supplies. Assuming the trunk cascades are limited to 25 or less, a trunk/power supply ratio greater than four is generally acceptable and indicates good powering methods with reasonable cascades. Again, this assumes a commercial power reliability of around 30 percent, which seems to be an average with available data.

The question now to be considered is: "What new power distribution techniques can be utilized to reduce power supply cascades?" A better understanding of commercial power issues will then be addressed in Section 2.0.

2.2 General Guidelines for Power Calculation Methodology

The primary intent of this information is to explore new design topologies and techniques, but it would be shortsighted not to mention some general guidelines regarding AC design techniques with any architecture. Current AC system designs usually involve only a general effort toward the calculation of load voltages and total supply loading. Often, cable system powering could have been designed with supply cascades at significantly lower numbers (had the designer spent just a little more time with the layout and better understood the concepts of system AC calculations).

In most system AC designs, load voltages will typically be higher than calculated, and calculated supply loads are often less than measured. Why would this be true? The following guidelines explore some answers.

Real system voltages often vary from calculated voltages for many reasons. This can be a frustrating exercise if the designer is not aware of this variance and expects to measure exactly what was calculated when field trips to compare results are conducted. Conversely, if you understand these limitations and caveats, they can be incorporated into your design to improve accuracy and reduce overall cascades. Our suggestion here is to take these variables into account, and to do so with careful supply placement and minimal cascades in mind.

The most common reasons for variation between calculated and actual levels are as follows:

- Manufacturers typically publish current drain (or power consumption) specifications for their equipment, which are higher than the nominal range of values. This is done to allow for those very few amplifiers that exceed that nominal range. For accurate designs, controlled measurement of a random sampling of amplifiers utilized in the system is recommended, with the mean value of measured current/power drains used for the design layout.

- Many (if not most) designers lay out systems using fully-loaded amplifier station values. For example, the rating for a trunk station that includes the reverse amplifier may be used, although the stations are subsequently operated without them. Use actual amplifier loading for the design to ensure accuracy.

- Often, actual system cable footages are less than those indicated on system maps. This can occur for a variety of reasons, but typically because it is a common practice during strand or as-built mapping to slightly overestimate footages. As an example, the real measurement is 102 feet, so the mapper writes down 105 or 110 feet to allow a little extra. This practice can inflate real footages by as much as five percent from actual with a significant effect on supply placement.

- Actual cable loop resistance values may be less than the cable manufacturer's published values. Obtain accurate measurements whenever possible.

Allowing the previous factors to accumulate without adjusting for them can inadvertently place many supplies that were not really needed, thus inflating the number of supplies and overall cascade(s).

In one design examined, these factors plus a lack of attention to proper supply placement lowered average loading on the supplies by almost 50 percent, and inflated the average supply cascade level to almost double what was necessary. Many cable design houses do not even consider the powering process an important part of system design. As has been already pointed out, this practice (or lack thereof) deepens the system's exposure to outages — with reduced overall system reliability.

The next part of this discussion will cover three additional techniques for attaining power supply reductions. The first, hardened trunk, is recommended for implementation as more serious efforts for cascade reduction are needed. Practices described are attainable with current equipment, and do not deviate from accepted industry engineering practices. The remaining two (reduced load voltage design and use of increased supply voltages) are not considered to be necessary to obtain adequate cascade reductions at this time. Using higher supply voltages also prescribes techniques that will require further research efforts before actual implementation could be accomplished in the industry.

2.3 Hardened Trunk Techniques

The term hardened trunk describes a general technique of separating trunk and feeder powering. In other words, provide separate power supplies for the trunk and feeder systems. Further, a basic premise is that the trunk portion must experience very little downtime. If commercial power does not meet specific and critical reliability considerations, then use of standby powering should be seriously considered. Thus, the hardened trunk powering technique will often utilize standby power at crucial locations in the trunk to meet necessary reliability standards. With the local supply in the feeder, the power to the subscriber's home is often off when the local supply is off. Thus, the subscriber is unaware that a cable outage is occurring. The hardened trunk technique therefore generally employs the following methodology:

- **Trunk powering —** Trunk is powered via separate supplies. Strategic location (often standby, sometimes status monitoring) of the supplies is necessary for the optimal configuration. The two powering systems are typically separated within the trunk station, with some equipment brands allowing for this more easily than others.

- **Feeder powering —** Feeder is powered with separate local supplies. Unless feeder power requirements are unusual, as is sometimes the case with interdiction, a single local supply per trunk station is optimal. Standby will normally not be required with the local unit.

As stated, hardened trunk techniques are built upon the premise of strategically located supplies with established reliable commercial power feeds since the hardened trunk should always be kept energized. If commercial power reliability standards cannot be attained (through methods prescribed in Section 2.0), trunk standby powering would be the next recourse with power supply status monitoring worthy of serious consideration. Implications of increased maintenance with standby powering are discussed further in Section 3.0 of this chapter.

Use of hardened trunk offers the following basic advantages:

- It significantly reduces power supply cascade levels. Typical cascade reductions are in the 60 to 75 percent range compared to normal design placement for identical RF plant layouts. Since the trunk is powered separately, supplies can be placed with some increased degree of flexibility (in optimal locations), and often loaded to higher percentages when load types/conditions permit, thus increasing supply operational efficiency. As stated earlier, proper supply load percentage is dictated by many variables including the type of amplifier power supplies used.

- It allows standby power technology to be optimally applied and operated. Systems that employ extensive standby powering often experience difficulties because of higher required maintenance levels. Hardened trunk allows for a more specific application of standby to the trunk only, thus bringing maintenance efforts to focus on crucial front-end locations.

Since hardened trunk methods place more trunk stations on fewer supplies, a somewhat increased vulnerability occurs in that more customers will be affected when and if a trunk supply goes down from loss of commercial power, particularly when that supply is at the front end of the system. The first two or three supplies, at the very least, should therefore have the following characteristics:

- Be optimally placed using power company statistics on highly reliable commercial powering locations.

- Employ standby powering with appropriate maintenance practices (if needed) described in Section 3.0 of this chapter.

- If standby is employed, consider the use of status monitoring at those critical supplies, so that it is immediately known when a supply is without commercial power.

With hardened trunk, the overall amount of supplies in the system actually increases while the cascade of power supplies to any one customer is dramatically reduced. Table 2 illustrates reductions possible. Sample powering designs were performed on a portion of an Ohio system comprising approximately 1,600 miles of plant.

Initial system statistics for the sample area were as follows — 85 miles of plant; 82 trunk amplifiers; 471 line extenders; and 41 power supplies. The worst-case supply cascade is 13. This system was upgraded from 300 to 550 MHz, with quite heavy electronics loading introduced.

Supply Section	Current	Hardened
Supply Voltage	60	60
Total # System Supplies	41*	91*
Worst-Case Supply Cascade	13	5
Average Supply (I) Loading	8.05 A	10.26 A
Average # Trunks/Supply	2**	9**
Estimated Outages/Month: End of Cascade	0.45***	0.17***

* Total supplies increase to 91. Each feeder area fed from a trunk has a local supply (total of 82) plus nine supplies for the hardened trunk system.

** This number was discussed as a general rule-of-thumb for good performance: {<4 = problems; >4 = OK.} The number 9 calculates supplies on the trunk system only.

*** The outages/month number shown represents only those outages caused by commercial power or power related issues. Outages from other system sources are not included in these calculations.

Table 2 - Current Design Vs. Hardened Trunk Technique

As shown in Table 2, the total number of supplies increases, but supply cascades and projected system outages due to powering alone are reduced 62 percent. Power supply outage numbers were calculated using actual outage data from the system subsection while changing the supply cascades only as shown. Actual system commercial power reliability was also utilized for the calculations. With an overall system goal of 0.6 outages/month in total for any customer, the 0.45 due to powering alone is unacceptable with power supply cascade of 13.

The ability to separate trunk and feeder powering in amplifiers and equipment varies a great deal from manufacturer to manufacturer. In some brands, the simple clipping of a wire on a fuse panel is all that is necessary. With others, internal modifications plus the addition of external power inserters will be necessary. It is the consensus of this task force that any design changes and modifications necessary are well worth the effort when power supply cascade reductions are absolutely needed to obtain the requirements illustrated in Table 1.

2.4 Other Techniques for General Cascade Reduction

As already stated, the following two techniques are described here for discussion and research purposes. Actual implementation is not necessary yet since hardened trunk achieves satisfactory power supply cascade reductions in most applications examined.

One of these additional techniques is to reduce equipment load voltages, which generally reduces power supply cascades (whether normal design or hardened trunk was employed), is to use lowered acceptable design load voltages to cable actives. This technique also provides some further gains in "flexibility of placement" of supplies, whether trunk-only or trunk and feeder.

Sample designs with hardened trunk were performed on a fictitious trunk-only AC power layout, with the following factors varied: cable size/type, and minimum load voltage limits. Trunk amplifier power loading was held at 45 W and assumed to be switchmode type. In each design, a maximum of 15 amperes total power supply load was allowed, with the supply placed in the optimal location of the powering layout. Table 3 illustrates results with those varied parameters, to determine maximum design limits.

# Directions Trunk Feeds from Supply	Cable # Type	Trunk 40 V	Amps 20 V	Fed % Change	Total 40 V	Amp 20 V %	Load Change	Total 40 V	Reach 20 V	Ft. % Change
2 Directions	.412	7	9	26.8	5.96	9.37	57.2	2,950	4,055	37.5
4 Directions	.412	13	15	15.4	11.2	14.6	30.6	2,950	4,055	37.5
2 Directions	.500	7	9	28.6	5.86	8.71	48.6	3,440	4,730	37.5
4 Directions	.500	13	15	15.4	10.9	13.8	25.9	3,440	4,730	37.5
2 Directions	.750	11	11	0	10.6	10.6	0	8,750	8,750	0
4 Directions	.750	17	17	0	14.6	14.6	0	6,875	6,875	0
2 Directions	1	13	13	0	12.3	12.3	0	13,235	13,235	0
4 Directions	1	18	18	0	14.9	14.9	0	10,900	10,900	0

Table 3 - Design with 45 Watts per Trunk Station

As can be seen from Table 3, further reach and placement flexibility can be gained from lower acceptable load voltages at amplifiers. Percentage increases are dependent on the size/type of cable employed and to some extent the size of loads powered, although for simplicity's sake that was not a variable shown in the table. In general, smaller size cables realize good gains with often substantial increases in reach. Increases in the number of amplifiers fed, plus an overall powering reach of as much as 40 percent were attainable in some runs with .412- and .500-inch size cables. In larger cables, such as 1-

inch or greater, increases of up to 10 percent could occasionally be attained, but improvements were generally marginal.

Supply Voltage	Trunk Power Load	Total Trunk Amplifiers	Trunk Amps in Cascade	Power Supply Load-Optimal	Power Supply Load Reach	% Move From Optimal	Feet Moved From Optimal
60 V	35 W	16	6	11.76 A	13.51 A	8.5 %	1,122
300 V	35 W	60	20	8.385 A	9.834 A	30 %	13,200
400 V	35 W	70	20	6.572 A	8.759 A	60 %	26,400

Columns represent:
- Supply voltage for study.
- Trunk powering requirements per station.
- Total number of trunk stations powered per supply.
- Number of trunks in cascade that were powered.
- Average current loading per supply when the supply was optimally located.
- Average current loading per supply when the supply was moved to maximum reach — that point that still allowed powering of the entire section powered when the supply was optimally located.
- The percent movement from optimal to maximum. In other words, the flexibility in feet possible from power supply at the optimal location to maximum variance, as a means of determining overall placement flexibility.
- The movement in feet possible from optimal to maximum. In other words, the flexibility in feet possible from power supply at the optimal location to maximum variance as a means of determining overall placement flexibility.

Table 4 - Hardened Trunk Flexibility Study

The type of equipment employed in the system and manufacturers' specifications on amplifier voltage flexibility (range-selects, etc.) will determine the extent to which this technique can be applied. Consult your equipment data or the manufacturer for further details and information.

It should again be emphasized that the techniques discussed in this section apply whether hardened trunk or normal powering design concepts are employed.

An additional technique other than hardened trunk is to use higher supply voltages. Research has been conducted into the possible use of higher supply voltages (greater than 60 VAC) for the cable TV industry. The voltage range examined in most detail was 300 to 400 VAC quasi-square wave. There are, in fact, several cable systems in operation in the United States today that utilize supply voltages in this range. Advantages with this approach are considerable, but the greatest by far is in increased flexibility of supply placement. The real lack of flexibility in placing AC supplies with present power design techniques cannot be overemphasized at this point. Section 2.0 of this chapter deals almost entirely with the optimal placement of AC supplies within the commercial power grid. That section implies a reasonable amount of flexibility in the location of the supplies, and is basically not attainable with current design topology and techniques without the use of increased supply voltages.

Results of various sample hardened trunk designs as shown in Table 4 further demonstrate possible increases in flexibility with higher voltage.

First of all, note that the samples in Table 4 to determine flexibility were for supply placement in a hardened layout. These numbers therefore represent a best-case flexibility, and are better than would be encountered with typical trunk/feeder power designs. At 60 VAC powering, the supply could be relocated by only 1,122 feet from the optimal supply location and still make the design work. At the opposite end of the spectrum with 400 VAC, the supply could be relocated by as much as 60 percent or 26,400 feet (5 miles), with the subsequent design still working. This kind of flexibility is vital when considering the options discussed in the next section of this chapter.

Some early discussions were held regarding the possible use of higher voltages in cable systems. Voltage use in this range is a possibility, although the subject certainly gives some serious concern.

These include:

1) *Code approval (NEC, NESC, UL, and OSHA).* Initial contact has been made with some of these agencies, but much remaining work would be necessary before full approval to move to these voltages could be obtained.

2) *Trunk short circuit analysis.* The kilovolt/amperes (kVA) available from a supply operating in the 300 to 400 VAC range with a 12 to 15 ampere output are considerable to say the least. If this option were pursued, further research would be necessary to provide for a better understanding of short circuit analysis in the coaxial cable system

with the likely development of new overcurrent protective devices for the industry a requirement.

3) *Possible trunk entry connector problems.* Use of these higher voltages could involve some risk for the type of mainline connectors typically in use today. This area would require further examination as well.

4) *Personnel safety requirements.* Last, but certainly not least, are general concerns for personnel safety when moving to voltages in this range. New safety procedures, requirements and training would ultimately be needed.

At this point, the use of higher voltages is suggested for consideration in a hardened trunk layout where the higher voltages would be used only in the trunk portion. This alleviates some safety concerns, but leaves most of the previously listed factors for further research. If an operator seriously considered this application, the factors listed must be given a great deal more consideration and there must be a stronger effort toward achieving full understanding. It also is possible that limiting the supply voltage to 240 VAC or less may make this more palatable for the typical electric utility and cable operator, since secondary voltages are in this range and are generally considered to be "worker-friendly" as compared to higher primary voltages (greater than 240 VAC).

Hardened trunk techniques present a significant method by which to reduce power supply cascades, where either cascade level or commercial power reliability (or both) exceed acceptable levels, therefore making system powering redesign necessary.

3.0 Understanding/Working with the Local Power Utility

This section will cover the local electric utility system layout and its implications for overall cable system reliability. Are there ways to optimize reliability for the power drawn from them? How much does supply placement really affect reliability?

3.1 Understanding the Commercial Power Grid

Figure 1 represents the typical commercial power distribution grid. The front end of the system (that closest to the substation or power source) is shown as three-phase while the remainder of the grid is shown single-phase for simplicity sake. Keep in mind that the entire primary system is three-phase, connected in either wye or delta configuration. Most, if not all, of the components shown in the figure will be present in a well-engineered system.

Basic principles of power grid design are safety (for the general public and utility workers), the limitation of high fault currents to protect the system from catastrophic damage, and the ability to restore service to the largest number of customers in the shortest time possible even under the most severe conditions of weather or plant failure.

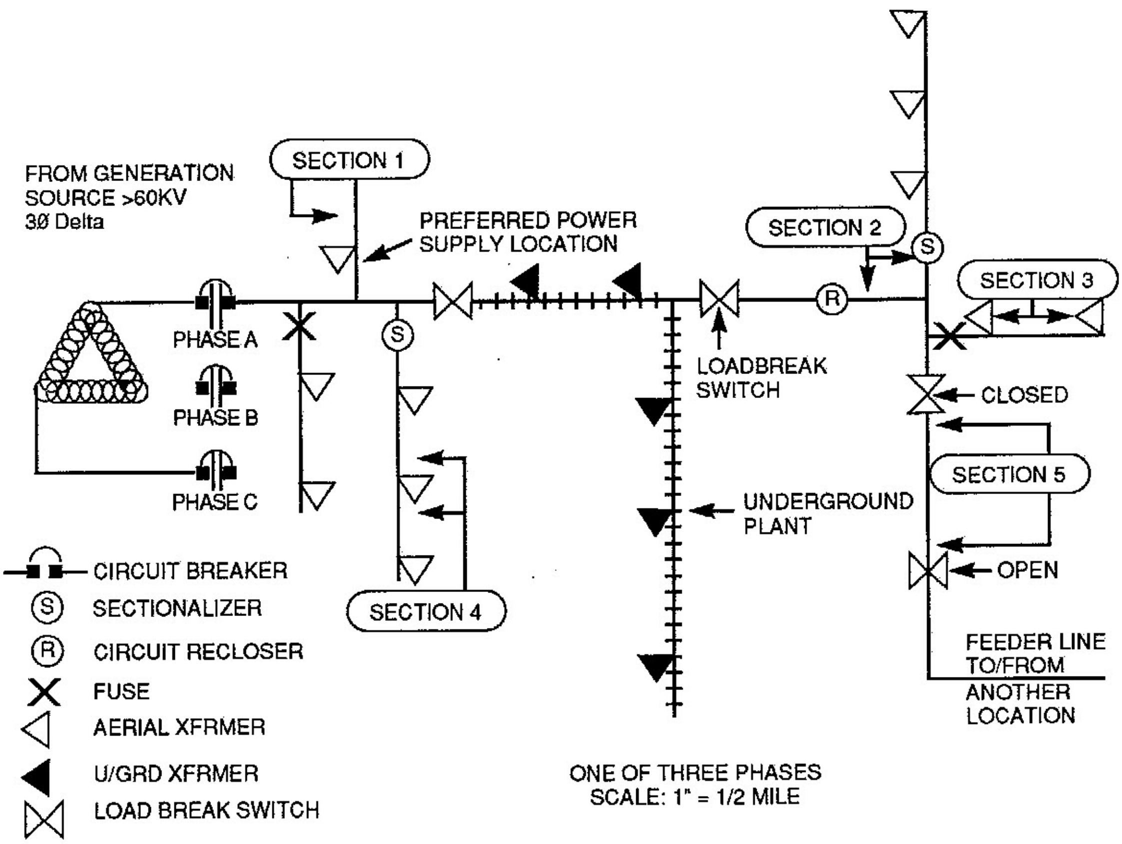

Figure 1 - Typical Power Distribution System

The following provides a general description of the primary protective devices shown, their functions, and limitations.

Substation:
Serves as a "voltage step-down transformer," outputting a voltage in the range of 4 to 35 KV to each distribution feeder served by the substation.

Substation circuit breaker(s):
This has a fault-response curve that is dependent on the magnitude and length of time that a fault is present. Fault currents above a certain magnitude generate an immediate response from the breaker, while faults of lesser value incur a time delay before the breaker reacts. The substation breaker is typically programmed to perform three cycles or operations before it permanently opens during fault conditions. The substation breaker is designed to react more slowly than other feeder protective devices. The idea is to isolate the fault with other devices before the substation has to take down the entire feeder.

Reclosers:
This is the next level of fault protection in the feeder leg. A recloser reacts to fault currents just as the substation breaker does. Reclosers and breakers are said to be "coordinated," which means that their fault detection characteristics are complementary. A recloser reacts to a load-side fault much more quickly than the substation circuit breaker can. With this type of coordination, a recloser would isolate a fault before the substation circuit breaker interrupts the entire line. Reclosers are typically placed in a portion of a feeder line that is expected to have (or has had statistically) a higher level of fault incidence due to such things as dense trees, potential car-pole accidents, etc.

Sectionalizers:
This is the next level of fault protection. A sectionalizer reacts to loss of power rather than fault currents. Basically, sectionalizers are simpler and less expensive than a recloser or circuit breaker. They are used to isolate or "section-off" portions of a feeder system when faults occur. The number of customers affected is minimized by isolating sections of feeder during fault conditions. Since sectionalizers operate on loss of power rather than fault currents, they are essentially "triggered open" when the source side device opens (substation circuit breaker or recloser).

An internal counter tracks the number of times that power is lost on the distribution line. They are generally set to remain open after experiencing one less fault operation than that of their source side protective device. For example, if the substation circuit breaker is programmed to "lock-out" after three unsuccessful attempts to reactivate a feeder line, the sectionalizer would be programmed to remain open after the second loss of power.

Fuse:
This provides the simplest level of protection. Fuses are typically located in feeder line spurs that exceed five pole spans in length where reclosers or sectionalizers are not used. They are fast-acting, require manual reclosure, and would probably be one of the last elements of a feeder line system to be reactivated. On the other hand, a cable power supply located downstream of a fuse could potentially be more reliable than in a section of feeder which contains a sectionalizer since the fuse reacts only to a fault that occurs downstream from it.

Load break switch:
This is the remaining major component of a feeder system. These switches are located throughout a feeder system in order to conveniently re-route power around damaged sections of plant and to restore service to segments from different directions. Aerial load-break switches can be recognized by the presence of a switch handle on the side of a pole that is attached to a long insulated rod running up to the switch location. The switch handle resembles a shovel handle and always is padlocked.

Given the figure and component descriptions, the following general guidelines can be given regarding cable power supply placement:

1) Where possible, keep power supplies close to substations, but on short side spurs to avoid the high fault/switching currents that can exist on main feeders close to the substation. The preferred location for a power supply would be a short side spur that does not include a fuse or other protective device, as illustrated in Section 1 on Figure 1.

2) Avoid areas downstream of reclosers such as Sections 2 and 3 of Figure 1. They are normally utilized by the power utility in high fault areas.

3) If possible, avoid areas fed by sectionalizers, such as in Section 4 of Figure 1.

4) Avoid power distribution areas between load break switch points as in Section 5 of Figure 1.

5) Where possible, avoid distribution lines protected by fuses. As stated earlier, however, they are preferable to recloser or sectionalizer feeds since they only blow when fault

current conditions occur downstream of the fuse location. Generally, feeder lines or spurs less than six pole spans in length do not have protective or switching devices installed. These are often optimal locations for power supply placement, particularly where they extend from main lines close to substations.

One approach for existing cable systems would be to relocate power supplies, where necessary and possible, to a point where they can take advantage of the automatic fault restoration capabilities of the power feeder system (circuit breakers), and avoid those locations where they may be shut off for long periods of times, such as downstream of reclosers or sectionalizers. Placing power supplies downstream of devices that require manual resetting such as sectionalizers will increase cable system exposure to lengthy commercial power outages.

One final caveat must now again be recognized regarding supply placement areas. Present cable plant powering layout techniques do not allow anything beyond a very modest flexibility in supply placement. The hardened trunk techniques described earlier provide improvement in supply placement flexibility. The reduction of acceptable load voltages provides a further modest improvement. Only the use of higher voltages offers a quantum increase in supply placement flexibility. When we discuss moving supply locations to avoid areas past reclosers or sectionalizers, the size and scope of the commercial power grid area requires a great deal of flexibility in supply movement to fully resolve issues in this manner.

3.2 Utilizing Power Utility Outage Data

The preceding section sought to determine power utility grid reliability based on our understanding of the function of certain protective devices. It is important to identify power grid sections that are demonstrated to be unreliable, by examination of the power utility's own plant outage data. Data is available from most utilities that can facilitate an operator's understanding of power distribution grid sections to avoid based on performance. This in turn can be used to locate or relocate supplies to optimize commercial power reliability. The table on the next page shows some example data.

Substation Name	Ckt. No.	Prot. Equip. Operating No.	Date	Rpt No.	No. Cust. On Cir.	No. Custs Affect	MaxMin. Out of Service	Total Cust. Mins. Out	Basic Cause	Equip. Involved	Condition of Equipment
San Gabriel	2106	OCB	2/26/88	116	3,889	3,889	87	60,077	Auto or truck	Pole/Arms	On ground
San Gabriel	2106	OCB	3/07/88	133	3,889	144	83	11,932	Bird	O/HCond.	Flashover/Leakage
San Gabriel	2106	Fuse330335	5/08/88	248	3,981	116	150	16,992	Equip. fail	U/G cond.	Burned open
San Gabriel	2106	Rclr20438	2/10/89	160	3,920	4	65	260	Equip. fail	U/G cond.	Burned open
San Gabriel	2107	Fuse10146	7/06/88	372	6,538	2	57	114	Equip. fail	U/G cond.	Burned open
San Gabriel	2107	Fuse40094	7/18/88	423	6,538	31	94	2,914	Equip. fail	Dist. Tran.	Malfunction
San Gabriel	2107	Rclr D82	10/12/88	632	6,668	2,903	483	51,259	Auto or truck	OH equip.	Malfunction
San Gabriel	2107	OCB	6/01/89	381	6,640	6,640	6	39,840	Distr.Subs.FA	None	Normal
San Gabriel	2107	Fuse9913	7/17/89	499	6,735	4	106	424	Bird	OH cond	On ground
San Gabriel	2107	Rclr D82	7/25/89	512	6,735	2,918	Unkn.	Unkn.	Auto or truck	Pole/arms	Broken

Table 5 - Typical Power Utility Outage Data Sheet

Typical data gathered by the local power utility from its plant outages include:

- Substation feeding the outage area
- Feeder line number
- Number and description of protective device feeding outage area
- Date of occurrence
- Number of customers on the entire feeder line
- Number of customers affected by the outage
- Outage duration in minutes
- Total customer minutes out-of-service
- Cause of the outage
- Equipment involved in the outage
- Condition of the equipment involved

Table 5 is actually some real data from a West Coast power utility (with names changed to keep the utility company anonymous):

Again, the information in Table 5 is a very brief sample of the type of data available. While data will vary from different localities and companies, early conclusions seem to indicate the following:

1) Aerial power plant is generally more reliable than underground, primarily because underground plant is more difficult to repair and takes longer to fix during emergency restoration conditions.

2) Street light circuits are maintained separately from other electrical distribution circuits. While it was initially surmised that they would be more reliable than other distribution circuits, that has not been the case upon further investigation. Street light circuits should generally be avoided for supply powering. Outage data is normally not kept on these circuits and they are typically also the very last to be repaired under emergency conditions.

3) Reliability of the three-phase primary system will often vary from phase to phase depending on design architectures used. Some discussions should be held with the local utility to determine if one phase is more or less reliable than others, and if the utility is willing to allow the concentration of cable loading toward the more reliable phase(s).

4) Other individual and increased reliability circuits sometimes exist in the power distribution system (e.g., a high reliability feed placed to serve a local hospital). It is sometimes possible to place power supplies along these types of runs.

3.3 Develop a Close Working Relationship with Local Utility

Most major utilities have a distribution operations office, which, among other functions, electronically monitors the condition of electrical feeder systems in its jurisdiction and coordinates outage restoration, circuit switching, maintenance, and construction activities in its district. Cable operators should become acquainted with the operations manager for its power company district. The operations center can provide planned service outage information, as well as the location of unplanned outages.

Further work with power utility engineers has suggested that if the cable system were to label or designate cable supplies in a manner that would relate them to the device number of their nearest upstream electrical distribution protective device, the cable system could quickly pinpoint any affected power supply locations by providing this number to the utility's operations center. The third column of the sample power company outage data in Table 5 illustrates this "protective equipment operating number." Such a labeling scheme also could be helpful in notification of planned service outages. This engineering tie to the electrical power plant could be incorporated into system maps, billing system outage tracking schemes, or other outage data tracking systems.

4.0 Optimized Application/Operation of Standby Powering

Standby powering technology has been available for quite some time, but many operators have experienced less than successful results in its application. This lack of optimal application and results has to do with the complexity of the technology, and in particular the correct selection and maintenance of batteries required. This section of this chapter begins the task of seeking answers to some of the industry's misunderstanding and misinformation associated with standby technology.

There is much work remaining in this area. Ultimately, the goal here is to answer to past failures and to make recommendations for change and optimal application in the cable system. How can this technology be best applied? How can we achieve desired results with minimal maintenance applied in critical areas?

Due to the detail and extent of research necessary in this area, a separate working group was established to:

- Develop recommended standby and non-standby equipment specifications
- Develop recommended application methods for supply electronics and batteries (particularly charging circuits)

Results and recommendations from that group will be forthcoming in the next several months. Meanwhile, the following represents some early conclusions.

4.1 Standby Power Supply Design and Reliability

Several manufacturers offer standby power supplies in a number of configurations. Most utilize a ferroresonant power transformer as the key component in the design. Ferroresonant transformers are very effective at providing voltage regulation, spike attenuation, noise filtering, high reliability and output short circuit current limiting. The additional components necessary for the standby function are: battery charger, batteries, inverter circuit and logic control circuit/status monitoring interface. Standby power supplies are less reliable than non-standby supplies in terms of MTBF, primarily because of higher electrical component count. The most significant factor affecting standby power supply reliability is the batteries — how they are maintained, choosing the correct type for the application, correct charging and float techniques, and ambient temperatures encountered by the batteries.

There are three main battery types available for use in standby power supply applications: gel cell, absorbed glass mat (AGM) and liquid lead acid (automotive-type battery). Selection of the proper battery for use in standby power supplies is the first and foremost action that a system operator can take to improve system reliability. The following is detailed information on each type of battery.

1) *Gel cell batteries*: Gel cell batteries have been used in this application for over 15 years with good results. The gel cell design is a lead-calcium plate construction in an epoxy case filled with gelled electrolyte. The case is sealed (so it is maintenance free with no water to add) and is slightly pressurized to aid in the internal recombination process. There are pressure relief valves that vent at 1-2 PSI differential pressure. Gel cell batteries can be used in any orientation mechanically without leaking. Some states actually require gel or AGM batteries to be used in pole-mount power supply applications for safety reasons. If a vehicle hits the pole in an accident and the batteries fall,

liquid acid is not spilled. The gel cell battery tolerates higher ambient temperature operation better than the AGM or liquid lead acid designs. Even so, the significant cause of premature battery failure with gel cells is high temperature operation. Battery service life is typically reduced by 50 percent for every 15° F increase in temperature over 77° F.

2) *AGM batteries*: The AGM battery is similar in construction to the gel cell with one distinction: the case is not completely filled with gelled electrolyte. Rather, the electrolyte is absorbed in a porous glass mat separator that acts as a sponge between each plate to hold the electrolyte in contact with the active material on the surface of the plate. The AGM battery has a higher acid concentration in the electrolyte (higher specific gravity) and consequently is prone to increased corrosion of the positive plates, which is accelerated with higher temperatures. This characteristic, coupled with less gelled electrolyte than the gel cell, makes the AGM prone to shorter service life in warmer climates.

The AGM battery is an economical choice and can be reliable for use in controlled environment applications such as an air-conditioned headend, in an uninterruptible power supply (UPS) in the office, or in standby supplies in the colder northern climates where the average temperature is 80° F or less.

3) *Liquid lead acid batteries*: The liquid lead acid or "wet" topology (automotive-type battery) is tempting for use in standby power supplies because of its lower initial purchase price and common availability. Unfortunately, this battery may be the least reliable and most expensive in the long run when all factors are considered. First, the liquid lead acid battery is designed for high rate discharge for such things as engine starting purposes, and not for low rate discharge and deep cycling with long standby time. It is optimized to deliver 300 to 500 amperes for 30 seconds for engine starting.

The gel cell and AGM batteries are designed for float service where they are always connected to a float charger to counteract internal self-discharge, and when they are discharged (standby operation), charge at low rates of 20 to 30 amperes for a longer period of time. The liquid lead acid battery currently appears to be the most expensive battery in terms of maintenance and safety liability. Water must be added frequently, especially in hot climates. If there is no temperature compensation of the power supply battery charger, overcharge can occur in high temperatures, which quickly "gasses" the electrolyte out of the cells, causing permanent damage and loss of capacity. The liquid electrolyte can leak or spill and there can be considerable hydrogen venting, which contributes to an extreme safety hazard to the service technicians and a high liability risk to the system operator.

The current recommendation is to use gel cell batteries for standby power supply use in all climates, AGM batteries in controlled environments or colder climates, and to avoid the use of liquid lead acid batteries.

The following are factors that affect battery service life:

1) *Ambient temperature.* High temperatures cause increased self-discharge, increased corrosion of the positive plates, increased gassing of the electrolyte (liquid lead acid battery) and accelerated drying out of the gelled electrolyte. Cold temperatures reduce standby time, require increased charge voltages, and can freeze electrolyte and crack the case if the battery is discharged completely and exposed to freezing temperatures.

2) *Charging procedure.* The battery charger must have accurate voltage regulation and be calibrated properly for the type of battery used. The charger should have temperature compensation. Batteries require an increased charge voltage at low temperatures and a decreased charge voltage at high temperatures. Temperature compensation utilizing a battery temperature probe accurately and automatically adjusts the charge voltages with changes in battery temperature. Proper location of the temperature probe appears to be on the side of the middle or highest temperature battery. Equalize charge (elevated float) is not recommended for AGM batteries, but is acceptable for gel cell batteries and is usually necessary for liquid lead acid batteries.

3) *Prolonged storage without charge.* Batteries should be considered perishable goods. They cannot be stored for extended periods of time in the warehouse without charge. Most battery manufacturers recommend charging stored batteries a minimum of every three months. Batteries are date-coded so the user can determine the manufacture date. It is recommended that a procedure be implemented to charge all batteries in storage every two to three months until they are placed in service in the power supply. Batteries that sit for longer than six months, especially in high temperatures without charge, lose capacity permanently. It is not uncommon to see only 40 to 60 percent capacity left after eight to 12 months in storage without recharge.

4) *Unequal battery voltages in series string connections.* Most standby power supplies use either two or three 12-volt batteries connected in series (24 or 36 VDC). If one of the

batteries fails or deteriorates, it can cause damage to the adjacent batteries. With a float charge voltage connected to the battery string, the voltage across each battery is determined by its individual internal resistance. If one battery has a significantly different resistance than the adjacent batteries, an unequal division of voltage can occur, which essentially overcharges the other batteries. If this condition is not identified and corrected, permanent loss of capacity or failure of all of the batteries will result. This is a reason for regular preventive maintenance on standby units.

It is recommended that each power supply location be visited every six to 12 months and each battery voltage be measured under load to determine overall condition and lifetime. What follows is a tentative procedure, which is still under development:

Place the power supply in standby. This will load the battery string with approximately 25 to 35 amperes. Measure the voltage across each battery in rapid succession. If the voltage in any battery measures 0.5 volts or more different than the adjacent batteries, replace it. It also is advisable to match batteries in groups of three in the storage area for installation or replacement as a group. Sort the batteries (new or used) with an automotive-type load tester and use color-coded stickers to identify batteries with the same voltage as a particular color (e.g., the batteries with the green stickers get installed together as a matched set, etc.). In general, batteries also should be sorted by manufacturing date/time whenever possible. By matching the battery strings prior to new installation as well as when a single battery needs to be replaced, the service life of the batteries can be increased by as much as two years or more.

Verify cooling operation in power supply enclosures. Ensure all vents, louvers, etc., are clear for maximum airflow. Space the batteries apart on the battery shelf approximately 12 mm to maximize airflow and cooling around each battery and to lower the temperature. Be aware of various enclosure designs. Versions with batteries on the top shelf or high in the enclosure should be used in colder climates only, due to heat buildup in the upper compartment. (It is actually beneficial in winter to keep the batteries warm for maximum standby capacity.) Use versions with the batteries on the bottom shelf in the warmer climates to keep the batteries as cool as possible. In ground-mount pedestal enclosures, be sure that the cool air intake louvers at the base of the cabinet are not obstructed by dirt, leaves, vegetation, etc.

4.2 Establish Preventive Maintenance Procedures, Identify Required Equipment

A preventive maintenance procedure for power supplies can be as simple as a one-page checklist that instructs the technician to perform each test and record the data. This would be kept in a log book in the power supply cabinet or back at the shop.

The following are items that should be checked:

- Visible signs of corrosion, electrolyte leakage or excessive swelling of the battery cases.

- Loose, corroded or damaged battery wires or terminals.

- Battery voltage under load as previously described. Use safety glasses and keep face away from batteries when putting the unit into standby to protect against injury if a battery were to arc or explode.

- Measure and record AC output voltage and current (always use an RMS digital meter for accuracy).

- Check all fuses, pilot lamps and connectors for proper operation.

- Disconnect batteries (or open fuse or circuit breaker) and check charger output voltage. If the charger is temperature compensated, refer to the power supply manufacturer's specifications that indicate the correct output voltage at the present temperature of the batteries. Verify the battery temperature probe is connected to the side of the center battery. If the charger voltage is incorrect or malfunctioning, follow manufacturer's instructions for repair.

- Transfer the power supply in and out of standby operation several times. Verify correct operation. Record the elapsed run time from the hour meter (if equipped). This data can tell the system operator how long the power supply has operated in standby between each maintenance visit. If the actual standby time at a particular location is consistently low (i.e., reliable utility power), it may be possible to install less expensive lower-ampere hour capacity batteries at this location, or eliminate standby entirely. If the standby time is consistently high, the operator may choose to install higher capacity batteries or an additional string of batteries in parallel. If possible, the power supply could be moved to a more reliable AC power location as suggested previously in Section 2.0 of this chapter.

A separate small tool box is recommended specifically for power supply preventive maintenance. This tool box should include the following:

- Work gloves for handling hot power supply units or leaky batteries
- Safety glasses
- Portable battery load tester
- RMS digital voltmeter with clamp-on current probe
- Spare fuses, pilot lamps, battery cable kit, and battery terminal hardware
- Small brush for terminal cleaning, and corrosion inhibitor spray for battery terminals
- Keys for enclosure door locks
- Replacement AC service entrance fuse or circuit breaker
- Power supply instruction manual
- For the truck: Matched set of batteries, service power supply, extension cord for generator powering if necessary during repair or maintenance

4.3 Identify Options for Status Monitoring of Standby Power Supplies

Particularly in this section, additional research is necessary before final recommendations will be made. Our "first pass" yielded observations that follow.

Status monitoring interface capability is available for some of the standby power supplies currently manufactured. There are two primary communication methods for the status data: 1) parallel interface for connection to the power supply monitor port in a dedicated data transponder; and 2) or in conjunction with amplifier status monitoring systems.

The following data are typically provided from the power supply to the status monitoring computer system:

- Line operation or standby mode
- Output voltage
- Output current
- Tamper alarm (is the enclosure door open)
- General alarm (has the power supply failed self-test)
- Battery voltage (allows a remote determination of battery health, capacity and estimated run time remaining during an outage)
- Test enable (places the power supply in standby to test inverter and batteries remotely)

The serial interface provides the same status data, but allows use of RF data modems (for two-way plant) to facilitate power supply data communication independent of amplifier monitoring systems. Serial data also can be communicated via a transmitter located at an end-of-line data accumulator, or via a telephone modem. More on this will follow.

When a power supply goes into standby mode because of a utility outage, the status monitor system can immediately notify the dispatch center. By monitoring the rate of discharge of the batteries (decline in voltage), an estimation of standby time can be achieved and a generator truck can be dispatched to the location to continue operation after the batteries have discharged and until utility power returns. By frequent remote tests of each power supply, marginal batteries, blown fuses or circuit malfunctions can be identified and corrected prior to a power outage. This capability greatly increases the powering reliability of the system, results in reduced maintenance visits (lower cost because of fewer truck rolls), and provides statistical data of power supply and battery performance.

Status monitoring always has been considered to be of high operational cost, because two-way plant is typically the proposed method. Telephone lines or RF transmitters could be installed at each supply location, but this typically has met with serious concerns for a variety of reasons. A new idea under consideration would utilize the forward cable plant, plus data accumulators and a few telephone return lines (or RF transmitters) in the following scenario:

1) Data transmitters at each standby location would transmit data in the downstream path toward the end of the trunk line. Besides the information mentioned previously, the data stream would include a unique identifier code for each location. Each unit would transmit in even and established time intervals (perhaps one-minute intervals) to a receiver (data accumulator) located toward or at the end of the trunk line or standby powering section.

2) Since transmission is in the downstream direction, each cable system would be able to utilize this method as long as several forward frequency choices were available. One possibility would be the spectrum located between Channels 4 and 5, or perhaps in the FM band.

3) A data receiver/accumulator would be located at the end of this string of standby power units. It would collect data and monitor the output of the unit for unusual activity.

4) A transmitter would dial into dispatch or contact the cable technical operations in some established fashion, if one or more of the following were to occur:

- Loss of communication from one or more of the power supplies that communicate with it,
- Any change in supply in standby condition feeding the receiver,

- An alarm or out-of-tolerance condition at any unit feeding the receiver, and
- Assuming the alarm receiver also stores data from the data stream of all valid supplies within its group, it would either be periodically polled by the status monitoring computer, or would periodically dial into the system to download any stored information ultimately to be analyzed and archived.

The alarm receiver would likely need some sort of battery backup to keep it functional during the few times that a loss of power was experienced in its own area. Assuming that it is powered from the last standby location in the area only, a small battery would be needed to keep the receiver functional during those times that the standby unit is out of service.

This approach holds the promise to resolve many of the past concerns with status monitoring of supplies in the cable plant. Early studies indicate that a fairly large system could be monitored with a minimum of accumulator areas. One system examined contained a total of 500 plant miles, and could be monitored with around four or five receiver areas in total — with careful location of the alarm receivers.

The task force's recommendation is to implement status monitoring for maximum effectiveness of standby powering in the hardened trunk topology whenever possible and practical. Incorporate this with critical front-end supplies at the very least. For maximum reliability, implement at all hardened trunk locations.

5.0 Plant Powering Subcommittee Conclusions

There are definite areas in plant powering methodology to reduce commercial-related plant outages. Cascades of power supplies and associated commercial power reliability feeding each supply are key items in system reliability. Design philosophies are currently available that provide a 50 to 75 percent reduction of power supply cascades when existing supply cascades or plant architecture necessitates redesign. Hardened trunk is the recommended practice when significant cascade reductions are necessary. Other techniques considered were the use of higher voltages and extended (lowered) load voltages, which also provide further extension in reach, and an important increase in supply placement flexibility. The group does not recommended them at this time, since hardened trunk powering provides most improvements necessary in cascade reduction, and can be easily implemented compared to the other techniques examined.

A better understanding of the local electrical power distribution grid provides knowledge for the correct placement of supplies when flexibility in placement is possible. Working with the local electric utility also provides for a better understanding of less than optimal locations for supply placement, also further creating a good working relationship with the utility. This interface provides for information on planned maintenance and emergency restoration work during outage conditions.

Finally, standby powering is an established but often misunderstood and misapplied technology for keeping unreliable but critical commercial powering locations in service. Proper supply/battery maintenance is essential. In some instances status monitoring provides for absolute reliability when supply(ies) cannot be out of service.