POWERING LARGE SCALE HFC NETWORK

Hassan Kaveh
Alpha Technologies Pty Lid
Unit 6, 8 Anella Avenue
Castle Hill, NSW, 2154
Australia

Abstract
The first ever large scale Hybrid Fiber/Coax (HFC) network has been successfully implemented in Australia by Optus Vision. One of the key elements of the system architecture is the delivery of uninterrupted AC power to the fiber node and the line amplifier in order to support a "life line" telephony service.

1.0 Introduction

Design and delivery of a life line telephony system in an HFC structure have long been considered unfeasible, due to the legislative need for providing a highly reliable and stable power source, along many hundreds of kilometers of network cable with less than a few milliseconds of interruption under all possible outage and fault scenarios.

The worldwide expansion of networks offering high bandwidth transmission of voice, video, data, and internet access has put a new emphasis on power demand and reliability. This would hasten the pace to replace the existing narrowband twisted pair access network in order to provide broadband services. The aim of this paper is to outline some of the major design considerations of powering such a system.

Several powering voltages such as low frequency (1 Hz), 3 phase UPS, centralised and distributed 30, 45, 60, 72 and 90 V AC have been used for sometime. The suitability of the options available for a particular architecture has to be carefully evaluated. The merits of each option are covered elsewhere [1,2,3]. The most widely used voltages for powering traditional cable TV and HFC network are the 90 and 60 V AC via a distributed or centralised mean.

The 90 volt powering has been introduced to the CATV industry in the recent past as it offers:

- typically one node per power supply.
- greater design reach.
- power supply location flexibility.
- easier to maintain an outage with mobile generator.
- higher power output per power supply.

These and other benefits have convinced the operators in Orlando, Tampa, San Diego and Optus in Australia to move away from the traditional 60 volt and take up the 90 Volt option.

2.0 Powering Evolution

The majority of the cable TV systems around the world use AC power supplies that provide conditioned and regulated 60 or 90 Volts AC to the active devices in the field. The vast majority of the supplies used are "ferroresonant" based power transformer topology.
The ferroresonant transformer design has almost 50 years of pedigree and substantial followers in the CATV industry. The inherent reliability and line conditioning characteristics of the ferroresonant transformer in the very hostile environment in which they are operated, is the key to its popularity. Due to inconsistency and unreliability of the power from the local utility grids, the service provider has the responsibility of supplying power to the critical network devices during the outage period. This can take the form of extended battery back-up (of up to 8 hours) or a combination of battery back-up, as well as the standby generator. This is highly crucial for the life line telephony service provider and is generally governed by the statuary regulation covering such services. A typical coaxial "tree and branch" architecture for a distributed system is illustrated below:

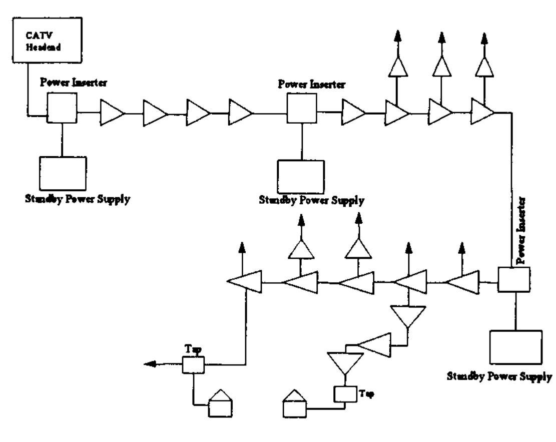

Fig 1: Tree and branch coaxial architecture

3.0 Ferroresonant Power Supply

A ferroresonant transformer differs from a regular linear power transformer in many ways. The most desirable of which is the two components magnetic aspects of it. The transformer is constructed from a specially designed magnetic lamination core with separate windows for the primary and secondary coils. Unlike a linear transformer the ferroresonant core is designed to go into magnetic saturation. The second component is an AC capacitor that, with a resonant winding on the transformer secondary, forms a resonant tank circuit. A simplified equivalent circuit is depicted in Figure 2

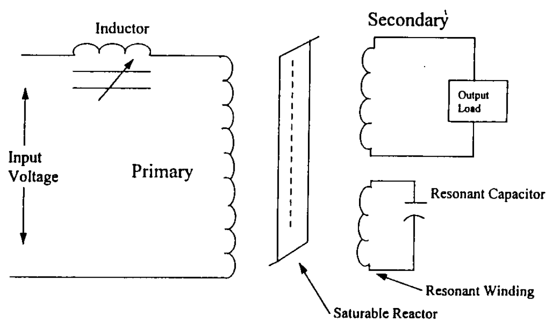

Fig 2: Simplified equivalent circuit of a ferroresonant transformer

The ferroresonant transformers of today, are much the same way as when they were first patented by J.C. Sola in 1938. In most designs, the structure is formed with interleaved "E I "laminations and magnetic shunts are inserted between the primary and secondary windings as indicated in Figure 3.

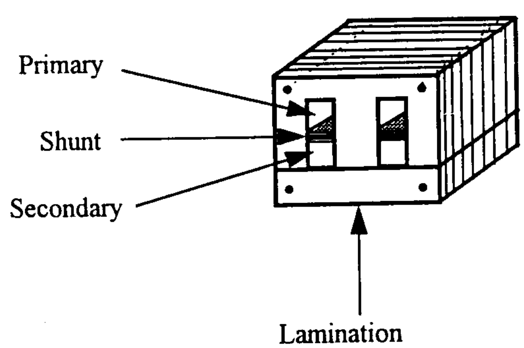

Fig 3. Construction of EI laminated ferroresonant transformer

In general, the Ferroresonant Power Supply **(FPS)** can be considered as an LC low pass filter with a comer just above the utility line frequency followed by a roll off 40 dB per decade [4]. The line conditioning property of a FPS provide relatively constant output voltage when there are substantial fluctuations in the supply voltage. It is also used to isolate the critical load from both common-mode (typically 120 dB) and transverse mode (over 60 dB) electrical noise line to ground. It is therefore a combination of a voltage regulator and an electrical noise filter. [4]

Load regulation of a FPS is provided by the use of a shunt magnetic path which has an air gap between it and the main EI lamination. The air gap is used to limit the flux in the shunt portion of the FPS and therefore preventing the magnetic saturation. In short it forms a "closed loop" whereby the fluctuation in the output load current is compensated for by the flux variation in the shunt circuits.
From an electrical/magnetic point of view, the voltage applied to the primary causes magnetic excitation of the main flux path which in turn excite secondary winding. Once the tuned secondary goes into saturation, high circulating currents flow in the resonant tank (a LC network), which in turn causes the magnetic saturation of the main flux path. At this stage of saturation, the reduction or increase in the utility supply will not affect the output voltage for as long as the core remains in the saturated state. This line conditioning property of the FPS is of extreme importance in the field due to the close proximity of the power supply to the utility grid and therefore the direct coupling of any supply transient onto the primary winding of the power supply itself. Attenuation factor of over 1000 to 1 has been observed. The extreme raggedness, and at the same time the simplicity of the FPS circuit without the need for any electronic shutdown circuitry, in the event of line transient has been a dominating factor in selecting this type of topology. Consequently very high (greater than 100,000 hours Mean Time Between Failure) is achievable in the very hostile environment (extreme heat, cold and vibration) in which the power supply unit is expected to operate.

An exciting feature of a FPS is the "output foldback" characteristics. Figure 4 illustrates the foldback characteristic of a typical 15 Amp FPS. This highly desirable and distinct property, limits the fault current by reducing the transformer output voltage once the network demand exceeds the 20 Amps mark and hence protects the power supply as well as the coaxial cable and all components downstream from it.

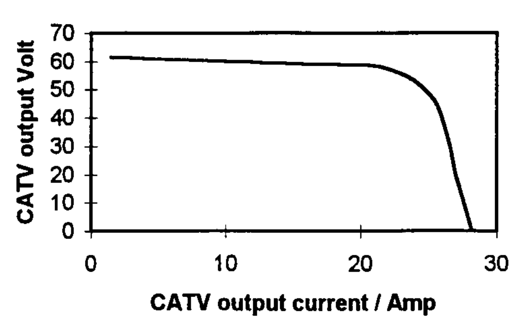

Fig 4. Foldback characteristics of a typical 15 amp FPS

4.0 FPS and Its Future

Considering the information provided so far the FPS appears to be a natural choice for cable TV and HFC powering. The main disadvantage of the FPS is its efficiency at light loads, compared to the switch mode power supply. The theoretical efficiency for FPS value can be as high as 94%, but typical design can operate at about 90% efficiency, depending on the loading level. There are several factors contributing to the relatively low operating efficiency which occurs at light loads. Some of these factors are purely as a result of system application and the specification by the end users. These are covered in other publications [4,5,6,7], but it's enough to say that a sound choice of the line/load regulation, normal operating line voltage and load current, can enhance the power system efficiency substantially. For example, in Australia the line voltage is predominantly above the nominal 230 volts and therefore reduced efficiency at occasional low line voltage could be tolerated at the expense of higher efficiency.

The prime considerations for powering of the HFC network are the Reliability, Availability and Maintainability **(RAM).** Current design of standby FPS has been very successful in meeting all of the above mentioned criteria. The future trend is somewhat difficult to predict. Can a SMPS, with component count of around 1000 be as reliable as a standby FPS with its line conditioning characteristics? The current Modem Switch Mode Power Supply **(SMPS)**, used for powering exchange centres in a controlled environment (air conditioned), do not appear to have the same level of RAM.

5.0 The Choice of Waveform

The transfer of power through a coaxial cable to feed the active devices in an HFC network has been long established and as the system evolved, the need to minimize any losses as a result of this transmission path has been well examined and optimized. With the advent of switch mode regulator for powering the line amplifier and other active devices the economics of operating an HFC system has become even more important. The input AC power to SMPS is rectified, filtered and regulated to provide the one or more DC voltage(s) required to operate the active components within the amplifier. Modem SMPS employed in the line amplifiers are highly efficient (> 90%) and utilize electrolytic capacitors to filter the rectified DC as shown in figure 5. The DC energy stored in the front end capacitor are used for sustaining the regulator output during the short period (typical hold up time of 15 mS) in which the input to the SMPS is interrupted. The period in which the capacitor charging takes place varies in duration depending upon the voltage being presented to the input of the SMPS. Due to the constant power characteristic of the SMPS, as the voltage decreases the current being drawn increases correspondingly.

The voltage drop due to the internal resistance of coaxial cable used for carrying the 90 or 60 Vac can vary depending upon the type of cable used. The resistance per kilometer of coaxial cable can vary from 0.5 to 3 Ohms/Km. An amplifier at the end of the coaxial cable draws more current (longer windows) in order to compensate for the lower input voltage.

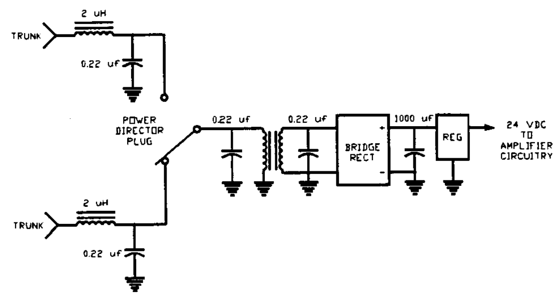

Fig 5. Typical internal AC/DC power converter in trunk amplifier power supply

The traces in figures 6 to 8 illustrates the output current and voltage waveforms due to differing load current from a laboratory based cascaded SMPS as shown in photo 1.

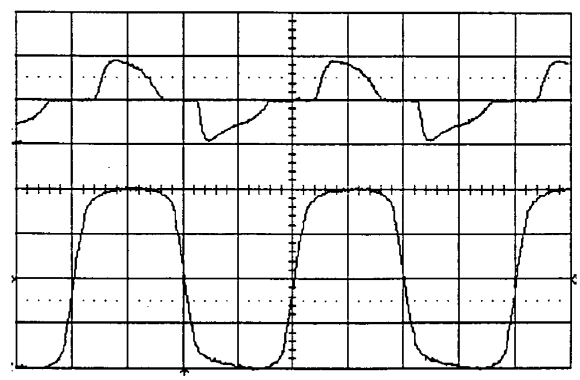

Fig 6. Current and voltage waveform for a 2.5 A load. (Scale: Current 5 A/div, Voltage 50 V/div)

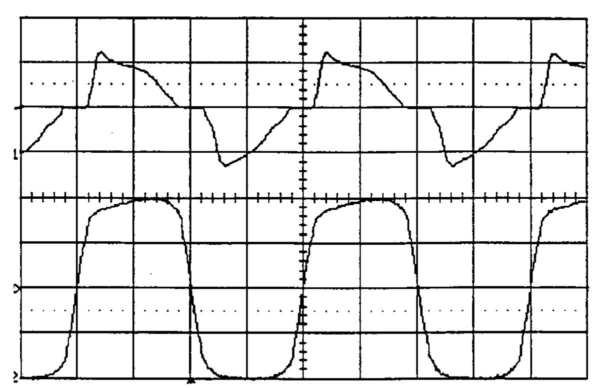

Fig 7. Current and voltage waveform for a 7.5 A load. (Scale: Current 10 A/div, Voltage 50 V/div)

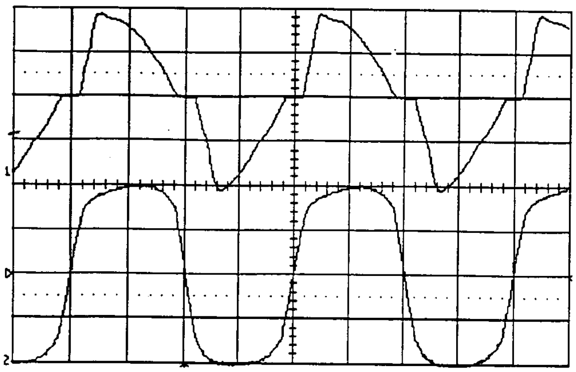

Fig 8. Current and voltage waveform for a 16.4 A load. (Scale: Current 20 A/div, Voltage 50 V/div)

Having established the load characteristics it is now appropriate to examine what waveform would be most suited to the load being served. The electrolytic capacitors are commonly utilized in nearly all of the SMPS used in the active devices in use today. These capacitors are significantly waveform sensitive and are peak responding. If such load form a significant part of the system load, on a sinusoidal DC to AC inverter, the inverter must often be significantly overrated, which is costly and may reduce system efficiency. A much smaller, lighter system can be designed if the waveform can be shaped to reduce the peak and RMS currents to the load.

A potential candidate could be a square wave, but closer examination would reveal that as the peak, average and RMS are equal, then any square wave will have too low a peak voltage or too high an average, or both. A better solution is to use a trapezoidal waveform [4]. As the flat crest is progressively widened the peak and RMS load currents rapidly drop while the average and RMS voltages slowly rises, allowing a range of improved waveshapes. Although the optimum wave does depend on load characteristics, almost any trapezoidal waveform is better than a sine wave. A trapezoidal with a 50% crest and 5% upslope would be a good universal choice.

6.0 Standby Powering

The move towards the standby power supply has taken place in the last decade or so in an effort to enhance the system availability. Transient voltage surges and spikes induced by lightning or caused by sheath current and utility switching operation are some of the serious threats to reliable HFC operation. Other factors such as:

- oversized vehicle tearing down overhead plant
- poor installation
- inadequate battery maintenance
- wind related storm activity resulting trees to fail on plant
- utility power interruptions

are some of the most common reasons for long or short outage.

To maintain the integrity of a life line telephony service the avoidance of any interruption is critical. To cater for such disturbance, power supply manufacturers of the FPS came up with the standby off-line concept. The standby FPS technology has since evolved into a highly sophisticated hardware that has the distinct advantages of the line regulation of the FPS with the added bonus of providing the energy from the battery bank to generate output power during the outage period. In standby FPS transformer, there are two primary windings and one secondary winding. Because the resonant secondary winding circuit controls the waveshape of the output to the system, there is no difference in waveform appearance, frequency and voltage between utility fed energy and that of the battery DC. When interruption to the utility in the form of brownout or blackout occurs, the inverter/charger primary converts to inverter operation from the previous battery charger mode and the AC line primary is disconnected from the utility line to prevent the feedback of power to the utility whilst the power supply **is** in the standby mode. See figure 9. As the system load is permanently connected to the resonant tank circuit winding, the circulating energy in this circuit can maintain the output whilst the smooth transition takes place from the mains to standby power. The result of which is a seamless transfer between two energy providers to the secondary winding. A functional diagram of a standby off-line FPS is shown in figure 10. IS]

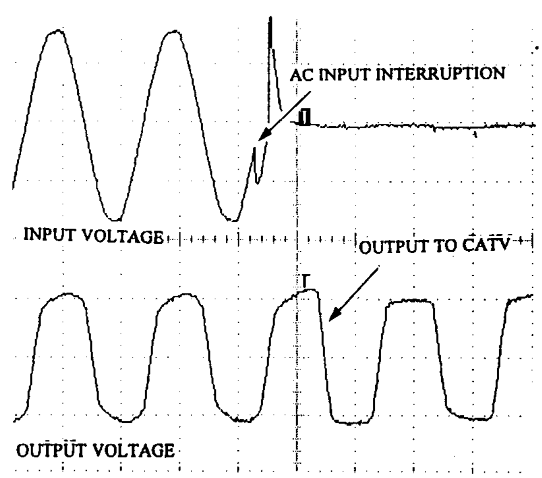

Fig 9. Standby FPS **-** Transfer from utility supply **to** battery

7.0 Distributed Versus Centralised powering Architecture

The demand put upon the cable operators for higher availability and reliability of the cable TV network over the last decades or so, has been responsible for great many innovative solutions by the power equipment manufacturers in the move towards the standby FPS.

The last decades or so, has been responsible for great many innovative solutions by the power equipment manufacturers in the move towards the standby FPS. The trend setting ideas of the past has allowed today's system to be so radically different from those of a few years ago in reliability and availability.

As the pace of migration from cable TV to fully integrated HFC network is gathering speed, so does the argument over the method of powering the system. The factors affecting the decision on powering architecture are too numerous to mention and is outside the scope of this paper. There are studies by others [1,10] who have explored the system architecture and the readers are referred to these articles.

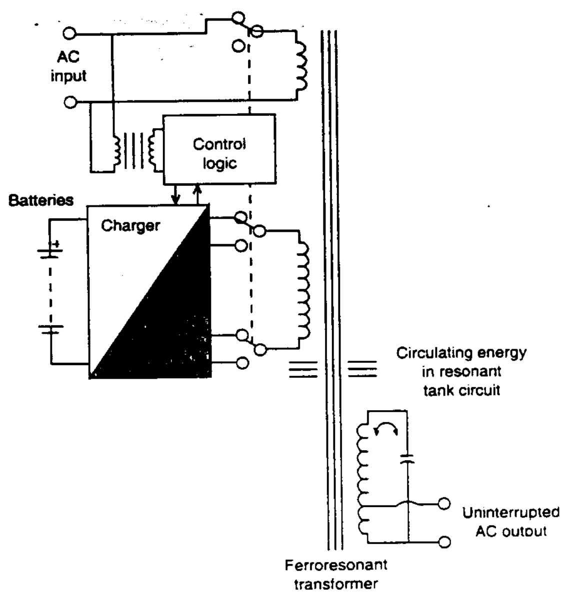

Fig 10. Single ferroresonant UPS functional block diagram

7.1 Distributed Powering

This method of powering is favored because of the ease in which the system can be built and upgraded. A typical pole mounted distributed power system consisting of LIPS and battery bank is shown in photo 2. A well managed and strategically placed mobile generator fleet that could be dispatched to isolated power outages is of absolute necessity to maintain the powering needs. Alternatively, a truck based converter that is fed from a reasonably inexpensive alternator from the maintenance vehicles can be a real alternative to having a mobile generator. This option has been tried by several north American cable companies and is under consideration in Australia. This has a distinct advantage that a small converter, which is permanently installed on the vehicle can be utilized to provide clean power to the FPS during the planned or unplanned outages, but also for powering the test and instrument equipment throughout the life of the system from the initial commissioning right up to periodical maintenance. This option has several major advantages such as:

- lower life time cost than that of a generator
- no need for maintaining a fleet of mechanically
- based generator units.
- almost zero noise pollution.
- elimination of flammable fuel for generator and its
- storage in a densely populated area.
- no safety and vandalism concerns
- easy to use

It has been suggested that a small converter placed in a trailer with a sealed battery bank can be used for long outages. This could be an ideal choice for an operator with a small fleet of maintenance vehicles. Other advantages could be the ability of the vehicle to be refueled, or allow the technician to have a meal break. During this period the pole based battery bank can supply the FPS with the energy require to run the inverter, as it has been charging during this powering mode period. The alternative method of powering could be the supply of external DC power directly across the pole mounted battery bank and allow the inverter mode of operation with the standby FPS. Another innovative approach can be a vehicle based converter that produces a 90 V AC quasi square wave output, which is suitable for direct connection across the hard line.

The use of a DC generator has been in service for a long time and is of a field proven technique. This has the key advantages of lower noise level compared to that of a sinusoidal AC generator as the maintenance of output frequency is eliminated and therefore lower idle speed and fuel economy under low load condition.
The response time to a catastrophic failure such as a motor vehicle accident with the pole supporting the FPS housing can be very short as the temporary supply can be available almost as quickly as the maintenance vehicle reaches the scene of the accident.

7.2 Centralised Powering

Centralised powering with integral generator backup facility is considered the most reliable powering method by some operators. A typical arrangement for such powering technique is shown in photo 3.
The key advantages of centralized powering are: unlimited capacity, reduced number of service and maintenance centers.

On the down side, the large size of a cabinet, ascertaining easement for installation and planning regulation could be mentioned.
From the visual pollution, the centralised option is naturally the most suitable choice as the environmental harmonization of one medium sized ground mounted cabinet, is substantially easier than that of several pole mounted units. This method of powering has several merits such as:

- It can provide a natural migration from HFC to telephony
- initial lower cost
- could furnish adequate power for curb side
- telephony interfaces and NIU's
- having an N+I redundancy capability
-

Photograph 3 depicts a centralised power supply cabinet with an integral standby DC generator.

8.0 Status Monitoring

The status monitoring of the battery bank and the power supply unit are the keys to trouble free system operation. Adequate monitoring technique can provide the desperately needed advance notice of deterioration of the battery bank and failed control section of the power supply. In an operating environment such as Australia where the ambient temperature can at times exceed the 40 degrees C, it is important to correctly gauge the deterioration in battery capacity well before they are required to replace the utility main as the provider of energy to maintain the operation of the network. The combined power system and battery status monitoring have been in use in the past. The normally high ambient temperature of the Australian environment has been instrumental in developing a highly practical "chimney effect" in the design of the pole mounted cabinet as well as the extra care and attention to the temperature compensation of the battery charging. Remote monitoring (via modem) of the individual battery units, as well as, the standby FPS via the parallel communication port has proven to be highly beneficial in efficiently monitoring the status of a complete pole mounted unit.
A typical arrangement used for remote monitoring of the power supply and battery status is shown in figure 11.

9.0 Conclusion

The future development of the HFC network is guaranteed for many industrial and emerging countries as perhaps the only means of combating the raging demands for the new telecommunication services such as voice, data, video and other interactive services. The experience in Australia has conclusively erased any fear on the technical and commercial feasibility of a large scale integrated HFC network providing lifeline telephony. The powering architecture is however difficult to predict. Distributed arrangement has been successfully implemented in Australia and there are other upcoming projects in the pacific region in which a large scale system are underway. The economic sense of the HFC network has certainly been an important factor for prospective operators.

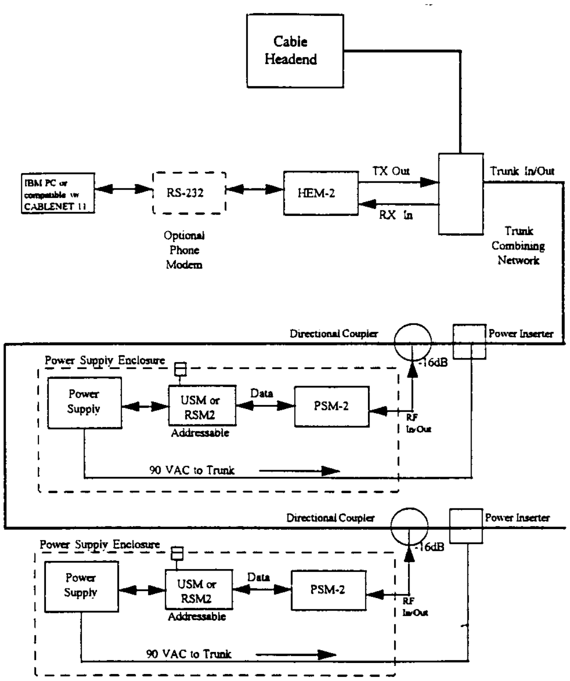

Fig 11. Status monitoring arrangement

Acknowledgments

The author wishes to thank Freydoun Mekanik and Dr. Tom Sloane for their assistance with this article.

References:

[1] F. Kaiser, T. Osterman, "Broadband network powering issues", Proceedings of International Telecommunications Energy Conference, *1996*, pp. 15 to 18.

[2] D. Kuhn, E. Lo, T. Robbins, "Powering issues in an optical fiber access network", Proceedings of International Telecommunication Energy Conference, 1991, pp. 51-58.

[3] N. Dalarsson, "A recommendation for centralized powering of local network elements" Proceeding of International Telecommunication Energy Conference 1996, pp. 367-375.

[4] T. Osterman "Improving power supply efficiency", Proceeding of 1987 NCTA, 1987, pp48-53.

[5] Alpha Technologies, Inc. "Dethroning the sine wave", Proceeding of PCI, April 1984.

[6] D.Sorenson, T. Osterman, "Powering stability and loading in a modem communications network", Communications Technology Magazine, June 1994, pp. 112-127.

[7] D. Johnson "Powering for reliability", Proceedings of SCTE cable -Tec Expo, June 1997, pp. 219-222.

[8] F. Kaiser, T Osterman. "Moving with times" CED magazine, June 1992.

[9] T. Sloane, F. Mekanik, "Effect of line failure phase angle in ferroresonant UPS", Proceeding of APEC, 1996, pp716-721.

[10] K. Mistry and T. Taylor, "Hybrid fiber/coaxial systems powering issues" Proceedings of International Telecommunications Energy Conference, 1994, pp. 75 to 82.

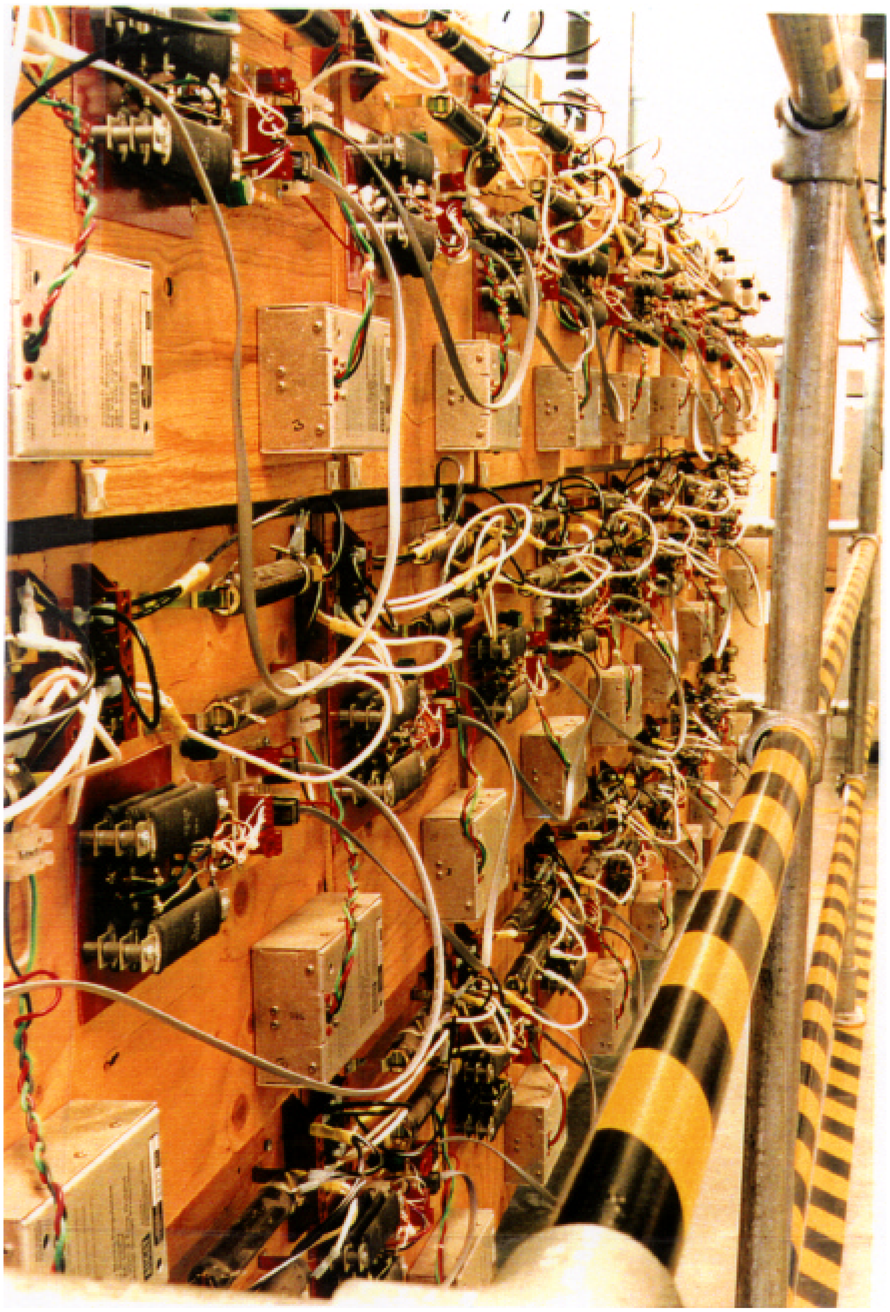

Photo 1 The cascaded SMPS used for cable load simulation

Photo 2 Pole mounted distributed standby power supply

Photo 3 Ground mounted centralised powering systemwith integrated DC generator