APPLICATION OF FERRORESONANT TECHNOLOGY IN HYBRID FIBER COAXIAL ARCHITECTURE

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Abstract
The successful implementation of large scale Hybrid Fiber/Coax (**HFC**) network in Australia and more recently in other Pacific Rim countries has given the system architectures the necessary confidence for the future projects The powering requirement has for so long been the discouraging factor in development of the HFC network.

The delivery of uninterrupted AC power to the fiber node and the line amplifier in order to support a "life line" telephony service can now be considered resolved.

1.0 Introduction

The worldwide demand for the networks offering high bandwidth transmission of voice, video, data, and internet access is increasing faster than ever. The logical and the most cost effective method for implementing such system is the HFC network. The increasing demand for access to such services, has put a new emphasis on power demand and reliability. The ease of implementation as well as the commercial advantages of HFC in the developed and developing countries alike, has been well proven to be the case. Operators of the existing narrowband twisted pair access network are seriously considering the move towards the HFC architecture to take advantage of the new technologies.

The aim of this paper is to outline some of the major design and application considerations for powering such a system, as experienced by some of the pioneers in this field.

The operating voltages such as very low frequency (1 Hz), 3 phases UPS, centralised and distributed 30, 45, 60, 72 and 90 V AC have been in use for sometime. The merits of utilising any of the above option are covered elsewhere[1,2,3]. However, The most favoured options for powering, in majority of modern Cable TV (**CTV**) and HFC network are the 90 and 60 V quasi square wave AC via a distributed or recently the centralised powering option.

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

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

These and other benefits have persuaded the operators to move away from the traditional 60 volt and take up the 90 Volt option.

2.0 Why Ferroresonant?

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.

The ferroresonant transformer has been in existence for about half a century. It benefits from highly desirable, reliability and line conditioning features. Considering the very hostile operating environment in which they are operated, this is the major element, contributing to its popularity.

A typical coaxial "tree and branch" architecture for a distributed powering system is illustrated below:

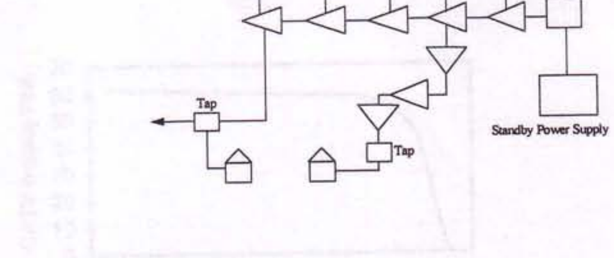

Fig 1: Tree and branch coaxial architecture

3.0 Ferroresonant Power Supply

A ferroresonant transformer differs from a regular linear power transformer in many respects. The most desirable of which is the two components magnetic aspects of it.

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.

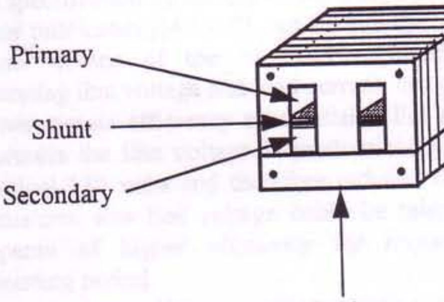

Fig 3. Construction of EI laminated ferroresonant transformer

The transformer is constructed from a specially designed magnetic lamination core with separate windows for the primary and secondary coils. Unlike the linear transformer, the ferroresonant transformer 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

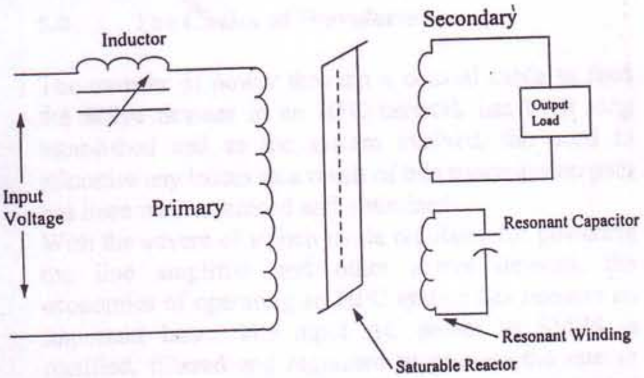

Fig 2: Simplified equivalent circuit of a ferroresonant transformer

In general, the Ferroresonant Power Supply **(FPS)** can be considered as an LC low pass filter, with a corner 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. In other word, it is a combination of a voltage regulator and an electrical noise filter.

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 (an 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 unit 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 ruggedness, 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 permanently connected and is expected to operate.

Another exciting feature of an FPS is the "output foldback" characteristics. Figure 4 illustrates the foldback characteristic of a typical 15 Amp FPS. This highly desirable and unique property, limit's the fault current by reducing the transformer output voltage once the network demand exceeds the designed limit (normally 150% of the nominal operating current) and hence protects the power supply as well as the coaxial cable and all other equipment connected downstream from it.

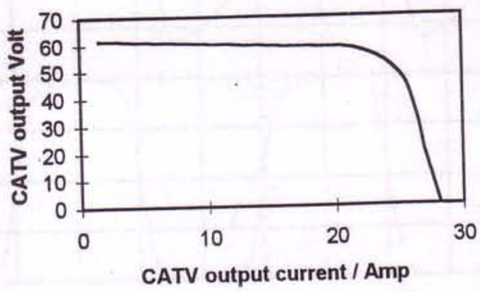

Fig 4. Foldback characteristics of a typical 15 amp FPS

4.0 FPS and Its Future

Considering the information provided so far the FPS appears to be a natural choice for powering the CTV and HFC plants. The main disadvantage of the FPS is its efficiency at light loads, compared to that of a Switch Mode Power Supply **(SMPS)**. 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 that 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 for majority of the operating period.

The prime considerations for powering of the HFC network are the availability, reliability and maintainability. 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 modern SMPS, used for powering traditional telephone exchange centres in a highly controlled environment (air conditioned), do not appear to have the same level of reliability

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 minimise any losses as a result of this transmission path has been well examined and optimised.

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 an important issue. 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.

Modern SMPS employed in the line amplifiers are highly efficient (> 90%) and utilise 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 kilometre of coaxial cable can vary from 0.5 to 3 Ohms/Km. An amplifier at the end of the coaxial cable draws more current in order to compensate for the lower input voltage.

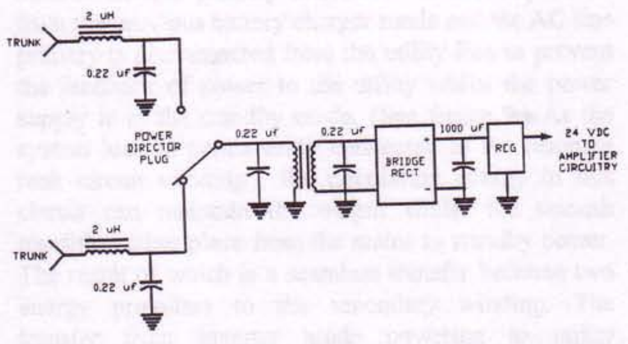

Fig 5. Typical internal AC/DC power converter in trunk amplifier power supply

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

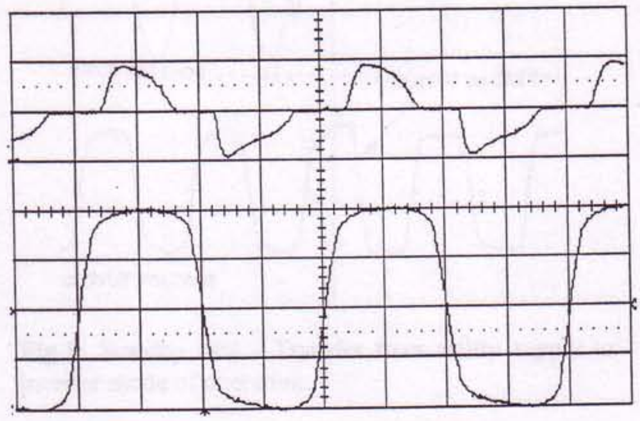

Fig 6. Current and voltage waveform for a 2.5 A load. (Scale: Current 5 A/div, Voltage 50 V/div)

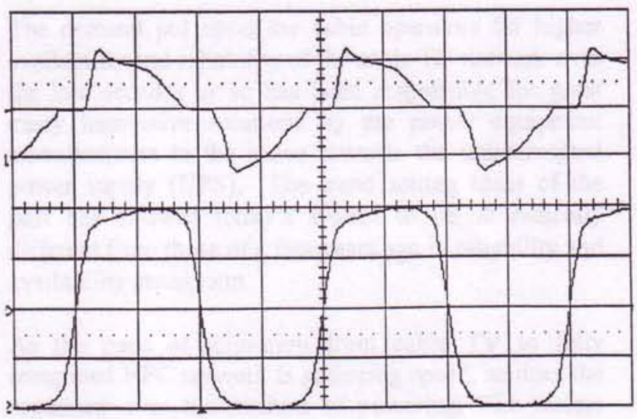

Fig 7. Current and voltage waveform for a 7.5 A load. (Scale: Current 10 A/div, Voltage 50 V/div)

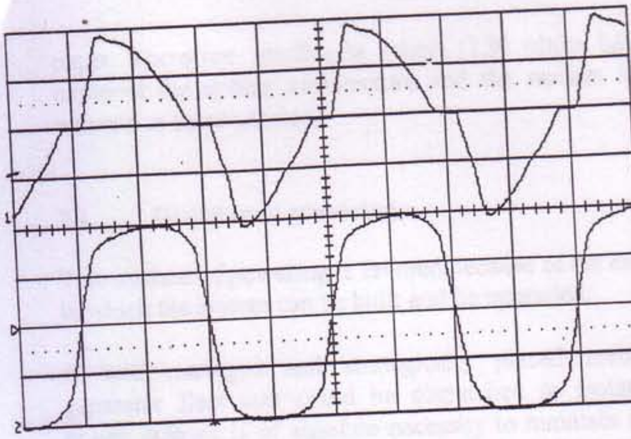

Fig 8. Current and voltage waveform for a 16.4 A load. (Scale: Current 20 A/div, Voltage 50 V/div)

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 utilised 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[5]. 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. Transitory 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.

To maintain the integrity of a life line telephony service the avoidance of any interruption is critical. To accommodate such interruptions, 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 maintained 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. The transfer from inverter mode powering to utility powering occurs with no noticeable transient at the output voltage waveshape.

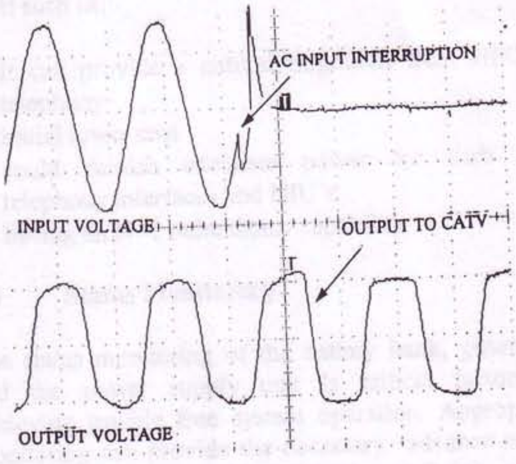

Fig 9. Standby FPS - Transfer from utility supply to inverter mode of operation.

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 uninterrupted power supply (UPS). 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 standpoint.

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 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 [1,9] whom have explored the system architecture and the readers are referred to these articles.

7.1 Distributed powering

This method of powering is favored because of the ease in which the system can be built and be upgraded.

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 which is fed from a reasonably inexpensive alternator from the maintenance vehicle 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 by Optus vision 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, not only during the planned or unplanned outages, but also for powering the test and instruments equipment throughout the life of 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 unit
- almost zero noise pollution.
- elimination of 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 small fleet of maintenance vehicles. Other advantages could be the ability of the vehicle to be re-fueled, 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 supply of external DC power directly across the pole mounted battery bank and allow the inverter mode of operation by 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 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 lower idle speed and hence fuel economy under low load condition
The response time to a catastrophic failure such as 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 operator.
The key advantages of centralized powering is its unlimited capacity, reduced number of service and maintenance centers. ease of remote monitoring and on line diagnostic capability.

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 merit 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+1 redundancy capability

8.0 Status Monitoring

The status monitoring of the battery bank, generator, and the power supply unit is critical factors in achieving trouble free system operation. Appropriate monitoring can provide the necessary 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.
A typical arrangement used for remote monitoring of the power supply and battery status is shown in figure 10.

9.0 Conclusion

The future development of the HFC network makes sense for any developed and developing 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 relative ease in which an HFC network can become a reality and in a revenue earning stage, from the