IMPROVING POWER SUPPLY EFFICIENCY

Tom S. Osterman

ALPHA TECHNOLOGIES INC.

ABSTRACT

Power supply efficiency has become very important to all CATV system operators as electrical power rates continue to rise. Efficiency can be improved in several different areas of a plant powering system. Even a 2 to 3 percent increase in efficiency can add up to a surprising cost savings over time.

INTRODUCTION

New developments in CATV technology have brought increased capabilities and transmission quality at the expense of increased power consumption. As cable systems become more "power hungry", system designers have focused more attention on powering efficiency. Efficiency has to be considered carefully in new plant design as well as system rebuilds. This paper will suggest some ways to improve the efficiency of the typical CATV powering system.

AC POWER SUPPLIES

By far the majority of North American CATV systems use AC power supplies that provide conditioned and regulated 60 volt ac power to the active devices in the system. Most of these power supplies are based on the "Ferroresonant" power transformer topology. The Ferroresonant transformer design has been around for over 40 years and has proven to be extremely reliable as well as providing other important advantages.

A ferroresonant transformer differs from a regular linear power transformer in many ways. First of all, a ferroresonant transformer is a two component magnetic regulator.

It consists of a specially designed lamination core with separate windows for the primary and secondary coils. Unlike a linear transformer, a 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. (See fig. 1.)

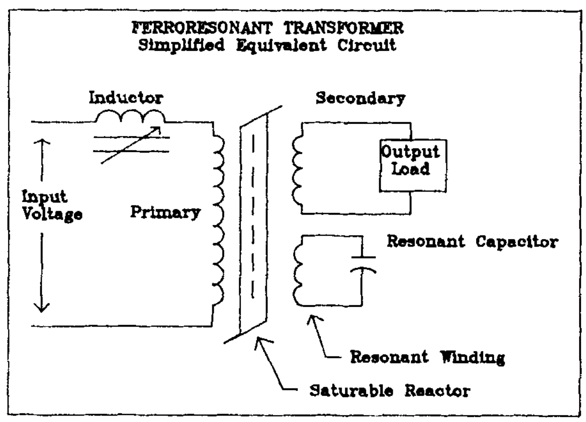

FIG. 1

A ferroresonant transformer can be easily understood as an LC low pass filter with a corner just above the line frequency (60 hz) followed by a roll off of 40 dB per decade.

In typical operation, voltage present at the primary will excite the main magnetic flux path which in turn excites the secondary winding which is tuned by the resonant capacitor (usually several microfarads). As the secondary goes into resonance high circulating currents flow in the resonant tank circuit which drive the main flux path into saturation. Once the core is in saturation, normal voltage fluctuations at the primary will not pass through and increase the secondary voltage. Any decrease in primary voltage will not affect the secondary voltage as long as the core remains in saturation. This transformer once it is saturated will provide line regulation over a wide range of input voltage, (usually 80 to 140 VAC).

Load regulation is provided by the use of a shunt magnetic path which has air gaps between it and the main magnetic path which is operating in saturation. The air gaps limit the flux in the shunt path preventing saturation in the shunt portion of the magnetic circuit providing a good linear response. If the output load current in the secondary is increased, the resonant circuit "Q" drops and the circulating currents will then decrease. The shunt flux also will decrease allowing an increase in the main magnetic flux path, that in turn transfers more energy from primary to secondary thus compensating for the increase in the secondary load current. This provides load regulation.

The transformer regulation can be improved by using a "compensation coil", otherwise known as a "buck" winding. This is a part of the primary winding that is physically wound on the secondary to aid in regulation. This design is not optimal for CATV systems because it compromizes the isolation and noise attenuation capabilities of the transformer.

Most ferroresonant transformers can withstand a dead short on the secondary for an extended time without damage due to the foldback characteristics of the shunt circuit. (see Fig. 2.)

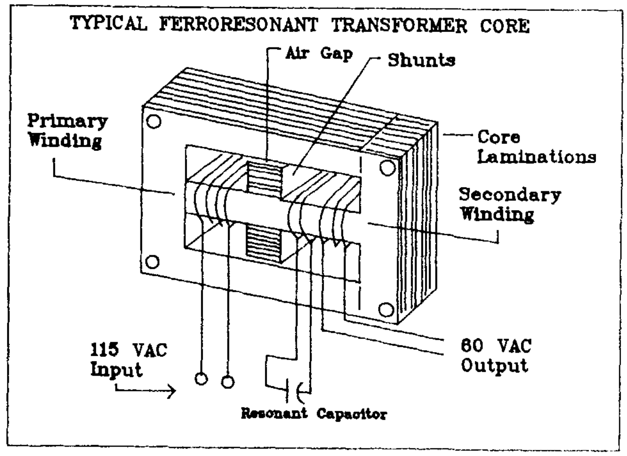

FIG. 2

It is important to note that the output waveform of a ferroresonant transformer is clipped, it is often described as a "Quasi-square wave". This wave shape is caused by the transformer core saturation and is desirable for CATV systems because of its lower peak voltage which is easier to rectify and filter in the Dc power supplies in trunk stations and other active devices. This output wave shape can be corrected by an additional winding on the transformer which is appropriately called a "correction coil". The output can be corrected with this winding to become a sine wave with low distortion if desired, but is rarely used in CATV plant powering.

The ferroresonant design offers both line and load regulation which provide protection from voltage surges and sags at the primary. The majority of utility power problems are characterized by dropouts or sags caused by momentary line faults, utility switching operations and heavy equipment such as motors and compressors coming on line in close proximity to the CATV AC power supply. A ferroresonant transformer can provide output power for as long as a one cycle dropout (depending on load). This is known as hold-up time which is provided by the energy stored in the resonant tank circuit described previously.

The most important advantage of ferroresonant based power supplies is their outstanding isolation characteristics. The primary and secondary windings are in separate window areas of the core and thus are physically isolated from each other. This minimizes capacitive coupling from primary to secondary and greatly reduces the possibility of voltage spikes and noise being coupled to the secondary and then to the load. It is common in certain parts of the country to see utility powerline transient voltage spikes up to 1,500 volts regularly and spikes up to 5,000 volts occasionally. The ferroresonant transformer does an excellent job at attenuating these spikes and protecting the output load from damage. Typical noise attenuation is 120 dB for common mode noise referenced to ground, and over 60 dB for transverse mode (line to neutral).

NO FREE LUNCHES

The ferroresonant based power supply is a natural for the CATV application, but it does have its disadvantages. As the saying goes "there are no free lunches", you can't get something for nothing. Ferroresonant transformers are not as efficient as linear power transformers. The textbook maximum efficiency for a Ferroresonant is about 94 % but typical designs run as low as 80%. There are two main causes for inefficiency in a ferroresonant transformer; core loss and I^2R drop (otherwise known as copper losses). The losses can be directly related to temperature, as the operating temperature increases, so will the losses. Copper has a positive temperature coefficient, its resistance will increase about .4 % per degree C. Core losses caused by eddy currents will increase over temperature and make up the majority of the loss in the transformer. There is another variable that relates to efficiency and that is the regulation tolerance. A ferroresonant transformer can be designed to meet less than a +/- 1 percent combined line and load regulation specification, but it will be very inefficient due to the large circulating volt-amps in the resonant tank circuit. The tank circuit will have to be running at a high energy level to maintain the tight regulation over line and load changes.

Efficiency will be the best at close to full load and low input line because most of the circulating VA is being delivered to the output load. Efficiency will be worse at nominal or high input line with less than full output load, again, because of the large amount of circulating VA in the tank circuit that is not being used by the load and is subject to core loss and winding resistance losses. This scenario is common in new CATV installations where system designers often load the power supply to 75% capacity worst case. This offers a safety factor and room for future expansion, but it does so at the expense of efficiency (see figure 3.) A ferroresonant transformer will always run more efficient if operated close to its rated full load output current.

FERRORESONANT TRANSFORMER +/- 3% REGULATION
EFFICIENCY VS. OUTPUT LOAD

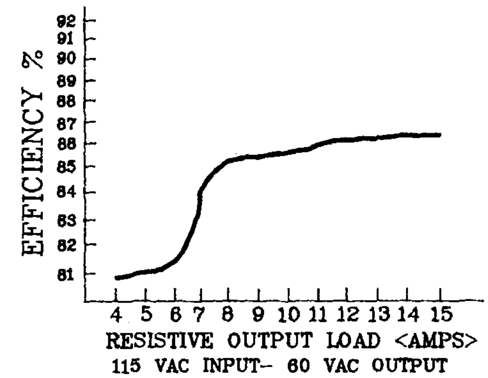

FIG. 3

DC SWITCHING POWER SUPPLIES

There is a relatively new family of DC power supplies known as "switching power supplies". There are several topologies including boost, buck, forward, and flyback converters whose main job is DC to DC conversion, either step up or step down. Switchers offer much higher efficiency than the older linear "series pass" regulators. Some switchers can run up to 98% efficient compared to 40 to 50% for an equivalent linear supply. Switching power supplies are being used in CATV trunk stations and other actives because of the massive gain in efficiency as well as reduction in physical size (watts per square inch) and weight. The switching power supplies in the full featured trunk stations offered by the major manufacturers have efficiencies close to 90% and more importantly, have an input line regulation tolerance of up to +/-30% ! Their variable duty cycle design offers this wide line regulation range while maintaining very high efficiency.

This takes us back to the ferroresonant AC power supplies, why maintain +/- 3% output regulation (which is the typical specification) when the active devices to be powered by the AC supply can accept up to a +/- 30% variation in input voltage ?

It can be argued that I^2R drops in the cable spans between power supplies can eat up some of the power so that a lower voltage is presented to each Active further down the span. But with systems using 450 MHz, the trunk amplifiers are closer together and are linked by larger cable which has lower 60 hz loop resistance, so that the 60 VAC I^2R drop is lower from the power supplies to the loads.

If the regulation specifications for the AC power supplies were relaxed to a plus or minus five percent or even a plus or minus 7 percent, transformers could be designed with less energy in the tank circuit and thus higher overall operating efficiency (see figure 4.) This could mean an increase in efficiency of up to 7 percent for some power supplies.

This wider regulation tolerance would not cause any ill effect to the DC power supplies in the active devices in the system and would provide increased efficiency.

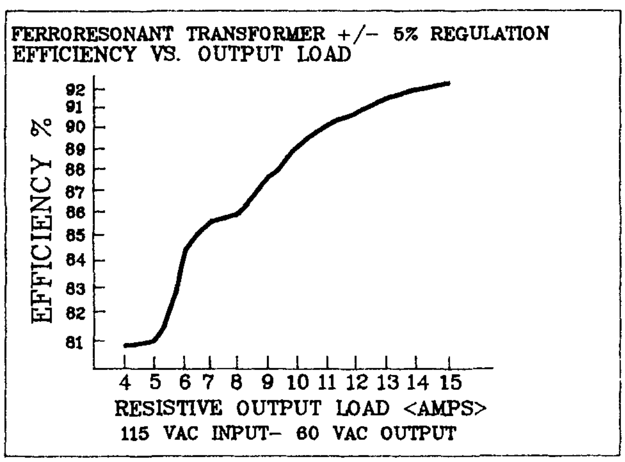

FIG. 4

If a reduction of 7 percent power consumption was multiplied by the number of power supplies in the system, multiplied by the Kilowatt Hour rate that is being charged by the local utility. It will become obvious the magnitude of cost savings that is possible. This can be achieved by using the Ferroresonant transformer power supply primarily for its extremely effective protection against transients, utility line noise, dropouts, lightning strikes and as a pre-regulator for the DC power supplies in the Active devices in the CATV plant.

The other obvious advantage to the Ferroresonant AC power supply is the battery back-up standby mode for protection from complete utility power outages. The ferroresonant transformer uses hold-up time as mentioned earlier, to cover the brief interruption in power as the power supply transfers in phase from utility power to battery backed inverter mode. This is so effective that the load sees no interruption in the AC waveform during transfer in either direction. The transformer will also regulate the change in battery voltage as presented to the AC inverter stage from high battery to low battery while maintaining a steady AC output voltage. With the wider regulation tolerance implemented, the transformer efficiency would be higher and thus the standby time would be longer for the same battery pack.

RELATED TOPICS

It is important to note that the load power factor can influence the regulation characteristics of a ferroresonant transformer. Switching power supplies look like a partially capacitive load to any AC power supply. This is due to the large DC filter capacitor after the input rectifier in the switcher. There is also a complex relationship with the effect of the DC output filter capacitor as the switching duty cycle changes with fluctuations in AC input voltage and output load variations.

This makes for a complex load to model accurately. As the load power factor in some systems could approach .7 P.F. (leading) due to the load capacitance. The effect this has on a Ferroresonant power supply is to effectively add the load capacitance in parallel with the resonant tank circuit capacitance, which will de-tune the tank slightly. This will increase the output voltage by a certain amount depending on the actual load power power factor. If the transformer was loaded to the other extreme with a .7 P.F. inductive load (lagging), the tank circuit would be de-tuned in the other direction producing a drop in output voltage.

Thus it is important to remember that in testing a Ferroresonant AC power supply, a purely resistive load or a load using incandescent light bulbs is not necessarily an accurate simulation of the characteristics of the real world loading in the cable plant. Some power supply manufacturers are aware of this phenomenon and design their transformers accordingly.

Another possible way to improve powering efficiency in a CATV system, is to use solid copper center conductor trunk cable instead of the more popular copper clad center conductor cable. It is possible to reduce the cable loop resistance by at least 20%, and this would reduce the I^2R loss in the cable between the power supplies and the loads. A plant designer would have to evaluate the estimated power savings over a certain amortization period versus the initial extra cost of the solid copper center conductor cable.

A related topic to the discussion of efficiency, is the issue of utility billing for CATV plant power usage. The method used varies with each utility and CATV company. Some systems are billed by the nameplate rating of the power supply. It is important to measure the true power in watts that is being used by the input of the power supply as it operates in the field. This will take into account the actual loading of each supply including losses. If XYZ power Co. reads the nameplate output rating of the power supply as 14 amps and then multiplies that by 115 volts supplied to the power supply input, they would charge the cable system operator for 1,610 VA or 1.61 KWH multiplied by 24 hours for a daily consumption of 38.64 Kilowatt hours multiplied by the going rate of, lets say $.15 per KWH. That power supply would cost the CATV operator $5.79 a day to operate.

This example assumes the mistaken conclusion that the power supply is actually fully loaded to the 14 amp rating (are most power supplies in the system fully loaded ?) XYZ Power co. also made an error in figuring the true power usage of the supply. It should be calculated as 14 amps output load multiplied by the output voltage of 60 VAC which is 840 VA output load. Next calculate the power lost due to the inefficiency of the power supply. Assuming, for the sake of example, the power supply was only 84% efficient. 840 VA divided by .84 equals 1,000 VA, This is 1 kilowatt hour. Next multiply by 24 hours to arrive at 24 Kilowatt hours per day. This is the true power usage of the supply per day. To calculate the operating cost, the system operator must multiply the total daily usage by the cost per kilowatt hour charged by the local utility. For example, $.15 per kilowatt hour. This KWH cost multiplied by the 24 KWH per day consumption rate equals the true power supply operating cost of $3.60 per day!

I suggest the use of a clamp-on True Rms wattmeter to measure the input power of each power supply in the system to get an accurate indication of the real power consumption of the system. Instead of the power supply nameplate ratings. Then compare the measured consumption with what you are being billed for by the utility. Some cable systems get billed at a very low commercial rate, in which case measuring each power supply might not be worth the effort. If the system is measured and there is a substantial over billing by the Utility, A system operator might want to consider installing metering at each power supply to ensure a fair billing representing the true power usage of the system. The potential cost savings could pay for the cost of installing the meter hardware in a few months, after which there would be a noticeable reduction in operating costs.

SUMMARY

Efficiency is important to CATV system operators because of the direct relationship to operating costs. Even small improvements made in the system to gain power efficiency can amount to a substantial savings over time, depending on the total system power consumption and the cost of electricity.

A relaxation of Ferroresonant power supply regulation specifications, solid copper center conductor cable, switching power supplies in active devices, and accurate power consumption measurement by the utility are all possible ways to reduce operating costs for a CATV system.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the following people for their contribution to this paper.

Jeff Geer, Alpha Technologies Inc.

Howard Bobry P.E. Independent Consultant

Merv Eaton, Albar Inc.