Longitudinal Sheath Current(s) in CATV Systems

Summary of Issues

Longitudinal sheath current describes the condition in a CATV plant where AC currents are flowing on the cable sheath which are created by voltage potentials outside the self-regulating cable system main AC power supply. These external currents occur because of the shared path with the power company ground neutral system. Any load imbalance in the power company primary and secondary systems will result in some amount of current flowing [back] through their neutral system. Because we bond with this grounded neutral system, our strand and sheath share a portion of that current to the extent of the ratio of the overall impedance of ours to theirs.

Effects of this sharing of the neutral imbalance current are somewhat misunderstood in cable technical circles. The purpose of this technical bulletin is to begin the process of a better understanding of issues and causes, the effect of said imbalance currents flowing in our system(s), and some recommended testing procedures and remedial actions.

Creation of Longitudinal Sheath Currents

Cable systems are required to periodically bond to the power company grounded neutral conductor system because of the National Electrical Safety Code (NESC), which describes recommended safety and construction procedures published by the IEEE. Bonding requirements of 4 per mile, as per the NESC, stem from safety procedures and requirements for utility workers. One obvious effect of said bonding is that, because we construct a more or less parallel *conducting* plant to their neutral system, we share in carrying a portion of their load imbalance current or any other power company transients in our system.

In theory, there are actually two types of LSC's induced into the CATV system. The first is the much discussed transient or surge current. It is normally fairly large in magnitude and short in duration - generally less than one second. These short duration surge currents are caused by lightning, residential load switching, and other power company problems such as arcing, faults, etc.

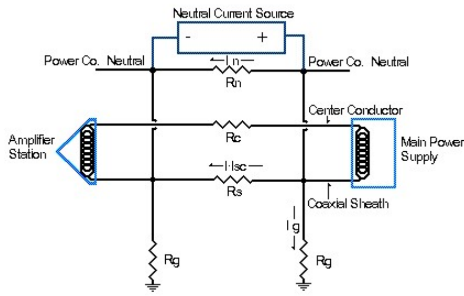
The second, and of more general concern for this report, is the long term LSC caused by *load imbalance currents* flowing in the neutral system. These are generally lower in magnitude, but longer in duration - often for minutes or even hours. These sources of neutral currents are generally caused by unbalanced loading in local areas of the *three-phase power system*, in *single-phase 100 ampere spurs and branch circuits*, and by the improper loading of *single-phase 220 volt distribution transformer circuits*.

Any neutral currents; whether due to short duration transients, system faults, switching transients, or unbalanced loads; will flow in part through the cable system coaxial sheath(s) when the system is properly bonded. If the outer conductor of the cable were a perfect conductor with zero skin-depth at all frequencies, cable shielding would be perfect as well. That is not the case, however, and any current flowing through the sheath will cause a subsequent voltage drop, which in turn couples to the electro-static and magnetic fields within the cable. **Longitudinal sheath currents therefore create *longitudinal voltage drops*,** which then cause additional voltages spread across the coaxial cable system. The interaction of these induced waveforms with those of the normal CATV quasi-square wave supply are quite complex, with vector-value peak voltages commonly exceeding 2 to 3 times the nominal voltage. Actual voltage addition at the supply is complex and often difficult to quantify.

The *magnitude* of the voltage transferred is dependent on the:

- Magnitude of the [imbalance] current
- Cable inductance, capacitance, and conductance properties
- Cable termination characteristics

The following figure illustrates the basic LSC introduction mechanism:



Additional System Voltages
Caused by LSC

Any neutral current source will cause current to flow. This total neutral current will divide between the neutral conductor current (I-n), cable sheath current (I-lsc), and current through the ground system (I-g). I-lsc causes a voltage drop in the affected spans of cable, and since it adds vectorially to the output of the systems constant voltage transformer, will cause the amplifier station voltage to become higher (or sometimes lower) than expected. This current will generally vary considerably with fluctuations in power company loads. Further, the LSC voltage added at an amplifier station will be the same - no matter what the CATV supply source voltage! Therefore, the higher the cable supply voltage, the less *percentage change* at the amplifier. Typical values measured in previously published industry papers on LSC's range from 10 to 20% over-voltage at 60v, with 20 to 40% over-voltage at 30v. Percentages at higher supply voltages could be easily calculated as well.

Power companies are not overly concerned with high neutral currents lasting several seconds, and consider any neutral current "normal" - *if it is self correcting*. Total neutral currents of 100 to 300 amperes are not uncommon, with less than 100 a norm for many areas. Calculations on percent carriage (neutral conductor, CATV sheath, and ground path) performed recently by Warner Cable and Cable Labs demonstrate that the *percentage* of these "normal neutral" currents carried by the cable system may be anywhere from 20 to 75%! The percentage carried by the cable plant will vary according to several parameters including the number of grounds per mile and their effectiveness, the size of the neutral conductor, and size and number of CATV coaxial cables (combined sheath resistance).

Calculations on induced voltages from LSC's are now shown in the following table. Basic model assumptions are 2000 feet of cable between amplifiers, a *single* .750" cable lashed to strand, series pass regulators in power packs (worst case), and all complex voltages add in-phase (worst case). Amps one, two and three are in cascade from the main AC power supply. The final two columns, with LSC's of 300 and 1000 amperes respectively, represent transient conditions in the plant. The more complex out-of-phase LSC conditions are not examined in this report.

Calculated LSC Voltages

Power Supply (volts)	**60**	**60**	**60**	**60**	**60**	**60**	**60**
Amp 1 current draw (amps)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Amp 2 current draw (amps)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Amp 3 current draw (amps)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Sheath Resistance/Amp (ohms)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
C.C. Resistance/Amp (ohms)	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Longitudinal Sheath Current (amps)	**10**	**20**	**30**	**40**	**50**	**300**	**1000**
Ist Amplifier:Expected (volts)	57.75	57.75	57.75	57.75	57.75	57.75	57.75
Ist Amplifier:In-phase LSC (volts)	60.75	63.75	66.75	69.75	72.75	147.75	357.75
2nd Amplifier:Expected (volts)	56.25	56.25	56.25	56.25	56.25	56.25	56.25
2nd Amplifier:In-phase LSC (volts)	62.25	68.25	74.25	80.25	86.25	236.25	656.25
3rd Amplifier:Expected (volts)	55.50	55.50	55.50	55.50	55.50	55.50	55.50
3rd Amplifier:In-phase LSC (volts)	64.50	73.50	82.50	91.50	100.50	325.50	955.50

As can be seen by the above table, even small values of LSC can yield an "increasing voltage condition" when conditions are correct. Under high LSC values, voltages which could easily trigger or fire a transient protective device.

Several additional points are now in order. **Technically, grounding does not cause LSC's, but rather the bonding process alone**. And while this is empirically true, additional grounds placed by the cable operator may, in some instances, aggravate the LSC process. Therefore, the placement of extra grounds beyond the bonding process should be done judiciously. The general flow for these issues goes something like:

- Bonds **must be** placed between the CATV plant, and the parallel grounded-wye neutral system employed by almost all electrical utilities, per NESC requirements.....
- Once placed, the parallel CATV conductive plant shares in carrying a portion of the(ir) steady & non-steady state load imbalance current.....
- The overall impedance of the ground path needed by the cable system for adequate dissipation of transient energy including lightning strikes, may not be adequate through that achieved by the bonding process alone.....
- In instances where additional grounding is needed, the first and best option should be to work with the utility company to see if (their) grounding at specific bonding locations can be improved. In instances where grounding cannot be improved to adequate levels, additional grounds should be placed by the CATV operator.....
- Care should be taken when placing additional ground paths in the cable plant, since LSC's could theoretically be <u>increased</u> by this process. It should be noted that those situations are generally rare, with LSC's typically reduced in most instances as additional grounds are placed.
- Any improvement in ground potential at bonding locations reduces current through the neutral conductor <u>and</u> cable sheath(s).

In the final analysis, the ultimate question still remains "How much grounding is enough?" I believe the optimal solution is probably to represent methods for the cable operator to test for the presence of LSC's. When determined to exist, institute specific bonding/grounding or other procedures to reduce or eliminate the problem.

<u>Effects of Longitudinal Sheath Currents in the Cable Plant</u>
The following general problems are experienced in the CATV plant when LSC's are present:

- Sheath currents cause electrolysis and rectification in cable plants as dissimilar metal contacts develop. Beyond plant physical degradation, this can also cause unusual plant problems which are exhibited as both RF and AC symptoms.
- Immediate equipment failures are experienced as rapid-rise-time over-voltage conditions [transients] are coupled to the system through the parallel neutral system path.
- Long term failures of power packs are experienced due to excessive over-voltages at transformers, rectifiers and regulator circuitry.
- Burned amplifier traces and other components may result when protective devices fire in the presence of excessive LSC's.

In a more specific examination, an overall impact of LSC's on <u>amplifier</u> <u>power</u> <u>packs</u> is in order - since it's the most likely area you'll feel its effects:

- Power packs further from the main supply are the most likely to fail. Induced voltages from LSC's are often additive, and increase as one moves away from the AC supply.
- Remaining 30 VAC systems will find that LSC's present a more significant long term threat for power pack operation and subsequent failure.
- Switch-mode power packs will experience (and measure) higher **over-voltage** conditions than series-pass, given the same layout and system conditions.
- Series-pass power packs will attempt to internally dissipate the higher voltages present from LSC's. They are therefore more susceptible to overheating and premature failure than switch-mode, as the switch-mode adjusts the switching waveform and better compensates for the over-voltage condition.
- Although one naturally expects the system voltage to drop as one moves away from the main supply towards remote amplifiers, it does not take much LSC to reverse this trend - as demonstrated by the data calculations in Table One.
- If the LSC is in <u>opposite</u> <u>phase</u> to the voltage from the main supply, it can also (drastically) reduce the voltage at an amplifier station. The power pack, under some conditions, can drop out of regulation producing hum; and the amplification stages are left operating with low [DC] voltage which can produce excessive noise and non-linear distortions into the signals.
- In some instances, the system may actually oscillate between over and under-voltage conditions i.e., vary between additive and subtractive conditions!
- Since the sheath current contributes to the voltage across the amplifier station, the power output of the main power supply may not balance with actual power consumption of the CATV system amplifiers, creating a power *imbalance* in the cable system. Precise system effects from this situation are beyond the scope of this report.

<u>Recommended Solutions</u>

• Poor grounds through power company bonds <u>escalate</u> the situation. Referring back to Diagram #1, it can be readily seen that as the value of Rg increases, the percentage current carried by the other two paths must increase as well. It therefore behooves the operator to ensure good power company grounds at bonding locations. If poor grounds through bonding are found to exist, two options follow:

- Through mutual efforts with the power utility, seek to improve their grounds.
- Place new grounds in the cable plant, which would then be bonded to the power grounded neutral per NESC requirements, thus improving the value of their overall ground system as well.

The first method is the preferred approach. In many systems, the percentage of imbalance current actually carried by the ground system is very low, often on the order of 10% or less! An analysis of typical amp spacings, cable loop resistances, neutral conductors and ground paths suggests that "the parallel combination of grounds must be no higher than 20Ω -- for 10% of the neutral current to be drained through the ground path"! Assuming this parallel combination of 20Ω is attainable *at best* under typical power company conditions, the remaining 90% current flow will be carried by the neutral conductor and cable sheath - a significant value indeed. This helps to explain the problems often encountered in cable system operation under the presence of excessive LSC's. **It remains, however, that *any improvement* in the overall value of the grounding system, other factors remaining constant, will increase ground current and decrease neutral conductor and CATV sheath currents**.

- Utilize equipment which has rugged power traces and other components needed to withstand excessive LSC conditions.

- Utilize crowbar circuits in areas and equipment where LSC's are known to be a problem. The crowbar will fire, conducting LSC induced voltages to ground before damage occurs in most instances. It should be noted, as above, that excessive currents likely exist where LSC induced voltages accumulate to the crowbar firing point. Amp traces and other components must be rugged enough to survive subsequent currents that flow or equipment damage often results with the protective firing.

- Convert remaining 30 VAC systems to 60 VAC as soon as possible. Both calculations included in this report, and past experience in 30 VAC systems bears out the fact that LSC damage will be far more significant and consistent in a 30 VAC system. Remaining 30 VAC systems should be converted to 60 VAC as soon as budgetary conditions permit.

LSC conditions specific to a fully jacketed plant, including underground, present differing challenges and are not considered here. Bonding and grounding methods often must be altered when LSC conditions are found to exist in this environment.

Some equipment modifications may be necessary, where present line equipment is found to be inadequate in surviving excessive LSC conditions. Equipment AC paths must be able to handle conditions which exist when crowbar or other protective devices fire in the presence of excessive LSC's.

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