Fusing in Modern HFC Network for Improved Network Availability

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Abstract

Fusing or protection against over-currents in the cable TV coaxial distribution network is an area in which many misconceptions found a way into coaxial plant powering design. The origins of these misconceptions are numerous, but most of them can be traced to the interpretation of the rules of fusing in the power plant and power installations. A direct implementation of these rules results in lower reliability of the network without meeting the objectives of equipment and personnel protection, and fault isolation.

This paper presents the fusing analysis from the point of view of the two primary objectives of fusing:
1. to protect components and equipment from costly damage caused by over-currents; and
2. to isolate a faulty part of the network from the remainder of the network once the fault has occurred.

These two direct objectives are subordinate to the paramount objective of increasing system availability through:

1. *improved or at least maintained current reliability of the network, and*
2. *reduced repair time.*

The first decision during the fusing design is whether a fuse is required in a particular location and whether it can meet the objectives of fusing. If the answer to these questions is positive, the following criteria will decide about type, value, and other parameters of the fuse selected:

- *Maximum operating load current,*
- *Ambient temperature,*
- *Aging,*
- *Operating voltage,*
- *Frequency of the powering voltage,*
- *In-rush characteristics of the network, surge currents, etc.,*
- *Available maximum fault current,*
- *I^2t characteristics of the devices to be protected,*
- *Allowed voltage drop across fuse,*
- *Applicable standard agency,*
- *Ergonomics,*
- *Humidity, and*
- *Standardization.*

The paper analyzes all these parameters and presents a detailed fusing design for HFC networks, supported by the up-to-date principles of fuseology. Finally, it presents an example of fusing design in modern HFC networks.

INTRODUCTION

A hybrid fiber-coaxial (HFC) network consists of active and passive elements. To distribute RF signals, the network elements must also distribute low frequency energy to the active components. Moreover, the network operates in an environment that generates unwanted low frequency energy. This unwanted energy causes electrical stresses such as voltage transients and current surges. These electrical stresses and additional mechanical factors can lead to overcurrents. Therefore, most of the HFC networks include a low-frequency system comprising of:

- energy supply system (powering)[1];
- transient and surge protection elements (surge arrestors, amp clamps, grounding, etc.);
- safety elements (grounding, isolators); and
- overcurrent protection.

All these elements have specific characteristics to meet the following objectives:

1. provide for high level of service availability[2], and
2. ensure public safety.

The overcurrent protection system serves to meet the first one by providing

- improved reliability of the network, and
- reduced repair time.

Despite the importance of this system, its design was usually neglected by engineers designing the powering system. This void was filled up by front-line crew with a trail-and-error approach. The paper tries to remedy this situation by presenting a more rigorous approach to the design of the overcurrent protection system.

To protect the network against overcurrents, the elements of the protection system must react first to excessive currents. Hence, by definition, they are the weakest links of the network. This characteristic alone can lead to a dramatic degradation of network reliability if the overcurrent protection devices are not appropriate or the entire system is not designed properly. The best solution would be to avoid these devices altogether. Unfortunately, we somehow need to protect equipment against overcurrents and to isolate failures to minimize failure groups and speed up troubleshooting efforts.

Objectives of Fusing in HFC Network

The two primary objectives of fusing are:

1. to protect components and equipment from costly damage caused by overcurrents; and
2. to lower failure groups.

These objectives are subordinate to the main goal of improving network availability. Both elements of the availability — reliability and mean time to repair — must be addressed during overcurrent protection design.

To improve network reliability, the number of fuses must be limited to the minimum and they must be selected to minimize nuisance blowing caused by voltage transients, current surges, and temporary cable short condition while still protecting the network elements and isolating power faults. To minimize the amount of time required by a technician to locate a fault, fuse locations and their values must be selected according to rules of selective coordination in order to explicitly isolate faults.

Many system operators are trying to meet the objectives of the overcurrent protection system by using circuit breakers. However, circuit breakers have two characteristics that make their use difficult:

- tripping under overcurrent conditions, and
- high thermal dependency (significantly higher than time-delay fuses).

The first characteristic appears to help avoid nuisance outages but actually leads to increased annoyance of customers with intermittent service. The second characteristic makes it difficult to select elements that meet the inequalities for value selection in most locations that would require overcurrent protection to meet the objectives of the overcurrent protection system. Therefore, at the present status of technology, we considered fusing elements the best choice to meet the overcurrent protection system objectives. This decision was based on theoretical consideration and field experience. When used properly, fusing elements can provide better network performance than circuit breakers.

FUSEOLOGY[34]

There exist general misconceptions about fusing in cable TV coaxial distribution network. The origins of these misconceptions are numerous but most of them can be traced to the interpretation of the rules of fusing in power plant and power installations. A direct implementation of these rules results in lower reliability of the network without meeting the objectives of equipment protection and fault isolation.

Selection Criteria for Fuses

The first decision is related to the location of the fuse. This decision will depend on the answer to a question whether a fuse in the particular location can meet the objectives of fusing. If the answer to this question is positive, the following criteria will decide type, value, and other parameters of the fuse selected (the most important criteria are bolded):

1. Maximum operating load current:

The fuse must have an ability to carry the maximum operating current of the network. This ability can be affected by several factors. One of them is the way the fuse is installed. For example, the material of the fuse holders (clips) must have superior retention (such as beryllium copper) to avoid increase in contact resistance. Moreover, the printed circuit board (PCB) traces or conductor size connecting the fuse to other circuit components must be designed to dissipate heat.

2. Ambient temperature:

Ambient temperature is one of the major factors affecting the fuse rated current. The impact of the temperature will be different for different fuse types. For time-delay fuses, the rated current at

60°C is only 80% of the rated current at 25°C, whereas for fast-acting fuses, the rated current at 60°C is between 95 and 97.5% of the rated current at 25°C.

3. Aging:

Aging of a fuse causes the nominal value of the fuse to decrease due to the effects of the continuous current and overcurrents through it. Overcurrents are currents above the continuous rated current but are either not quite high enough to blow the fuse or are higher than nominal but do not last long enough to blow the fuse. These overcurrents can exist in a fuse for several seconds before a lower-value fuse, closer to the short, finally blows. So aging is a combination of time period for which a fuse operates and overcurrents that blow other fuses first but can affect the fuse in the cascade by reducing its current passing capability.

4. Operating voltage:

Generally, the voltage rating of the fuse must be greater than or equal to the operating voltage. This is critical only when the fuse is trying to open. A fuse must be able to quickly extinguish the arc after the fuse element has melted and prevent the system open-circuit voltage from restriking across the open element and passing energy to the protected element.

5. Frequency of the powering voltage:

For current passing fuses and power pack input fuses, the frequency will be 60 Hz or lower (note trials with 1 Hz or DC powering). Hence, most fuses will be suitable for the application. Fuses on the output of switch mode power packs can be subject to additional heat caused by harmonics of the nominal frequency.

6. In-rush characteristics of the network, surge currents, and maintenance procedures:

These factors will cause nuisance blowing if the fuse type and rated current are not adequate. Switch mode power packs used in modern RF equipment for higher power efficiency cause in-rush current at re-starts (up to 10 times of the nominal current). Current surges on coaxial network and incidental temporary shorts caused by improper maintenance practices are common. Time-delay fuses (or Slo-Blo) are ideal for these conditions. Fast-acting fuses may have to be rated at 150% to 300% of maximum operating currents to avoid nuisance blowing. The best parameter describing the ability of the fuse to withstand these conditions is I^2t or "Ampere Squared Seconds". This parameter describes how much total energy the fuse can dissipate before melting. This ties with the aging of the fuse.

7. Available maximum fault current and long term overload levels:

A fuse must be able to open under fault current or long-term overload conditions without damaging the fuse case. The interrupting rating of a fuse is the maximum current at the rated voltage that the fuse can safely open without rupturing or cracking the fuse case.

8. I^2t characteristics of the devices to be protected:

A fuse must be able to limit the energy passed before it completely opens to the level lower than the energy withstand rating of the device being protected.

9. Allowed voltage drop across the fuse:

Fuse resistance (cold and hot) should be negligible to avoid voltage drop that would affect network operation.

10. Applicable standards/agency:

UL listing in the USA is required.

11. Ergonomics (ease of removal, axial leads, visual indication, physical size, etc.):

These factors, often neglected by manufacturers and equipment evaluation/approval personnel, often affect the other factors (mean-time-to-repair — MTTR, incidental shorts, etc.). Physical size of the fuse can be limited by available space and packaging density, making handling during replacement more difficult.

12. Humidity:

In extremely humid conditions, sealed fuses should be used.

13. Standardization:

Standardized fuses are readily available to maintenance crews.

An additional issue of selective coordination must be considered if more than one fuse (or other current limiting device) are cascaded. Coordination is the act of isolating a faulted part of the network from the remainder of the network. Selectivity means positive coordination over the entire range of fault currents, assuring that faulty part is cleared by the first fuse between the fault location and the power source, counting from the fault, and that other parts of the network are not affected.

All these parameters and design rules should be taken into account in setting the fusing design rules for HFC networks.

CONDITIONS IN HFC NETWORK

Maximum Operating Load Current

A nominal maximum load current in most networks is limited to 15 A but may be as high as 20 A. Selecting fuses based on this assumption would lead, however, to a significant degradation in the network reliability. The cable TV network is subject to such phenomena as sheath currents and other disturbances that randomly fluctuate (increase or decrease) current load but are quite normal and common. The equipment is designed to withstand such operating conditions. Moreover, although the main line equipment current passing capability is specified for the nominal operating currents of 15 or 20 A, it can withstand overload currents of 25 A for a prolonged period of time (sufficient to remedy the fault conditions) albeit at derated performance. Hence, only limited protection is required for the main line equipment.

Increased protection may be required for distribution lines that use less robust equipment (lower current passing capacity). Operating currents for these runs typically do not exceed 8 A (may approach this number in urban areas) and are usually significantly lower.

Temperature & Aging

The fuses will be subject to temperatures as high as 80°C for summer months inside actives (the most likely location of fuses) or as low as –30°C for winter months if placed in line passives. The fuse selection process must take into account the highest operating temperatures. Aging would also be a significant factor for fuses in cable TV network.

Operating Voltage & Frequency

A modern HFC network will operate at 60 or 90 VAC nominal RMS voltage, 60 Hz (or possibly 1 Hz).

In-rush characteristics of the network, surge currents, and maintenance procedures

Time-delay fuses must be deployed. Alternatively, the rating of the fast-acting fuses must be increased to provide the same delay time for short-duration current surges to avoid nuisance blowing. For detail analysis of this issue refer to Figure1.

Available maximum fault current and long term overload levels

The fault current in coaxial section of the HFC network is limited by current limiting characteristics of power supplies or by cable resistance and is lower than 25 to 35 A.

I^2t characteristics of the devices to be protected

Newer main line equipment will withstand 25 A current for 2 hours. Older equipment and distribution equipment (line extenders and multitaps) will withstand 135% of their nominal current passing capacity (13-18 A for trunk amplifiers and LEs; 10-12 A for multitaps) almost indefinitely.

FUSING DESIGN

Fuse Locations

In a network with newer equipment designed for high fault currents, a fuse-link protection against overcurrents is required only for distribution (multitap) runs. All other network elements are protected by a current limiting at the power supply locations and by coaxial cable resistance and are designed to withstand these currents.

The other objective — isolating a fault — may require additional fusing on these main line legs that serve less dense areas or branching runs with lower number of homes passed.

The following locations are the only locations where fuses would serve their purpose:

1. Branching (sub-ordinate) main lines;
2. The last fusible location before multitap run and other equipment with limited current passing capability (usually a minibridger output port or line passive power directing port);
3. Output of a second active (second line extender) in tap runs in locations remote from the power supply.

Fuses should be installed in these locations only if the protection improves the plant reliability and improves MTTR through effective fault isolation. Actual fuse placements in these locations will depend on further considerations listed below.

Based on these objectives, the following practical guidelines for fuse locations are recommended:

1. No fuses to be placed in any location in which open or short would cause an outage to more than 50% of homes passed in the power supply area.

2. No more than one fuse to be placed between the power supply and a location in which open or short would cause an outage to more than 25% of homes passed in the power supply area.
3. No more than two fuses to be placed between the power supply and a location in which open or short would cause an outage to more than 10% of homes passed in the power supply area.
4. No more than three fuses to be placed between the power supply and a location in which open or short would cause an outage to less than 10% of homes passed in the power supply area. The third fuse to be placed only in long cascades.

Fuse Values

The fuse values in the locations listed above will be determined by the operating current, available fault current and the type of the fuse.

$$FuseRating \geq \frac{NormalOperatingCurrent}{0.75 \bullet K_{HT}}$$

where

K_{HT} is max. operating temperature correction factor (fuse type dependent).

$$FuseRating \leq \frac{Max.AvailableFaultCurrent}{K_{2h} \bullet K_{LT}}$$

where

K_{2h} is percentage of fuse rating for 2-hour opening time (fuse type dependent)

K_{LT} is min operating temperature correction factor (fuse type dependent).

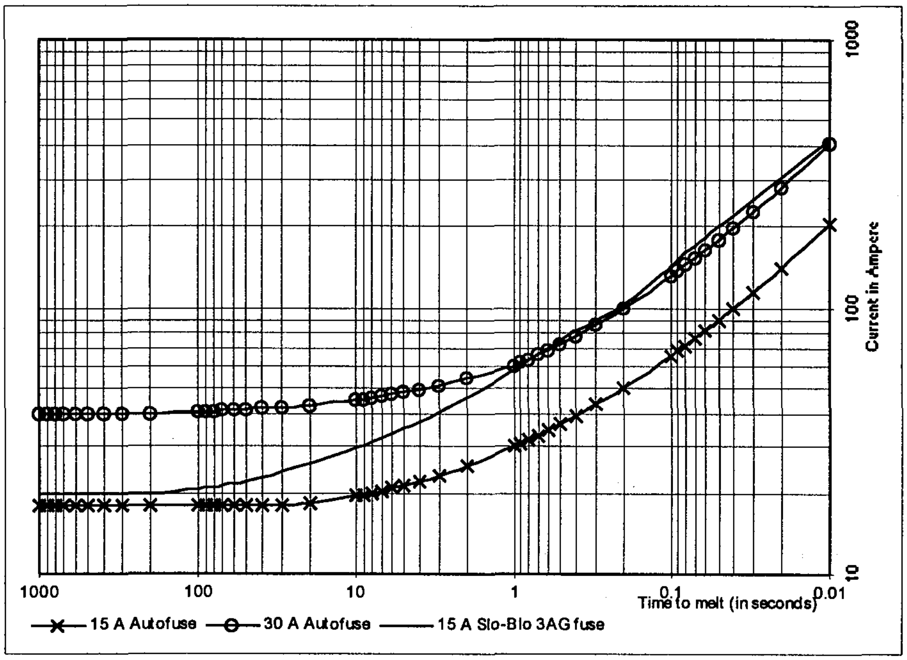
These two limitations decide about a rating of the fuse for a particular location. If these inequalities cannot be met for the location, either the fuse should be relocated or not placed at all.

Fuse Types

Time-delay fuses are preferable for the application in the HFC network and should be the only ones used in that environment. However, many OEMs shifted from 3AG and other type fuses available in the time-delay design to automotive type fuses of different fuse holder design. The automotive fuses are not available in the time-delay design. An alternative is to use fuse adapters that would accommodate time-delay fuses in equipment with automotive-type fuse holders.

A comparison between Fast-Acting and Time-Delay fuses is presented in Figure 1. Two characteristics: time to open at a given current and immunity to transients and surges (I^2t) are compared.

Figure 1: **Comparison of Fast-Acting and Time-Delay Fuse Characteristics: Average Current-Time Curves and I²t (ampere-squared-seconds)**



	15 A Slo-Blo Fuse (Littelfuse #313 015)		15 A Autofuse Fuse (Littelfuse #257 015)		30 A Autofuse Fuse (Littelfuse #257 030)	
Current Overload	Opening Time	Nominal Melting I²t	Opening Time	Nominal Melting I²t	Opening Time	Nominal Melting I²t
16.5 A	4 hours min.	1870 A^2sec	100 hours	340 A^2sec	infinity	1510 A^2sec
20.25 A	1 hour max.		½ hour max.		infinity	
30 A	5 sec. min.		0.15 sec. min.		infinity	
33 A	10 sec. av.		0.6 sec. av.		100 hours	
40.5 A	5 sec. av.		0.35 sec. av.		½ hour max.	
60 A	1.4 sec. av.		0.1 sec. av.		0.15 sec. min.	

Comments:

1) The 15 A Slo-Blo 3AG-type fuse can withstand 100,000 current pulses with 80 A peak value (corresponding to in-rush current with switch mode power supplies) of exponential shape with a decay time of 0.3 s each (20 cycles) or almost unlimited number of pulses of 10 kA peak value with a decay time of 10 μs (corresponding to lightning strikes). It can be used effectively for fault isolation.

2) The 15 A Autofuse can withstand significantly lower number of pulse overcurrents (1 pulse at 80 A peak current of 0.3 s decay time or approximately 20 pulses at 10 kA peak current of 10 μs). It can be used to isolate faults but at limited pulse immunity in comparison to 15 A Slo-Blo fuse that is also used for this purpose.

3) The 30 A Autofuse provides similar immunity to pulse overcurrents as 15 A Slo-Blo 3AG-type fuse but will not react to any current overloads existing in the HFC network (power supplies will limit the available short current to 25 A).

Selective Coordination[5]

To meet the objective of selective coordination, the following minimal fuse value ratios must be maintained for fuse cascades:

- for time-delay fuses of the same type - 2:1
- for fast-acting fuses of the same type - 3:1 in most cases

- fast-acting followed by time-delay - 1.5:1 in most cases
- time-delay followed by fast-acting - 4:1 and higher in most cases.

These ratios assume that the fault currents at the fuse locations are not significantly different.

The data show that fuse mixing or using fast acting fuses will significantly limit the number of fuse values that can be used in cascade if the rules of selective coordination are applied. Alternatively, the values of fuses farther in the cascade would be low and would result in their nuisance blowing. For example, if fast acting fuses are used and the protection and fault isolation rules ask for three fuses, their values would be 15 A, 5 A, and 1 A (next lower value available in Autofuse style). Note that the locations in which the 1 A fuse could be used would be very limited (low nominal operating current) and its immunity to transients would be dangerously low ($I^2t=0.4$ A^2Sec).

Voltage Rating

The voltage rating of the fuses should be 125 V or higher. Unfortunately, Autofuses are available only with 32 V rating, and 3AG Slo-Blo fuses are available with 250 V rating for values of up to 8 A. For higher current rating, the voltage rating is limited to 32 V. Fortunately, fuse selection guides allow for exceptions to the voltage rating rules if the maximum power available at the fuse under "dead short" is limited (currents lower than ten times the nominal operating fuse current).

Fusing Design Steps

The fusing design for cable TV plant shall follow the order described below:

1. Select fuse locations to meet the overcurrent protection objectives.
2. Calculate the allowed fuse rating range for all the location.
3. Starting from the location farthest from the power supply, select cascaded values for the fuses within the ranges calculated in step 2 and according to the rules of selective coordination.
4. Repeat this procedure for all fuse locations.

EXAMPLES OF FUSING DESIGN

The following examples of fusing design are applied to the HFC network with node design with distributed and centralized powering.

All the rules described above were applied. These rules were also applied to all TCI systems including traditional tree-and-branch designs. Although complete comparative data have not been collected yet, first results indicated significant decrease in fuse related outages. The implementation effort was huge due to the fact that each system developed its own procedures of deploying fuses, circuit breakers, and other means, often with the advice of the manufacturers. These piece-meal solutions, directed mostly towards protecting equipment of lower than required robustness, never accounted for the powering design specifics and never applied the system-type approach to the overcurrent protection design.

Figure 2: **Simple Example of Fusing with Centralized Powering**

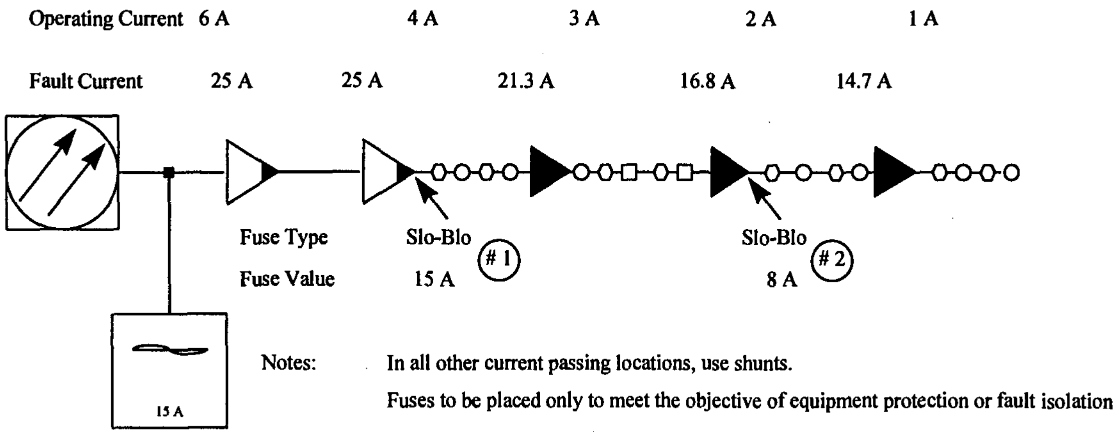
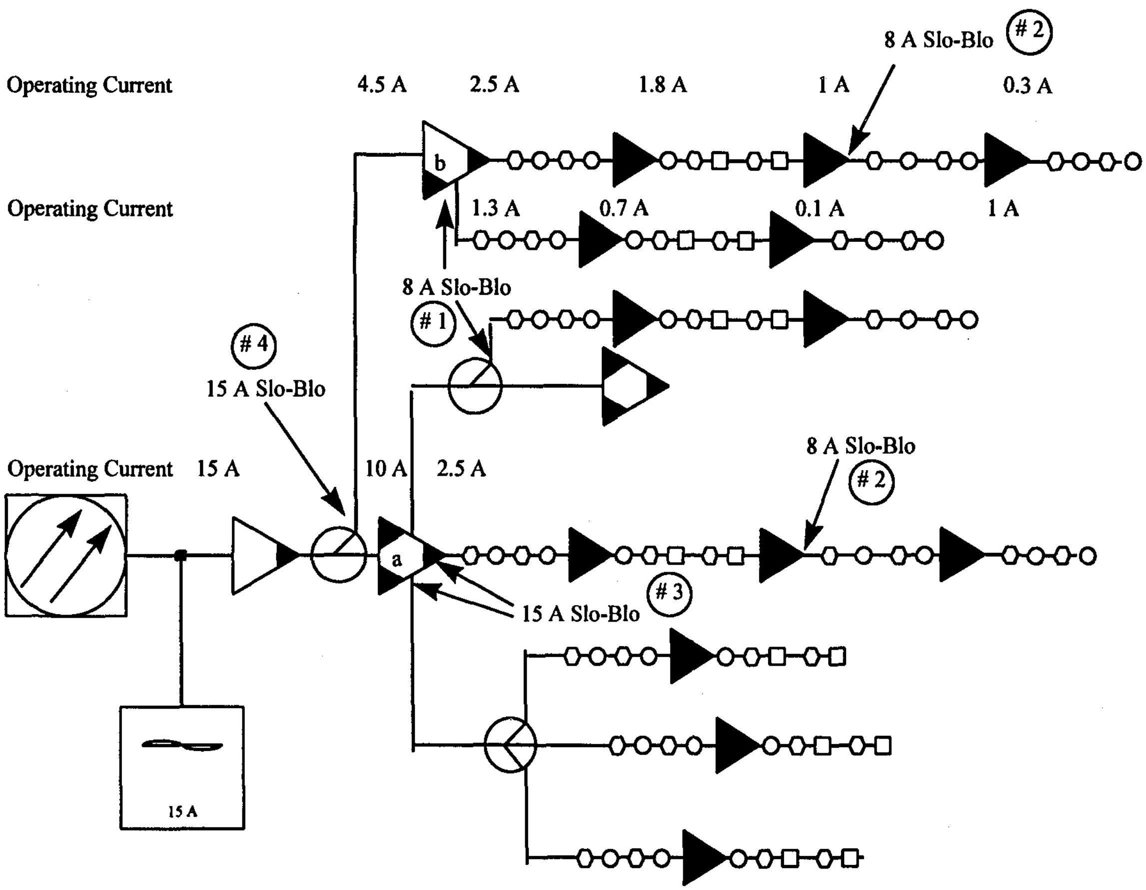


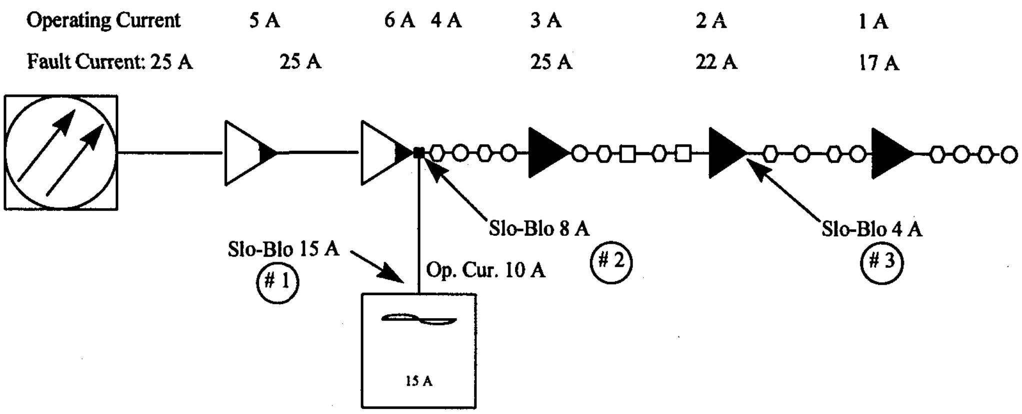
Figure 3: **HFC Node Fusing Design for Centralized Powering**



Notes: In all other current passing locations, use shunts.

Fuses to be placed only to meet the objective of equipment protection or fault isolation

Figure 4: Simple Example of Fusing with Distributed Powering

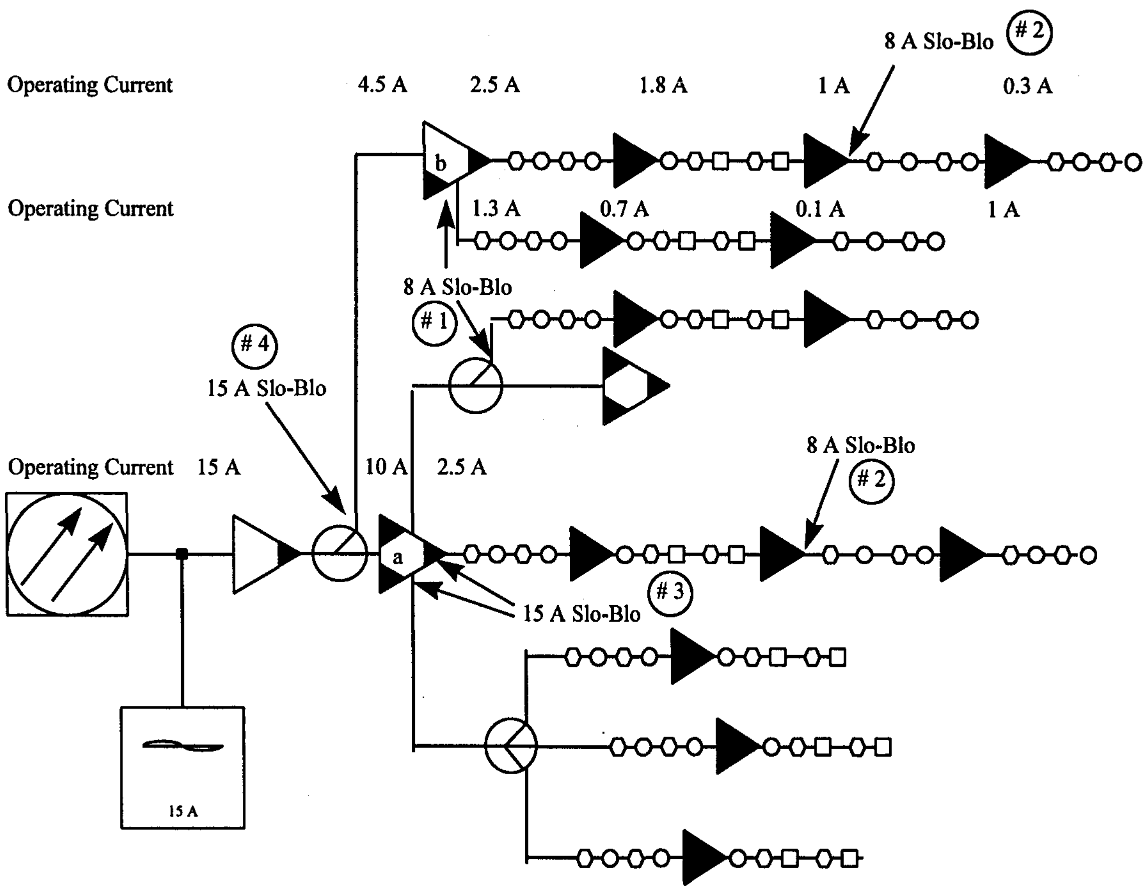


Notes: In all other current passing locations, use shunts.

Fuses to be placed only to meet the objective of equipment protection or fault isolation.

Use only shunts between the power supply and the node if the node is powered from this power supply.

Figure 5: HFC Node Fusing Design for Distributed Powering



Notes: In all other current passing locations, use shunts.

Fuses to be placed only to meet the objective of equipment protection or fault isolation

SUMMARY OF FUSING DESIGN

Time-Delay Fuses vs. Other Overcurrent Protection Elements

Time-delay fuses have characteristics that make them the most desirable for overcurrent protection systems in coaxial sections of the HFC network. 3AG type fuses have the highest values of I^2t for any fuse rating

Fuse Values and Fuse Cascades

The two most suitable values to meet the value selection equations and requirements of selective coordination are 15 A and 8 A. One more value, 4 A, for locations remote from the power supply can be added to the two selected. Lower values would result in increased nuisance blowing due to too low I^2t values.

The 15 A fuses can be used for operating currents of up to 8 A, 8 A fuses for operating currents lower than 4.5 A, and 4 A fuses for operating currents of up to 2.25 A.

ACKNOWLEDGMENT

The author wishes to thank Tom Shirk, a TCI filed engineer, for his work on creating practical guides on selection of fuse locations based on the calculations and fusing examples.

[1] Doug Combs, Oleh J. Sniezko, Tony E. Werner, Powering: Architecture and Voltages, 1996 NCTA Technical Papers.

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[3] Electronic Designer's Guide, Littelfuse, Form No. EC101-A

[4] Electronic Designer's Protection Handbook, Bussman, Bulletin EDPH

[5] Selective Coordination of Overcurrent Protective Devices for Low Voltage Systems, McGraw-Edison/Bussman, Bulletin EDP-2