Power Distribution for Branch Circuit Protection

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Overall protection of *Branch Circuits connected to critical loads* can be a very complex issue. These branch circuits are typically connected to UPS Systems so this type of source power will be discussed. There could be a very wide variety of UPS System types and critical loads to be considered. Likewise, there could be a wide variety of issues involving the protection of the overall system through the branch circuit protection devices; usually these protection devices would be either *circuit breakers or fuses*. Within each of these two categories of protective devices, there exists another wide variety of choices. When dealing with branch circuit protection, the primary factors to consider are the time-vs-current characteristics of the protective device, the time-vs-current characteristics of the power source, and the time that the critical connected equipment can operate at zero volts ("ride-through").

When evaluating the UPS system involved, one must first determine what type of UPS system is being used: True On-Line, Standby, or Off-Line. Generally, Industrial customers would tend to use a True On-Line system, but not always. A *true on-line system* would be one in which the Inverter section of the UPS system is intended to be connected to the loads during all normal operating conditions. This is normally accomplished through the use of an Automatic Static Transfer Switch. With this configuration, the output of the Inverter is connected to the primary position of the Static Switch, and the secondary position, or Bypass position, of the Static Switch is connected to an Alternate, or Bypass Source. The Bypass Source should normally be a separate electrical feed to the system rather than being "wrapped around" from the primary feed to the UPS system normal input. Additionally, in these on-line systems, the separate Bypass source is typically delivered to the UPS through a Transformer (usually a step-down/ isolating type) that is compatible with the UPS system's Inverter output rating. This is important when trying to determine the overall *"fault clearing"* capability of the system.

Determination of the overall fault clearing capability of the system is important since the primary intent of the system is to maintain constant regulated power to the critical loads. This can only happen if the selections of UPS system and fault protection devices is done properly.

Selection of the overcurrent devices depends on the type of excessive current the interrupting device will be required to operate under. An *inrush* overload can be as much as twelve (12) times the normal operating current level. These currents are temporary in nature and are normal during the start up of the applied load. A good example of this would be a motor or power supply starting with a surge current. The short duration of this inrush current does not cause any problems and should not open the overcurrent protection device. A sustained overload that would occur because of a defective component in the load but doesn't go to a complete short must operate the protective device after several minutes to prevent overheating of the protective device, wiring and portions of the affected load. A dual element fuse or circuit breaker is the best circuit protector when this overload condition exists.

A short circuit or fault current, on the other hand, could be many *hundred* times the normal operating current. If this high current is not cut off in few thousandths of a second, damage and destruction of insulation, melting of conductors, vaporization of metal, ionization of gases, arcing, and fires will result. To protect against this kind of damage, a non-time delay current limiting fuse (semiconductor type fuse) must be used. These fuses, under a short circuit condition, will completely open the faulted circuit in approximately one fourth (1/4) of a cycle.

The new HDR/Solidstate Controls power distribution panel will deal properly with both fault conditions. It contains both a fuse and breaker on each branch circuit. The breaker should be properly coordinated with the branch circuit rating and will protect the load during overload conditions. The fuse can be larger since its function is to clear short circuits. The fuse could be oversized as much as 300% of the circuit full load rating to permit motor and power supply start-ups and also allow other large transients that normally can be handled by the power source. This over sizing should be reviewed to make sure the source has enough interrupting capacity to allow the fuse to open in a quarter cycle during a short circuit.

Fast acting fuses as protective devices for critical loads have more advantages than the exclusive use of circuit breakers. Semiconductor protection fuses will tend to offer time-vs-current characteristics which exhibit very fast clearing times which can be matched to the fault clearing capabilities of the particular type of UPS system being used (assumed to be of the "On-Line" type) and the “ride through” capabilities of the individual critical load devices. A fault on a branch circuit will attempt to pull that circuit and all surrounding circuits to zero volts until the branch interrupter opens the connection between the source and the fault. The amount of time we experience this low voltage condition is a function of the source capacity and the amount of current that is allowed to flow to the fault (See figure 1). This current not only comes from the UPS but the fault will actually pull current out of the other loads as the voltage begins to collapse. Figure 2 shows how the fuse will limit the amount of current the fault can draw which will protect the other loads. Limiting the current also shortens the duration of the fault and reduces the time current is going into the fault. While some loads have “dual” power sources if the secondary is available, all the loads will experience a fluctuation until transferred and those that do not have the second power source will be at the mercy of the faulted system.

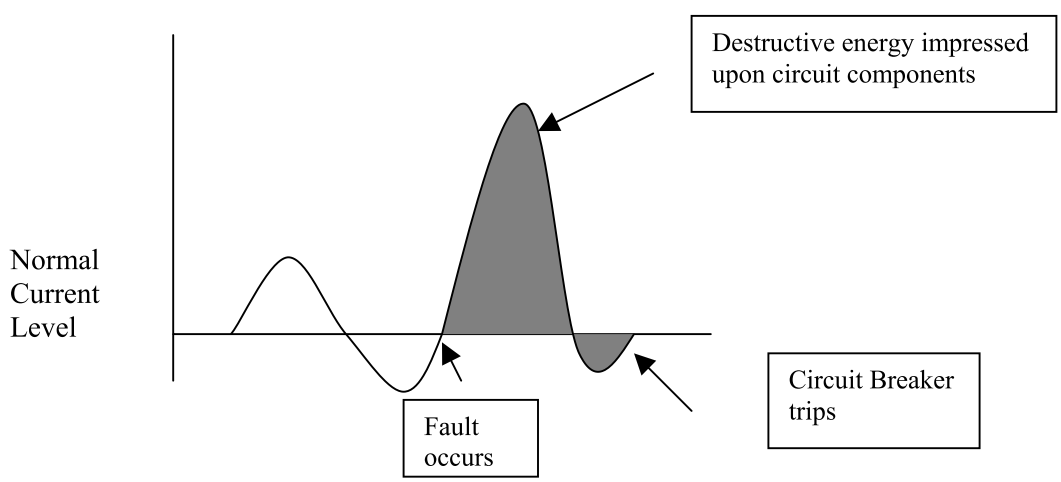

Figure 1. Current build up allowed by a non-current-limiting device releasing a large amount of destructive short circuit heat energy before opening.

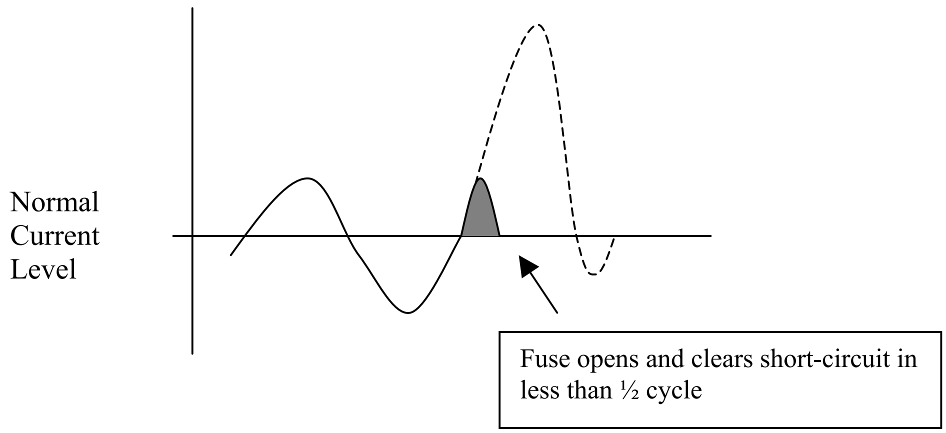

Figure 2. High-speed response of the current limiting fuse does not allow current build up to peak value

The current limiting capability of a semiconductor fuse is very important for load protection but is probably the least understood characteristic of this special type of fuse. Improved overall power distribution in critical areas does require reviewing of the available current in case a load device should fail. Properly sized power transformers with shorter runs to motor control centers have increased the available current to a level that could damage some or all of the components in the event of a short circuit at a load. In the opposite extreme, a UPS that does not have the available interrupting current to operate a semiconductor fuse, such as when the Bypass Source is not available, could rely on the slower types of fault protection. This could result in all the loads seeing a reduced voltage longer than can be tolerated for proper critical applications. The safety side of this issue is to make sure circuit damaging currents are not allowed to flow from the source to the fault. A current limiting device such as a semiconductor fuse will only allow current to flow for a quarter cycle before the fault current reaches the highly destructible level that might be available. This current limiting feature also will protect lower limit circuit breakers in series with them. The use of semiconductor fuses can eliminate the need for special bracing or high withstand ratings of other series components. Once a short circuit begins, currents could be 40,000 amperes or more in the first half cycle in circuits not protected by a current limiter. Faults at this level can generate a tremendous amount of heat and cause severe insulation damage or even an explosion. This type of fault can also create huge magnetic forces that could destroy bracing structures or crack insulators. These examples underscore the need for the selection of a protective device to limit fault current before it reaches its full potential level.

Properly applied current limiting fuses will instantaneously (less than ½ cycle) isolate a faulted circuit and protect the other circuits on the same phase from the effects of a voltage sag. Proper application means that the available short circuit duty at the end device is above the current limit threshold of the fuse. Otherwise, voltage-sensitive equipment will be subjected to low voltage during the extended interruption interval of the fuse. A short circuit causes the voltage to collapse to zero at the point of the fault. The voltage at the source is dependent on the impedance between the fault and the source. If the fault lowers the source voltage to less than 70% of rated RMS voltage and is allowed to persist for one cycle or more, voltage-sensitive relays and other devices (interposing relays, solenoids, SMPS's, etc.) will de-energize.

Computer systems, process controllers, microprocessors, programmable logic controllers, adjustable speed drives, etc., with switch-mode power supplies have inherent, but limited, stored energy in the capacitive circuit of the power supply. The stored energy is expended after about three cycles and is discharged after about one cycle for very low voltage sags. For example, if the voltage sags to less than 30% of rated RMS voltage for one cycle, the power supply will be lost. Circuit breakers, with standard trip ratings (15A, 20A, etc.), do not clear faults fast enough to prevent voltage sags (and outages) since they frequently trip in their thermal, time delay region (typically, between 30 and 60 cycles). Even when operating in the instantaneous region, a circuit breaker may take one to two cycles to clear a fault. For faults cleared by circuit breakers, a voltage sag will result on that phase. When voltage sags for more than one cycle motor contactors will drop out, solenoid valves will close, process controls variables in volatile memory will be lost and remote I/O will be lost. This may result in equipment and plant shutdowns. Current limiting fuses are the only protective devices that operate fast enough to prevent outages. Current limiting fuses, by definition, will totally clear a fault in less than ½ cycle; given sufficient fault current, in ¼ cycle or less. The key factor is that the available short circuit current should be greater than the current-limit threshold of the fuse. If not, the tripping time of the fuse follows its time-characteristic curve. To keep current magnitudes high, branch circuit impedance should be low.

The higher the UPS System's Inverter and its Automatic Static Switch's current capacity, the shorter the time required to open a fuse. Adequate overcurrent ratings are required to allow proper coordination with the branch circuit fuses to insure clearing of a downstream fault while maintaining the UPS system on line without a "shut-down" of the UPS Inverter or system. The faulted load would normally be transferred to the Bypass Source via the UPS system's Static Switch. The Bypass Source should be designed to have extremely high fault clearing capability much higher than the UPS Inverter. The bypass source is typically derived from a separate, low impedance utility feed capable of delivering the higher currents for longer periods of time. There are two key elements to consider: 1) the Bypass Source has a very high overcurrent rating via the Static Switch to allow faults to clear without damage or shut down to the system; 2) the Inverter has a high overcurrent rating in relation to the size of the branch protecting device which would normally allow it to clear faults in the event that the Alternate, or Bypass Source is not available during the fault condition. When using AMETEK Solidstate Control's Ferroresonant UPS the standard overcurrent ratings of the system components are Inverter - 560% for 1 cycle, 120% continuous and the Automatic Static Switch - 1000% for 1 cycle. PWM UPS Systems have a standard overcurrent rating of: 150% for 1 minute, 125% for 10 minutes, 100% continuous and the Automatic Static Switch – 1000% for 1 cycle. These ratings need to be considered when designing the load distribution.

The fault clearing capability and the overall system reliability is greatly enhanced by the use of semiconductor fuses as opposed to circuit breakers. The importance of the overcurrent ratings of the UPS system components relates to the UPS system's ability to allow proper fault clearing without "interlocking down" (shutting down to protect the internal components of the system), thereby creating a loss of primary power to all of the loads. Basically, if the power distribution system is designed properly, the only primary power loss due to the fault condition would be to the faulted branch circuit itself.

The only way to effectively create this higher reliability of overall UPS power continuity to the loads would be through the use of circuit breaker and fast acting semiconductor fused distribution connected from an On-Line UPS system with adequate overcurrent ratings.

Glossary of Terms

Ampacity
The current a conductor can carry continuously without exceeding its temperature rating. Ampacity is a function of cable size, conductor material (ex. Copper vs. Aluminum), insulation type and the conditions of use.

Ampere Rating
The current carrying capacity of a fuse. When the fuse is subjected to a current above its ampere rating, it will open the circuit after a predetermined period of time.

Ampere Squared Seconds, I^2t
The measure of heat energy developed within a circuit during the fuse's clearing. It can be expressed as "Melting I^2t", "Arcing I^2t" or the sum of them as "Clearing I^2t". "I" stands for effective let-through current (RMS), which is squared, and "t" stands for time of opening, in seconds.

Arcing Time
The amount of time from the instant the fuse link has melted until overcurrent is interrupted, or cleared.

Available Fault Current
The maximum short circuit current that can flow in an unprotected circuit.

Bolt-in Fuse
A fuse that is intended to be bolted directly to bus bars, contact pads or fuse blocks.

Branch Circuits
The portion of a wiring system extending beyond the final over current device protecting the circuit. Typically, individual loads, or sub-feeders, would be connected to each branch circuit.

Contacts
The external live parts of a fuse which provide continuity between the fuse and the balance of the circuit. Also referred to as ferrules, blades or terminals.

Circuit Breaker
A device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on predetermined overload of current, without injury to itself when properly applied within its rating.

Clearing Time
The total time between the beginning of the overcurrent and the final opening of the circuit at rated voltage by an overcurrent protective device. Clearing time is the total of the melting time and the arcing time.

Coordination
The use of overcurrent devices which will isolate only that portion of an electrical system which has been overloaded or faulted. See Selectivity.

Current Limitation
A fuse operation relating to short-circuits only. When a fuse operates in its current-limiting range, it will clear a short circuit in less the ½ cycle. Also, it will limit the instantaneous peak let-let through current to value substantially less than that obtainable in the same circuit if that fuse were replaced wit a solid conductor of equal impedance.

Electrical Load
That part of an electrical system which actually uses the energy or does the work required.

Element
A calibrated conductor inside a fuse which melts when subjected to excessive current. The element is enclosed by the fuse body and may be surrounded by an arc-quenching medium such as silica sand. The element is sometimes referred to as a link.

Fast Acting Fuse
A fuse which opens on overload and short circuits very quickly. This type of fuse is not designed to withstand temporary overload currents associated with some electrical loads.

Fault
An accidental condition in which a current path becomes available which by-passes the connected load.

Fault Current
The amount of current flowing in a faulted circuit.

Fuse
An overcurrent protective device with a fusible link that operates and opens the circuit on an overcurrent condition.

High Speed Fuses
Fuses with no intentional time-delay in the overload range and designed to open as quickly as possible in the short-circuit range. These fuses are often used to protect solid-state devices or in panels where it is critical to keep the low voltage attributed to overloads to a very short period of time.

Interrupting Rating (Breaking Capacity)
The rating that defines a circuit breaker or fuse's ability to safely interrupt and clear short circuits. This rating is much greater than the ampere rating of a circuit breaker or fuse.

> *The NEC® defines Interrupting Rating as "The highest current at rated voltage that an overcurrent protective device is intended to interrupt under standard test conditions."*

Magnetic Trip
Action is achieved through the use of an electro-magnet in series with the load current. This provides an instantaneous tripping action when the current reaches a predetermined value.

Melting Time
The amount of time required to melt the fuse link during a specified overcurrent.

Molded Case Switch
Switches that are UL 1087 listed devices that have no thermal protection but do have a self protecting high magnetic trip setting.

Overcurrent
A Condition which exists on an electrical circuit when the normal load current is exceeded. Overcurrents take on two separate characteristics – overloads and short circuits.

Overload
Can be classified as an overcurrent which exceeds the normal full load current of a circuit. Also characteristic of this type of overcurrent is that it does not leave the normal current carrying path of the circuit – that is, it flows from the source, through the conductors, through the load, back through the conductors, to the source again.

Peak Let-Through Current, I_P
The instantaneous value of peak current let-through by a current-limiting fuse, when it operates in its current-limiting range.

Rejection Fuse Block
A fuse block which will only accept fuses of specific UL class. Rejection is a safety feature intended to prevent the insertion of a fuse with an inadequate voltage or interrupting rating.

Rejection Fuse
A current-limiting fuse with high interrupting rating and with unique dimensions or mounting provisions.

Resistive Load
An electrical load which is characteristic of not having any significant inrush current. When a resistive load is energized, the current rises instantly to its steady-state value, without first rising to a higher value.

Ride-Through
Time that an electrical circuit can operate without input voltage by relying on internal stored energy to power the circuit.

R.M.S. Current
The R.M.S. (root-mean-square) value of any periodic current is equal to the value of the direct current which, flowing through a resistance, produces the same heating effect in the resistance as the periodic current does.

Selectivity
A main fuse and a branch fuse are said to be selective if the branch fuse will clear all overcurrent conditions before the main fuse opens. Selectivity is desirable because it limits outage to that portion of the circuit which has been overloaded or faulted. Also called selective coordination.

Semiconductor Fuses
Fuses used to protect solid-state devices. See “High Speed Fuses”.

Short Circuit
Can be classified as an overcurrent which exceeds the normal full load current of circuit by factor many times (tens, hundreds or thousands greater). Also characteristic of this type of overcurrent is that it leaves the normal current carrying path of the circuit – it takes a “short cut” around the load and back to the source. Another characteristic of a short circuit that allows this to occur is an extremely low (zero) impedance or resistance.

Short-Circuit Rating
The maximum short-circuit current an electrical component can sustain without the occurrence of excessive damage when protected with an overcurrent protective device.

Short-Circuit Withstand Rating
See Short -Circuit rating.

Single Phasing
This condition occurs when one phase of a three phase system opens, either in low voltage (secondary) or high voltage (primary) distribution system. Primary or secondary single phasing can be caused by any number of events. This condition results in unbalanced currents in polyphase motors and unless protective measures are taken, causes overheating and failure.

Thermal Trip
Action that is achieved through the use of a bimetal heated by the load current. On a sustained overload, the bimetal will deflect, causing the operating mechanism to deflect, causing the operating mechanism to trip. Because bimetals are responsive to the heat emitted by the current flow, they allow a long time delay on light overloads, yet they have a fast response on heavier overloads.

Threshold Current
The symmetrical RMS available current at the threshold of the current-limiting range, where the fuse becomes current limiting when tested to the industry standard. This value can be read off of a peak let-through chart where the fuse curve intersects the A-B line. A threshold ratio is the relationship of threshold current to the fuse's continuous current rating.

Time-Delay Fuse
A fuse with built-in delay that allows temporary and harmless inrush currents to pass without opening, but is so designed to open on sustained overloads and short circuits.

Voltage Rating
The maximum open circuit voltage in which a fuse can be used, yet safely interrupt an overcurrent. Exceeding the voltage rating of a fuse impairs its ability to clear an overload or short circuit safely.

Withstand Rating
The maximum current that an unprotected electrical component can sustain for a specified period of time without the occurrence of extensive damage.

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