Cold Load Pickup Issues

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prepared by working group D1

Abstract

This report describes cold load pickup and inrush problems as they affect protective relaying applications on distribution feeder circuits and provides guidance for protective system applications. A list of pertinent literature and recent studies is provided as well as some real life examples.

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1.0 Introduction

Usually when a distribution circuit is restored after an extended outage, the demand is greater than before the outage. Attempting to pick up this load can be problematic because the initial load demand after an outage can exceed the load demand that would have been observed at any time before the outage. This phenomenon is referred to as cold load pickup because the power supply has been unavailable for a period of time so that the load has reached a "cold" state before being re-energized.

Since in most cases cold load pickup current is greater than pre-outage current; cold load pickup affects fault detection. That is, protective relays can misinterpret the cold load pickup condition as a fault and initiate de-energization of an unfaulted circuit.

There are many factors that determine the magnitude and duration of cold load pickup. These include: outage duration, types of connected load, weather, restoration mode, outage causes, the presence of distributed generation and/or automatic transfer schemes, time of day, and load level. Each of these will be addressed in this report.

The goal of this paper is provide an understanding of the cold load pickup phenomenon and the options available with modern protective relays so improvements in the protection of distribution circuits can be achieved.

2.0 Description/Definitions

2.1 Cold Load Pickup

Cold load pickup is the phenomenon that takes place when a distribution circuit is re-energized following an extended outage of that circuit. Cold load pickup is a composite of two conditions: inrush and loss of load diversity.

The magnitude of cold load pickup current is a combination of non-diverse cyclic load current, continuously operating load current, transformer magnetizing current, capacitor inrush current, etc. The combination can result in current levels that are significantly higher than normal peak load levels. Cold load pickup current can be high enough to cause instantaneous overcurrent and/or time overcurrent relays to operate.

Cold load pickup is primarily an overcurrent condition. If degraded voltage is also a concern, then the application of voltage sensitive relays should also be considered.

2.2 Magnetizing Inrush

Magnetizing inrush current is the transient current required to satisfy the instantaneous flux requirements of transformers when transformers are energized. The magnitude of the initial peak magnetizing current, which is a function of residual flux and energizing voltage, can have an equivalent rms value many times greater than the full-load rating of the transformers. The duration of magnetizing inrush current is a function of source system and transformer equivalent impedances. The time constant can vary from milliseconds to seconds. Larger transformers will generally have longer decay time constants.

If a transformer has no residual flux, the maximum magnetizing inrush current will occur when the transformer is energized at the point where the source voltage is zero. In a three-phase system, because the three source voltages are 120° apart, inrush will occur on at least two phases.

2.3 Loss of Load Diversity

Loss of load diversity is the part of cold load pickup that occurs when distribution circuits are restored following sustained outages of several minutes to several hours. The concern is that the naturally occurring, random switching of a group of loads that independently cycle on and off may be lost. These loads are typically cycled based on temperature, pressure or liquid level. The post-outage load may be significantly greater than pre-outage load when numerous, normally diverse, cyclic loads are all drawing current at the same time. This current, due to the loss of load diversity, is combined with the other continuously operating loads. In this report, loads that cycle on and off by independent controls in load units are referred to as cyclic loads. Diversity refers to the percentage of independently controlled, cyclic loads that may be energized at any given time during normal circuit operation - 1 of 2 would be 50% diversity. The loss of load diversity may persist for many minutes before the random operation of independent controls returns to normal.

2.4 Hot Load Pickup

Hot load pickup is used to describe distribution circuit restoration after a circuit is tripped, but before the effects of loss of load diversity become evident. During hot load pickup, the number of pre-outage cyclic loads is essentially the same as the number of post-outage cyclic loads.

2.5 Capacitor Charging Current

Capacitor charging current is the transient current that flows when capacitors are energized. The magnitude of the initial peak can be very high, but the duration will be measured in microseconds or milliseconds. The magnitude of the initial peak charging current, which is a function of residual charge and energizing voltage, can have an equivalent value many times greater than the capacitor rating. The duration of charging current is a function of source system and capacitor equivalent impedances.

2.6 Load Inrush Current

Load inrush current is the short duration increase in load current, above normal, that occurs when motors are accelerating, filaments and electrodes are heating, arc lamps are starting, etc. The magnitude and duration of load inrush current is a function of the connected load and load type. Some loads, such as general purpose motors, may draw 6 times full load current for several seconds when starting. Other loads, such as resistance heaters may only draw a little more than normal current when first energized. Still other loads, such as heat pumps, may draw 2 times full load current when auxiliary heaters actuate.

Load inrush current is most prevalent on residential feeders since many loads have independent controls that usually operate randomly and most motors used in residential applications do not have contactors or undervoltage cutoff protection that must be manually reset when electric service is restored.

2.7 Voltage Recovery Inrush Current

Voltage recovery inrush current is the combination of magnetizing inrush current and load inrush current that occurs when a fault is cleared from the system. During faults, voltages on affected phases will be reduced. When faults are cleared, the sudden recovery of voltage can produce transformer inrush currents similar to, but generally not as severe as, those that would occur during transformer energization. If the voltage drop is severe enough, load inrush current may also be significant. During the period of reduced voltage caused by the fault, motor loads will decelerate. Low inertia, low torque motor loads in particular will contribute significantly to the load inrush current that will be present when the fault is cleared. Relatively small voltage dips (15%) for short durations (less than 500 milliseconds) can cause low-inertia loads with low pull-up torque, such as residential central air conditioning compressor motors, to slow and draw accelerating current (slightly less than locked-rotor current) until tripped by thermal protection. This increased lagging power factor current, flowing through the inductance of the transmission and distribution system components, creates additional reductions in system voltages. [A1]

If voltage recovery inrush causes a distribution circuit outage; hot load pickup problems and, eventually, cold load pickup problems may occur because one characteristic of voltage recovery inrush problems is loss of load diversity.

3.0 Factors Influencing Cold Load Pickup

3.1 Load Type

Load types can be categorized in many ways. From the perspective of cold-load pickup, the most important load characteristics are initial inrush upon re-energization and sustained inrush in excess of normal continuous load. Most types of load incur an initial inrush upon energization. The most common load types are as follows:

3.1.1 Lighting load

Lighting load consists primarily of filament and gas vapor lamps. Filament lamps most commonly use a tungsten filament in a vacuum or inert gas filled glass envelope. Filament lamps are used in residential, commercial, and industrial installations. Gas vapor lamps, such as fluorescent, mercury vapor, and sodium vapor are much more prevalent in industrial and commercial installations. Gas vapor lamps are generally connected to the utilization voltage wiring through a starter circuit.

3.1.1.1 Tungsten Filament Lighting

Tungsten filament lighting is typically connected directly to the utilization voltage wiring. The electrical resistance of the tungsten filament at room temperature is initially quite low. When electrical power is first applied to the lamp; a large inrush current causes rapid heating of the filament. The resistance of the filament raises to a value five to ten times the cold resistance, which causes the amount of current drawn by the lamp to stabilize and the lamp to emit a stable light output. Depending on the size of the filament, the inrush period can be from tens of milliseconds to hundreds of milliseconds. [A2] After this initial inrush period, the current drawn by the lamp is considered constant, and proportional to the applied voltage.

The results of test energizations of 2 kW tungsten filament lamps supported these guidelines. The maximum cold load inrush current was 62 amperes. This was 7.75 times the steady state current of 8 amperes and it took 217 milliseconds to heat the filament to reach the steady state. Tests also showed that the filament in the lamp will not cool to the cold resistance value during short 23 cycle interruptions. After the short power interruptions the maximum inrush current was 16 amperes. The current decreased to the steady state value of 8 amperes in 133 milliseconds. [A3]

3.1.1.2 Gas Vapor Lighting

Gas vapor lighting generally creates more visible light and less heat per unit of energy consumed than filament lighting. The startup process typically involves the application of a high voltage to establish the flow of current through the gas. The high-voltage starter circuitry initially draws more current than during normal operation. The starting process can be very quick, typically a fraction of a second for modern “instant start” mercury vapor fluorescent lamps, to several seconds for high-pressure sodium lamps. The starting current can be several times the normal continuous operating current.

Test energizations of 1240 Watts of fluorescent lamps showed inrush current of 21 amperes which lasted for one cycle. The current then decreased to 4 amperes until a steady state condition of 11.2 amperes was reached one second after initial energization. This sequence demonstrated the inrush to excite the ballast transformer of the light fixture before the delayed conduction of the gas tube. This type of pattern was consistent regardless of the length of the outage before the energization of the fixture. [A3]

3.1.2 Motor Load

Motors are used for many applications in residential, commercial, and industrial applications. Generally, large motors used in an industrial process have a contactor mechanism that is used to start the motor, and requires voltage to keep the contactor closed. When the power supply is interrupted, the contactor automatically opens, preventing the motor from starting automatically when power is restored. Manual intervention is generally required to restart the motor as part of an overall restart process. Because of this diversity, cold load pickup generally does not include large motor starting current inrush. Some motor starters are magnetically latched or are direct current actuated. Motors equipped with these types of starter circuits will ride through power supply interruption so for these motors inrush and running current must be included in cold load pickup events.

Numerous small motors that are used in cyclic residential, commercial, and industrial applications such as water pumps, air-circulating fans, refrigerator and air-conditioning compressors, do not have contactors and will restart automatically when power is restored following an extended outage. These small motor loads typically incur an inrush current that is about 5 to 8 times normal running current and may last as long as a few seconds. Notably, the motor starting current is highly inductive. After the initial starting current subsides, the load and applied voltage dictate the normal load current drawn by the motor. The normal running current drawn by the motor is proportional to the load and inversely proportional to the applied voltage.

Test energization of a ¼ HP freezer motor showed an average inrush of 22 amperes which was 6.88 times the normal run current of 3.2 amperes. The peak inrush current lasted for 217 milliseconds at which time the current started decaying but the motor did not reach steady state until 333 milliseconds after energization. The source to this freezer was adequate to hold the voltage at nominal value during the duration of the startup. [A3] If the voltage was reduced due to the highly inductive inrush current, the time to reach the steady state value may have been longer.

The test energization after only a 25 cycle outage produced the same level of inrush current, 22 amperes, but the time to reach steady state decreased from the 333 milliseconds to 217 milliseconds. [A3]

Similar tests were conducted with on a ¼ HP refrigerator motor. The test results showed an average inrush current of 15 amperes and a maximum of 18 amperes. The average inrush was 7.5 times the steady state run current of 2 amperes. It took 483 milliseconds to reach the steady state condition. The test after a 25 cycle interruption produced lower inrush current and shorter times to reach steady state, 6 – 17 amperes and with 217 milliseconds to reach steady state. [A3]

Also tested was a 3 ton air conditioner. The momentary interruption test and the cold load pickup test showed an average inrush current of 90 amperes which lasted for 117 milliseconds. The inrush current was 7.26 times the steady state run current of 12.4 amperes. The steady state value was reached in 267 milliseconds. [A3]

Some motor loads may run continuously, and are therefore always part of the cold load pickup current following power restoration. Thermal and pressure devices control many motor loads. Following an extended power outage, it is very likely that most, if not all, motors affected by the outage will be poised to start when power is restored. The overall effect of motor loads on cold load pickup will therefore be two-fold: an initial peak inrush caused by motor starting that may last a few seconds, and a sustained abnormally high current due to the lack of diversity in cyclic controlled motor load. The duration of the latter portion of the cold load pickup depends on how long it takes the running motor to satisfy the particular thermal or pressure requirements of its load.

3.1.3 Resistance Heating Load

Electric resistance heating is used for water, space and process heating applications. Electric resistance heating is generally cyclic in that it is thermostatically controlled. Therefore, its affect on cold load pickup is primarily due to the loss of load diversity.

The duration of the inrush current upon energization of electric resistance heating is generally very short-lived, in the several to tens of milliseconds range, similar to the filament lighting discussed earlier. The magnitude of the inrush current is generally only a little higher than the normal for low (less than 65^{O}C /150^{O}F) operating temperature heaters.

The duration of the inrush current upon energization can be several seconds for high operating temperature and process heaters. The magnitude of the inrush for such heaters can be several times higher than normal current.

The results of tests to measure the amount of inrush for the energization of both base board space heating and water heating units, following both prolonged and short (20 -30 cycle) interruptions, showed no appreciable inrush currents for either type of heating elements following either length of outage. [A3]

3.1.4 Magnetic Load

While not generally considered a "load", magnetic loads such as transformers and voltage regulators, nonetheless, play a factor in shaping the cold load pickup when power is restored after an outage. A simple fixed ratio transformer draws a substantial inrush current to magnetize its iron core when energized. This inrush current can be ten to twelve times the nominal current rating of the transformer when energized with nominal voltage. The inrush current can be considerably higher if the energizing voltage is above nominal voltage, due to the non-linear nature of wire-wound iron core magnetic devices. The magnetizing inrush current typically lasts for several cycles, decaying over this time to the normal transformer excitation current. However, if the applied voltage is above the saturation voltage of the transformer, a significant inrush current can continue until the voltage is reduced to within the normal operating range of the transformer.

Voltage regulators, while not as numerous as transformers, also draw high inrush current. While not statistically significant because of their relatively few numbers, voltage regulators are mentioned here because they can play a role in the voltage that is applied when the power is restored. In the case where the operating condition prior to the outage caused the voltage regulator to go to full boost, then when the power is restored, the voltage regulator may create a high voltage condition immediately following restoration that may, in turn, cause transformers to saturate. This condition may continue until the voltage regulating circuitry takes action to lower the voltage. This process may take tens of seconds, depending on the coordination delays used in the voltage regulating scheme.

3.1.5 Capacitive Load

Power factor correction and voltage support capacitors connected to the power system are generally not automatically disconnected from the power system when power is interrupted. They are therefore re-energized automatically when power is restored. High frequency transients that may have peaks ten to twenty times the normal load current typically characterize the inrush current associated with a capacitor bank. However, this high-frequency transient inrush generally subsides in a few milliseconds to a few cycles.

3.2 Outage Cause

An outage can be initiated by a myriad of causes, including: accidental contact, severe weather, vandalism, trees, animals, vehicles, equipment failure and/or contamination, etc.

The cause of an outage will not directly impact the cold load pickup. However, the nature of the cause, size and severity of the affected area, or extreme temperatures, may increase the duration of the outage which, in turn, may increase cold load pickup current or the duration until random cycling returns.

The possibility and duration of intentional outages, that is, rolling blackouts due to insufficient generation reserve or other power system limitations, should be included when cold load pickup issues are addressed.

3.3 Weather

The weather can influence the effect of cold load pickup on a distribution circuit following an outage. The following weather related factors will directly impact the amount of cold load pickup experienced following an outage. The first weather related factor is temperature. Either extremely hot or cold ambient temperatures will increase the amount and duration of the cold load pickup. The point usually considered to be "the minimum load temperature" is the daily average temperature of 65^{O} F. This is used for measuring either heating or cooling degree days, based on the National Weather Service published climatological data. The wind may also tend to affect the impact of the temperature. The amount of humidity in the air, the amount of illumination (sunlight heating objects), and the amount of snow cover will also influence the amount of the cold load pickup. Although a storm will not directly cause an impact, it may increase the length of the outage, i.e., more system damage and, thus, will lengthen the outage duration (see clause 3.5).

3.4 Time of Day and Load Level

Cold load pickup is highly dependent on the amount of load connected to a distribution circuit. When new facilities are placed in service, cold load pickup may not be a significant consideration because distribution lines are designed with allowances for future load growth. That is, the load factor for new distribution circuits may be less than 50%. As more customers are connected and existing customers add load, the load factor on existing circuits will increase and the likelihood of unwanted protective relay operation during circuit restoration increases.

The daily profile of the load on a circuit varies with the type of load (residential, commercial, agricultural or industrial), season, region, and day of week. A common daily profile for a winter work day is to have two peak load periods: one in the morning and the other in the late afternoon or early evening period. For the summer in regions with significant air conditioning load, the profile follows the temperature with the load building up throughout the day and the peak load occurring in the early evening.

In anticipating the load level for a cold load pickup event, the load level will be a multiplier of the load on the circuit at the time of energization on a similar day. That is a day with similar weather conditions, and day of the week. To base the cold load pick load level on the level of load at the time of the outage would be misleading. The cold load pickup event ends when the load level returns to the normal daily profile.

3.5 Outage Duration

The duration of an outage will greatly influence the effect of cold load pickup issues. As the length of an outage increases, the demand upon re-energizing the load will also increase due to the loss of load diversity. For example, a group of appliances that each cycles once every 30 minutes would lose all diversity for any outage exceeding 30 minutes. Cold load pickup recovery time will increase to the point where the outage duration exceeds the longest cycle time of any equipment connected to the feeder. Consideration must be given to provide relay settings that will accommodate the increased load currents experienced during cold load pickup.

3.6 Restoration Mode

If cold load pickup issues are thought to exist or to have caused a protective device to have operated, the most common practice applied is to sectionalize the circuit. In these cases, switches will be opened in order to remove load downstream from the protective device in order to reduce the cumulative cold load pickup effects. The downstream circuit may be split into halves or some other smaller segments depending on the number, type, and load of the customers served. Pre-event loading can be reviewed, if data is available, to aid in the sectionalizing procedure. The protective device that operated on the cold load pickup can then be closed to pick up the load immediately downstream. Additional circuit segments are then restored once the cold load pickup current has decayed for the segments energized earlier.

While most switching is done manually, remotely controlled switches can be used when they are installed on the system. As part of the restoration process, some utilities will disable the reclosing functionality of the protective device prior to attempting to restore load. After the circuit has been restored, the reclosing functionality will then be enabled.

Some electric service providers also request that their distribution customers turn off their loads under outage conditions in order to reduce the effects of cold load pickup, and turn the loads back on over a period of time after the power has been restored.

3.7 VAR Support

Power transfer is less efficient at a lower power factor. The increased current flow through the supply system impedances (power transformer leakage reactance and distribution feeder impedance) during cold load pickup can result in additional voltage drop and consequent reduced voltage at the load. Induction motors are highly inductive while starting and running under low-voltage conditions, resulting in additional voltage drop through the supply system. Low voltage at the motor terminals can exacerbate the low-voltage condition by causing the motor to require more vars and more current, resulting in further voltage drop. Under extreme conditions, voltage collapse or feeder tripping can occur. Tripping of the motor due to overheating or stalling will relieve the load on the feeder, but is not good for the motor or its load.

Effects of low power factor can be reduced by supplying the required vars closer to where the load requires the reactive power. This will avoid the drawing of inductive current through the supply transformer and distribution wiring. Capacitor banks can be applied on the distribution feeder to supply the required vars. Automatic controls that sense voltage or var requirements can control motor- or solenoid-operated switches to turn the capacitors on and off as needed to maintain voltage within acceptable limits and avoid both undervoltage conditions due to excessive var flow and overvoltage conditions during lighter load.

Switched capacitor banks installed on distribution feeders can contribute to the cold load pickup problem. Large motors are generally fed through AC contactors that drop out during the service interruption. When the feeder is restored, the large motor load is disconnected but the capacitor banks which are switched by controls operated AC powered switches are still connected. The capacitors with the reduced load can cause an overvoltage condition until the capacitor controls switch the capacitors off. The overvoltage can drive the connected distribution transformers into saturation which adds additional current to the cold load pickup event. The additional current caused by the saturation of the distribution transformer will be rich in harmonics. Overcurrent relays that respond to the rms value of the current will be influenced by this current but overcurrent relays that respond only to the fundamental frequency will not be affected.

Faster acting var compensators such as thyristor-switched capacitors or distribution static compensators will also alleviate voltage drop in the distribution feeder due to low power factor. These electronically-switched devices can quickly follow the load requirements and may have short-time overload capability to provide extra vars during periods of excessively high var requirements. Although generally applied for the benefit of the specific load connected, the resultant decreased var demand on the power supply system can be a benefit to the power system as well.

3.8 Distributed Resource

Distributed resources are electrical power sources located electrically close to the customer loads. Distributed resources may include on-site generation to carry the customer's load as well as generation that is connected to a distribution line for energy sales to the network. These generation sources are typically not setup to operate in a mode to follow the load requirements of the network.

When a fault occurs on a feeder with distributed resources connected to it, the distributed resources are typically disconnected from the system automatically and turned off. When the feeder circuit is restored from the primary source, the cold load pickup level will be a larger multiple of the level of the load before the fault than on a feeder without distributed resources because the primary source is picking up the total load. This includes the load that was being carried by the distributed resources before the fault. If the distributed resources do not have the capability to automatically reconnect to the energized system or have operators standing by to restore the generation, the distributed resources will be of no help in reducing the current from the primary source during the cold load pickup event.

There are a few exceptions to this typical condition which are explained in the following clauses.

3.8.1 Distributed Resources Designed to be Isolated with Limited Load

Some distributed resources (DR) are designed to be operated normally in parallel with the utility system but when the distribution line is faulted, the tie between the system and the distributed resource is opened. The DR is isolated with part of the DR customer's load. This type of installation is typically installed by industrial customers.

The load to be picked up by the primary source after the system has been restored will not include this customer's load or generation. Depending on the level of the industrial customer's load that was being carried from the primary source before the disturbance or the amount of surplus generation that the DR was feeding into the power system before the outage, the cold load pickup level could be equal to, less than, or greater than the load before the disturbance.

If the distribution circuit was designed assuming that the industrial customer's load would not be normally supplied from the utility source, the paralleling of the systems, after the system is restored, should be delayed until the circuit load has stabilized at an acceptable level that would permit the connection of additional load.

3.8.2 Distributed Resources Designed for Standby Operation

Some customers with, economically or functionally, critical loads will disconnect their loads from the system during a loss of service from the utility system and supply these loads with distributed resources. In this case the level of cold load pickup would be reduced by the loss of this load.

If the distribution circuit was designed assuming that these customers' load would be transferred to a standby distributed resource, the transfer of this load back to the utility source, after the system is restored, should be delayed until the circuit load has stabilized at an acceptable level that would permit the connection of additional load.

4.0 Estimating Load Levels Following an Outage

In order to determine load levels following a distribution circuit outage, load characteristics and the percent of each type of load connected to each distribution circuit must be estimated. Generally, load levels are estimated for peak load conditions, that is, peak winter heating load and/or peak summer cooling load.

After load types are identified, diversity factors are assigned for each load type. If it is anticipated that one-half of all connected space heaters will be operating during peak load conditions, then a diversity factor of 50% would be assigned to space heaters. When calculating cold load pickup the percent of each type of load should be divided by the diversity factor to determine the cold load pickup value, as all space heaters may be energized when power is restored. In Table 4.0 these factors are illustrated for a hypothetical circuit with predominately residential type of loads during heating season.

Table 4.0 – Load Type, Load Diversity Factor, Cold Load Pickup Factor (Winter)

Load Type	**Load Diversity Factor**	**Percent Circuit Load**	**Cold Load Pickup Factor (with loss of load diversity)**
Area Lighting	1.0	10%	10%
Resistance Space Heaters	0.5	25%	50%
Heat Pumps	0.5	25%	50%
Heat Pump Resistance Heaters	0.2	10%	50%(1)
Air conditioner	0.5	0%	0%
Miscellaneous Small Motors	0.25	10%	40%(2)
Large Industrial Motors	1.0	10%	0%(3)
Distributed Generation(4,5)			
Loads with Alternate Power Sources(5)			
Other Loads	1.0	10%	10%
	Total:	100%	210%

Notes:
1. Assumes supplemental resistance heaters actuate.
2. Miscellaneous small motors can be assumed to start faster than other general purpose motors.
3. Large industrial motors can generally be expected to automatically shut off when power is lost. If motors are equipped with magnetically latched motor starters or DC powered motor starters, the motors may attempt to restart when power is restored.
4. If loads normally supplied via distributed generation transfer to a distribution circuit, cold load pickup will be accordingly increased until distributed generation is restarted.
5. Cold load pickup is not applicable to loads with alternate power sources. Hot load transfers, that is, transfer with load diversity, do, however, need to be considered.

After cold load pickup factors have been established, total circuit current and time dependent current variations need to be evaluated. In general, four specific time intervals need to be considered: initial circuit energization which includes inrush current to all connected loads, 0.2 second inrush which characterizes circuit load as miscellaneous small motors are transitioning from starting to running, 2.0 seconds at which point steady state current has been reached, and 15 minute sustained load which characterizes circuit load before load diversity begins to recover. The inrush magnitude and duration varies with the type of load as explained in clause 3. [A2, A3]   This information is summarized in Table 4.1. Values in the table are multiples of the running current for each load type.

Table 4.1 – Load Type, Cold Load Pickup Model

	Multiple of Steady State Current / Time Interval			
Load Type	**Initial**	**0.2 Sec.**	**2 Sec.**	**15 Min.**
Area Lighting	2 - 8	1	1	1
Resistance Space Heaters	1	1	1	1
Heat Pumps	5 - 8	1	1	1
Heat Pump Resistance Heaters	1	1	1	1
Air conditioner	5 - 8	1	1	1
Miscellaneous Small Motors	5 - 8	5 - 8	1	1
Large Industrial Motors				5 - 8
Distributed Generation				
Loads with Alternate Power Sources				
Other Loads	1	1	1	1

Total circuit current should be determined algebraically as inrush to incandescent lights and heaters will be high power factor whereas motor starting current with be low power factor. Allowance can be made for reduced voltage, if during cold load pickup, distribution circuit voltage may sag.

The following is an example of taking the hypothetical circuit with predominately residential type of loads during heating season described in Table 4.0 and applying the values in Table 4.1 to provide an estimate for the current profile of the cold load pickup following a two hour outage. The typical load current for this circuit for this season, on this day of the week, at this time, with the present weather is 200A which will be the one per unit current for this event. The lighting and resistive heating load will be assumed to be at unity power factor where as the inrush for the motor loads will be assumed to be at zero power factor. The industrial motors were disconnected by the outage and were not restored, as shown in Table 4.2, until 15 minutes after the circuit was reenergized.

Table 4.2 – Example Cold Load Pickup for Hypothetical Circuit

Load Type	Initial Angle	Initial Magnitude	0.2 Sec. Angle	0.2 Sec. Magnitude	2 Sec. Angle	2 Sec. Magnitude	15 Min. Angle	15 Min. Magnitude
	Multiple of Steady State Current / Time Interval							
Area Lighting	0	8 (0.1)*	0	0.1	0	0.1	0	0.1
Resistance Space Heaters	0	0.5	0	0.5	0	0.5	0	0.5
Heat Pumps	90	4 (0.5)*	0	0.5	0	0.5	0	0.5
Heat Pump Resistance Heaters	0	0.5	0	0.5	0	0.5	0	0.5
Miscellaneous Small Motors	90	6 (0.4)*	90	6 (0.4)*	0	0.4	0	0.4
Large Industrial Motors	0	0	0	0	0	0	90	6 (0.1)*
Other Loads	0	0.1	0	0.1	0	0.1	0	0.1
Totals Multipliers for each Time Interval (note the diff. load angles)		4.8		3.0		2.1		2.2
Current for Each Time Interval		960A		600A		420A		440A

Note:
* The number outside of the brackets is the “Multiple of Steady State Current” from Table 4.1. The number inside the brackets is the “Cold Load Pickup Factor” from Table 4.0. The product of the two numbers is the multiple of the circuit’s normal current that this load type will contribute to the total circuit current. Quantities that have only one number, “Cold Load Pickup Factor”, are for load types that are not exhibiting inrush current in that time interval.

The circuit current will remain at the 2.2 per unit, the “15 Min.”, level or decline slowly while the load diversity of the circuit is regained. After the load diversity of the circuit is regained the circuit current will be at the normal one per unit level for that time of the day. This could be 200A but because the normal current level for the circuit cycles and the cold load pickup event has spanned a period of time the normal current level could be different. How long it will take to regain the load diversity will depend on a number of factors including the outdoor temperature following this heating season circuit outage. This estimating process made no attempt to estimate the length of the loss of load diversity. In the real life examples provided in the Appendix the load diversity on the circuits, in two cases, were regained in about an hour after circuit re-energization.

5.0 Voltage Recovery Inrush – Sympathetic Tripping

The voltage recovery inrush described in Clause 2.7 can result in tripping non-faulted feeders that are connected to the same source transformer as a faulted feeder. The following factors increase the probability of a sympathetic trip occurring:

- Time delayed fault clearing because it increases the time of the suppressed voltage condition
- High feeder loading
- Feeder load that is comprised of a high percentage of motor load
- Relatively low relay settings (ground and phase)
- Voltage dips low enough to stall motors but not low enough to drop-out the motor contactors

- Fast trip times on the feeder relaying because the feeder breaker will be susceptible to tripping prior to the distributed load's thermal unit tripping
- Low-set instantaneous relays used in fuse savings schemes being applied on the feeder

Figure 1 demonstrates the sympathetic tripping of an example feeder. Following a C phase to ground fault on an adjacent feeder, the neutral current on the feeder (bottom of chart) increased to about 700 amps, reduced to about 300 amps during the reclose into the fault and moved to 700 amps after the adjacent feeder locked-out. As can be seen from the chart the neutral current did not significantly decay during the following 3.9 seconds so the feeder breaker tripped. Once the feeder breaker tripped and reclosed the unbalance decreased and the circuit remained energized. [A4]

While this condition generally involves the circuit unbalance and ground relaying, other case studies have shown sustained phase currents over 1000 amps for similar instances and similar tripping has been experienced, especially where low set instantaneous phase relays have been used as a part of fuse saving schemes.

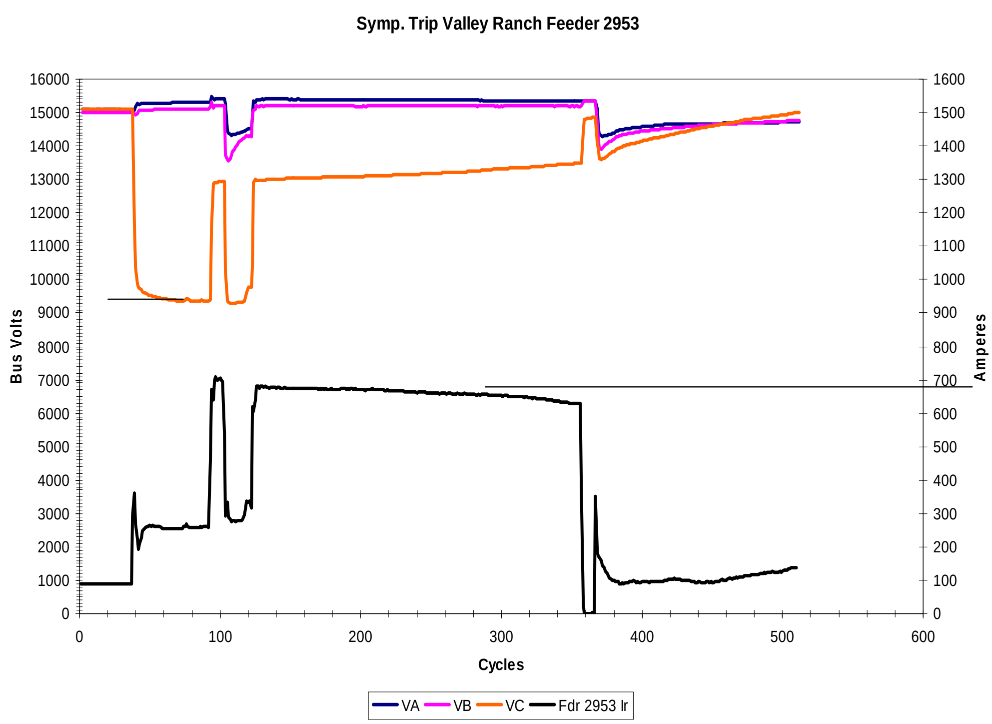

Figure 1 - Voltage Recovery Inrush – Sympathetic Tripping

The probability of experiencing sympathetic tripping can be reduced by the following steps, either collectively or individually:

- Setting the instantaneous overcurrent relays higher than the expected cold load pickup current and higher than the current experienced during a sympathetic trip event.
- Implementing alternate setting groups on non-faulted feeders in conjunction with faults that occur on other feeders served by the same substation transformer. The detection of this condition can use information from the local feeder and 1) other feeders on the bus, 2) the voltage on the bus, or 3) overcurrent information from the source transformer. This has been implemented using a broadcasted message over a digital local area network of a substation control system. This can simplify this logic somewhat, especially if a large number of feeders are on the same substation transformer.

6.0 Protection System Application Considerations

Relays are used primarily to detect faults on distribution systems and initiate operation of breakers to clear faults. Overcurrent relays, both time overcurrent and instantaneous are predominantly used. Relays are set to coordinate with down stream devices whether they are fuses, reclosers, or other relays. At the same time, substation feeder relays are set to coordinate with upstream relays and fuses.

Reference [A5] provides a detailed discussion on distribution relay coordination. In addition, the minimum pickup for the phase relay is some multiple of the maximum load on the feeder. The ground relay minimum pickup setting is higher than the resulting residual current due to the possible maximum phase load unbalance on the feeder. Since currents resulting from cold load pickup can be much greater than load current, the potential for overcurrent relays to operate during cold load pickup is great. What can be done to accommodate cold load pickup currents is limited by the type of relay being applied. The following discussion reviews what can be done to accommodate cold load pickup with these relay types: electromechanical, solid state, and microprocessor.

6.1 Electromechanical Relays

Three operating characteristics define electromechanical time overcurrent relays: the time overcurrent characteristic curve, the pick up current, and the time dial. The relay is set by adjusting mechanical devices, such as springs and set-screws. The settings are fixed and not able to be changed by automatic methods. Consideration for cold load pickup should be taken into account at the time of the protective system design and settings determination. This consideration should involve all three characteristics of the relay. If the relay package includes an instantaneous element, the element can be disabled or blocked for a period of time before and during load energization. This is done in order to permit ride through during the inrush part of the cold load pickup.

6.2 Solid State Relays

Solid state relays contain the same characteristics as the electromechanical relays, but predominantly use solid state electronics instead of electromechanical devices. Additional functionality is typical and includes such items as multiple time overcurrent characteristic curves. In some applications, rudimentary adaptive schemes have been employed. An example included a panel switch that enabled circuitry to double the current pickup as long as the switch was held in the closed position.

6.3 Microprocessor Relays

Microprocessor relays emulate the characteristics of the electromechanical and solid state relays, but use microprocessor based technology. Functionality is dramatically increased which allows multiple setting aspects:

- Timers to enable cold load pickup logic after the breaker has been open for a defined period of time
- Separate phase and ground overcurrent element multipliers to individually adjust the phase and ground overcurrent pickup while the cold load pickup logic is enabled
- Current detectors to sense when the cold load pickup phase and ground currents subside to below normal overcurrent pickup settings, thereby making is possible to automatically disable cold load pickup logic and restore normal overcurrent settings
- Timers to override the automatic reset in the event that the cold load pickup current includes a fault below the adjusted sensitivity of the overcurrent elements
- The capability to either block the instantaneous element or raise the time overcurrent pickup setting for a user selectable or adaptive period of time after the breaker is initially closed after lockout or on detection of inrush
- New setting groups can be selected to temporarily change settings during a feeder re-energization
- Multiple overcurrent element settings that can be switched in or out of service without disabling protection
- Torque-control logic to change the pickup of the overcurrent element(s) without shifting the time-current curve

However, the expansion in functionality increases the complexity of settings and the risk of either inadvertent operations or the failure to operate. For example, changing setting groups may not be the best practice if doing so momentarily disables protection. Also, shifting the time-overcurrent curve may not be desirable if coordination is impacted.

6.4 Distribution Feeder Recloser Operation

When service is restored after a prolonged outage, the cold load pickup current may cause reclosers to operate in a distribution system. The random operation of single phase reclosers can cause a significant rise in residual currents in feeder breakers and neutral currents in substation transformers. Reclosers may operate on both “fast” and “delayed” trip curves driving the reclosers to “lockout”. Under these conditions the reclosers will need to be closed manually to restore the load. Depending on the magnitude of the inrush current and the setting of the “delayed” recloser trip curves, the recloser may operate only on the “fast” curve and not operate on the “delayed” curve. This will result in the reclosers returning to a “closed state” after one or two trip operations on the “fast” curves. See an example of this type of operation on Figure 2 in “Appendix - Real Life Examples, A.1 Staged Test Results”.

Relays monitoring the transformer and feeder neutral current must be set with a high enough pickup and/or sufficient time delay to ride through the unbalance cold load pickup currents caused by the random operation of the single phase line reclosers if this type of fault interrupting device is applied on the circuit.

6.5 Automated Distribution Feeder Segmentation

Where-reclosers and automated sectionalizing switches have been installed out on feeders, it is possible to automatically recover cold load incrementally if cold load pickup is problematic. This strategy is implemented by simply opening feeder mounted devices automatically during conditions that produce cold load pickup conditions. These devices then either close automatically, or via SCADA, at an appropriate time after being reenergized and after establishing stable system voltage.

Establishing the time interval for opening these feeder devices is typically influenced by whether cold load pick up conditions exist prior to, or after, substation breaker lockout. If any reclosing open-interval produces cold load pickup conditions, these devices will typically open during that open-interval.

As with other cold load pickup considerations, several factors may govern the determination of the time interval for automatically closing an intermediate feeder device after it is reenergized. However, these factors are generally combined to ensure that the operating state of active upstream protection can accommodate the load profile added by the intermediate feeder device without tripping.

7.0 Conclusion

Cold load pickup needs to be included as one of the considerations when protective relay set-points are selected for distribution feeder protection. It's universally recognized that, when a feeder is restored after an extended outage, the load can exceed the normal feeder load until normal load cycling is re-established. However, numerous feeder specific variables need to be considered. The methodology described in this report provides a perspective of relationships between load type, load diversity, percent of circuit load for various load types, and cold load pickup. It is noted, however, that the methodology in this report was developed with the assumption that an outage of sufficient duration (to establish cold load pickup) has occurred during peak load conditions.

The conclusion of this working group is that cold load pickup needs to be addressed on a feeder specific basis as the factors listed in this report will vary due to localized conditions. The localized conditions, that may even vary between feeders at the same substation, may include the saturation of electric heat pumps with resistive heaters for supplemental heating, the availability of switches that allow loads to be transferred to other circuits while repairs are underway, the ratio of heavy industrial loads to other loads, etc.

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Appendix - Real Life Examples

The following is recorded data of load pickup events that were supplied to the working group from utilities in the United States. Except for the first example "A.1 Staged Test Results" the event data was captured during unscheduled operations of the power system. Due to the limitations of the recording equipment or the type of events; complete cold load pickup event data was seldom captured. Table A provides an index of the type of information supplied by the different examples.

Table A – Type of Cold Load Pickup Example Data

	Parts of the Events for which Data was Recorded	
Example	**Inrush**	**Loss of Load Diversity**
A.1	yes	yes
A.2	yes	no
A.3	no	yes
A.4	yes	no

A.1 Staged Test Results

The following are the results of two tests that were performed for the purpose of gaining a better understanding of the cold load pickup phenomena. Both of the tests were performed by a utility in the southeastern United States. In both cases, a substation transformer that carries the load of two distribution feeders is de-energized for a period of time and then re-energized by a transformer circuit breaker. This operation picked up the load of both feeders at the same time. The current is monitored on the low side of the transformer. Connected to the feeders are a variety of load types, but because these tests were performed on Sunday afternoons, most of the small industrial and commercial loads were not connected at the time. The test area included a large concentration of resistive and heat pump heating loads in the winter and electric cooling loads in the summer.

Test 1 was performed on a cold afternoon during the winter. The load before the transformer was de-energized was 171 amperes. The service to the load was interrupted for 39 minutes. The current through the transformer following the re-energization is shown in figure 2.

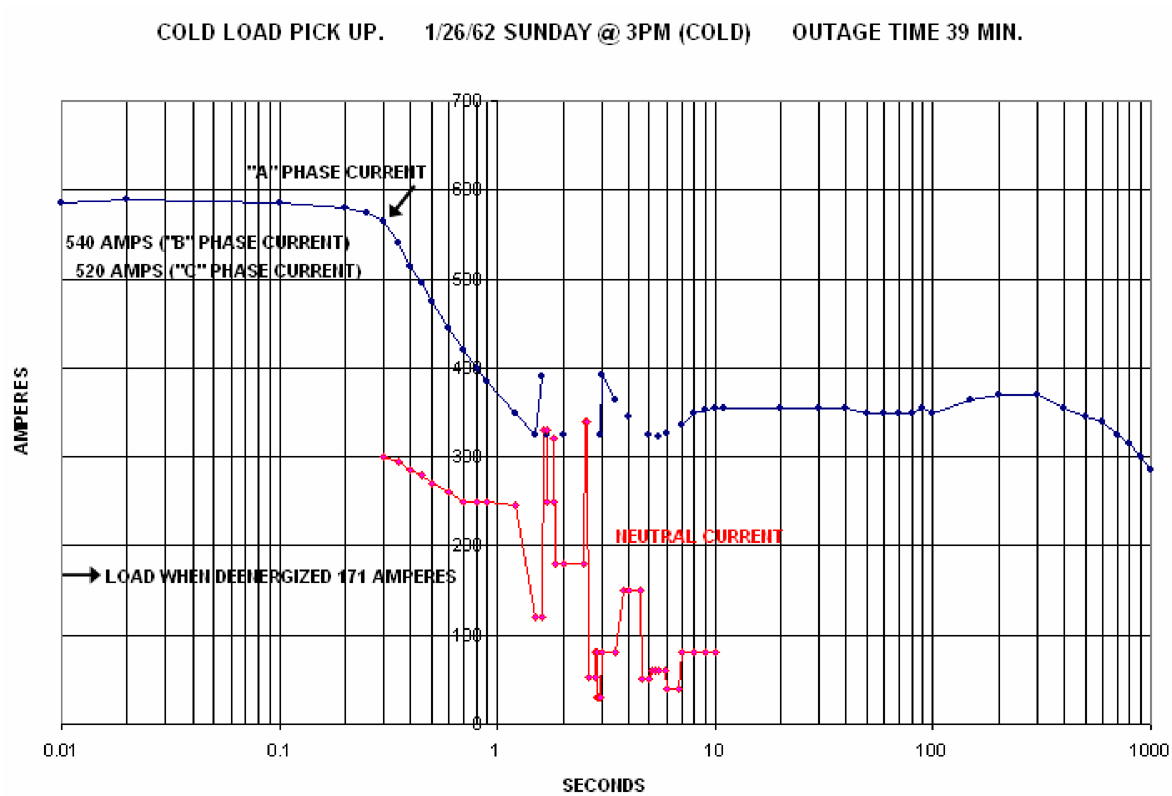

Figure 2 - Currents from the Winter Test

The inrush current was 580 amperes which is 3.4 times the pre-outage current. This first current plateau lasted for approximately 0.3 seconds. In 1.5 seconds the current decreased to approximately 320 amperes. The ratio of the two plateaus in current is approximately 2:1. In 1000 seconds some diversity was achieved and the current in the second plateau started to approach the value of the load current that existed before de-energization.

The amount of current in the neutral of the transformer is also shown on the graph. The neutral current initially after re-energization was 300 amperes. In about one second the current decreased to approximately 250 amperes. The neutral current then proceeded to alternate in a step fashion for an additional 10 seconds at which time it settled out to 80 amperes. The significant variations in the neutral current are attributed to line reclosers opening and closing in the distribution system.

Test 2 was performed on a hot afternoon during the summer. The load before the transformer was de-energized was 144 amperes. The service to the load was interrupted for 1 hour and 20 minutes. The current through the transformer following the re-energization is shown in figure 3.

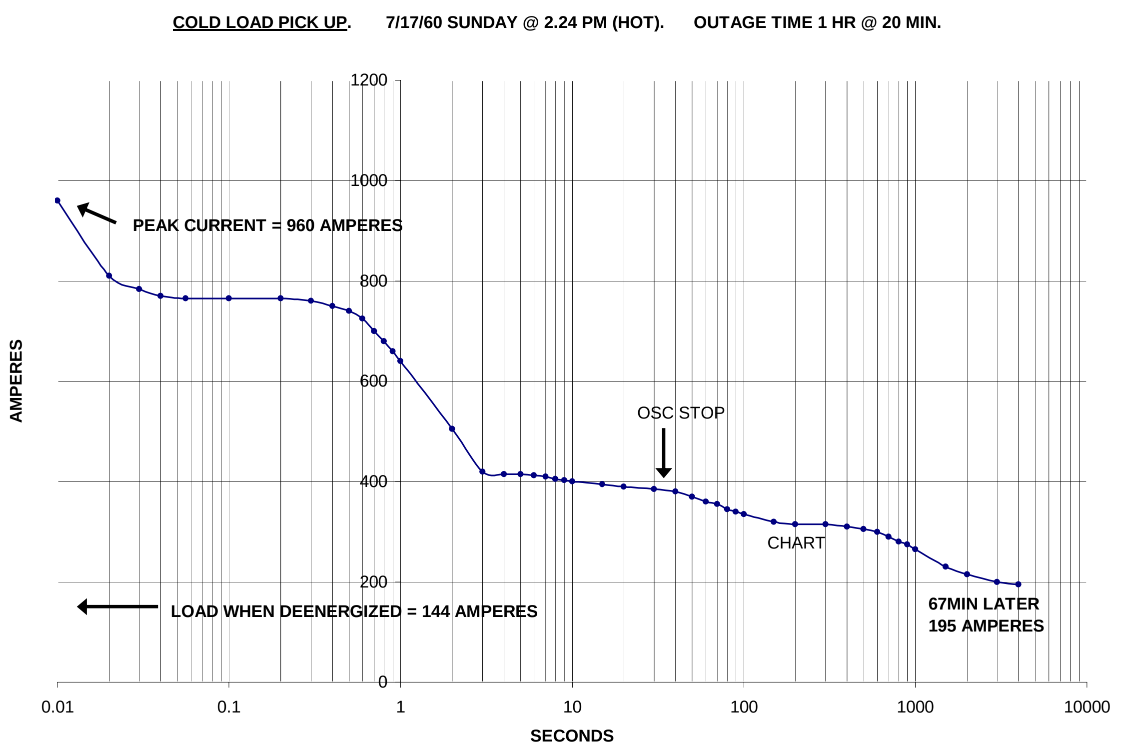

Figure 3 - Currents from Summer Test

When the transformer was re-energized a peak current of 960 amperes was recorded which was 6.7 times the pre-outage current. This current lasted for 1/2 cycles at which time it reached a plateau of approximately 770 amperes. This plateau lasted for approximately 0.4 seconds at which time the current decreased to a second plateau of 400 amperes. The ratio of the two plateaus is approximately 2:1. It would appear that load diversity started to take affect in approximately 1000 seconds, which is similar to the load recovery effects depicted in cold weather.

The following conclusions were derived from the result of these tests:

1) The cold load pickup in summer has a significant initial peak current for the first 1/2 cycle.
2) The ratio of the two plateaus is approximately the same for winter and summer. (2:1)
3) A more significant ratio is that between the first plateau and the current at 1000 seconds. For the summer condition, it was 3 and for the winter condition it was 2.
4) The transformer neutral current was recorded for the winter condition. It was not recorded for the summer condition. One might conclude that a similar unbalance occurs during all cold load pickup scenarios.
5) The magnitude and duration of the neutral and residual currents must be considered when setting ground relays
6) Both the summer and winter tests occurred on a Sunday, when industrial loads were minimal. It is reasonable to conclude that similar curves would be obtained during a work week when industrial loads are at a maximum because industrial load contactors would drop out when the station is deenergized. The significant difference would be the load recorded just before the banks are deenergized. Load reductions attributed to industrial loss would minimize the need to increase phase overcurrent relay pickup settings when a transformer is re-energized. However, it would not minimize the need to account for a significant unbalance in transformer neutral and residual circuits.
7) The second plateau for cold load pickup conditions in the winter time appears to increase from the period between 6 seconds to 600 seconds. This might be attributed to people energizing all available heaters to accelerate the heating of homes. The same ability to cool house in the summertime is not available with heat pumps and air conditioners; therefore, this phenomenon is not evident in the summertime.

A.2 Energizing a Distribution Network

Figure 4 shows the phase current recorded by a northeastern United States utility during the energization of part of their distribution network. The network was out of service for several hours prior to this re-energization. The utility has a control system which closes a number of distribution substation circuit breakers at the same time to energize all the sources to a section of the low voltage network. They were only interested in the inrush part of the cold load pickup, so the currents were only recorded until a constant value was reached. This current level is still higher than the normal load current level due to loss of load diversity.

The utility has a software system for predicting the inrush current for the energization of different sections of the network. The graph shows the close correlation between the prediction and the actual current value. The graph also shows that the inrush event is over in about one second after the energization of the circuit.

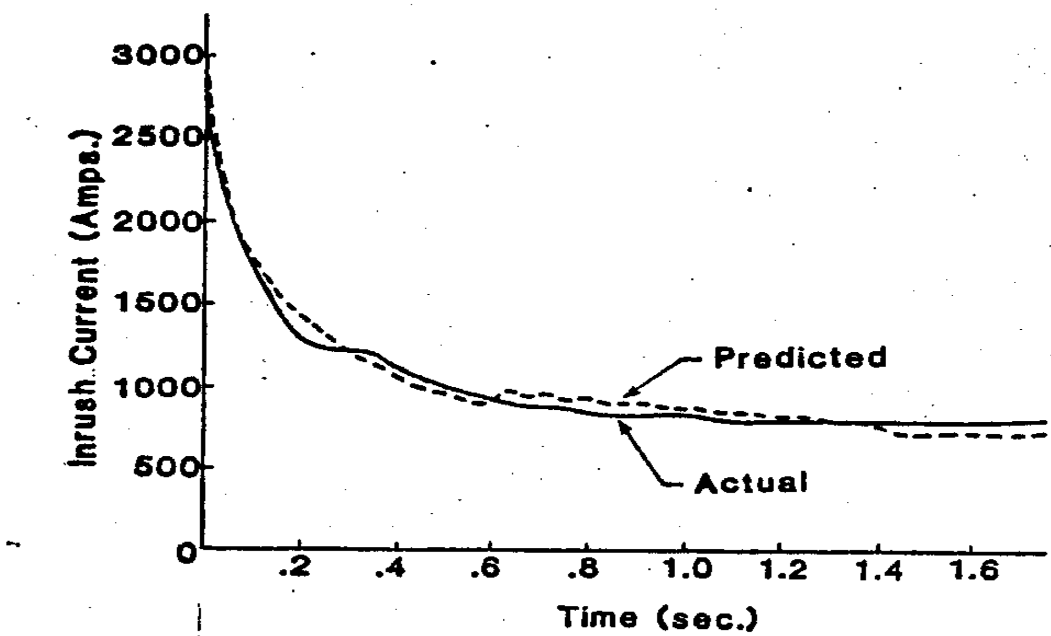

Figure 4 – Network Load Reenergization Inrush Current Profile

A.3 Northwest United States Cold Load Pickup Event

Figure 5 shows the loading on a 12.5kV feeder that serves customers along the Pacific coast in the northwestern United States. The outage started on November 6, 2006 at 16:18 and lasted for nine hours. The load was picked up at 1:18 the morning of November 7. The minimum temperature in that area was 34 degrees. The load on the feeder is primarily a mix of commercial and residential, with some small industrial load. There is a large amount of electric space heating and a majority of that load is resistive heating as opposed to heat pumps. There are no generators connected to the feeder.

Due to the slow sampling rate the chart does not show the inrush of the cold load pickup event. The three phase currents are shown. The pre-outage current was 150 amps. The currents were back down to that level in about 4000 seconds (1 hour and 6 minutes).

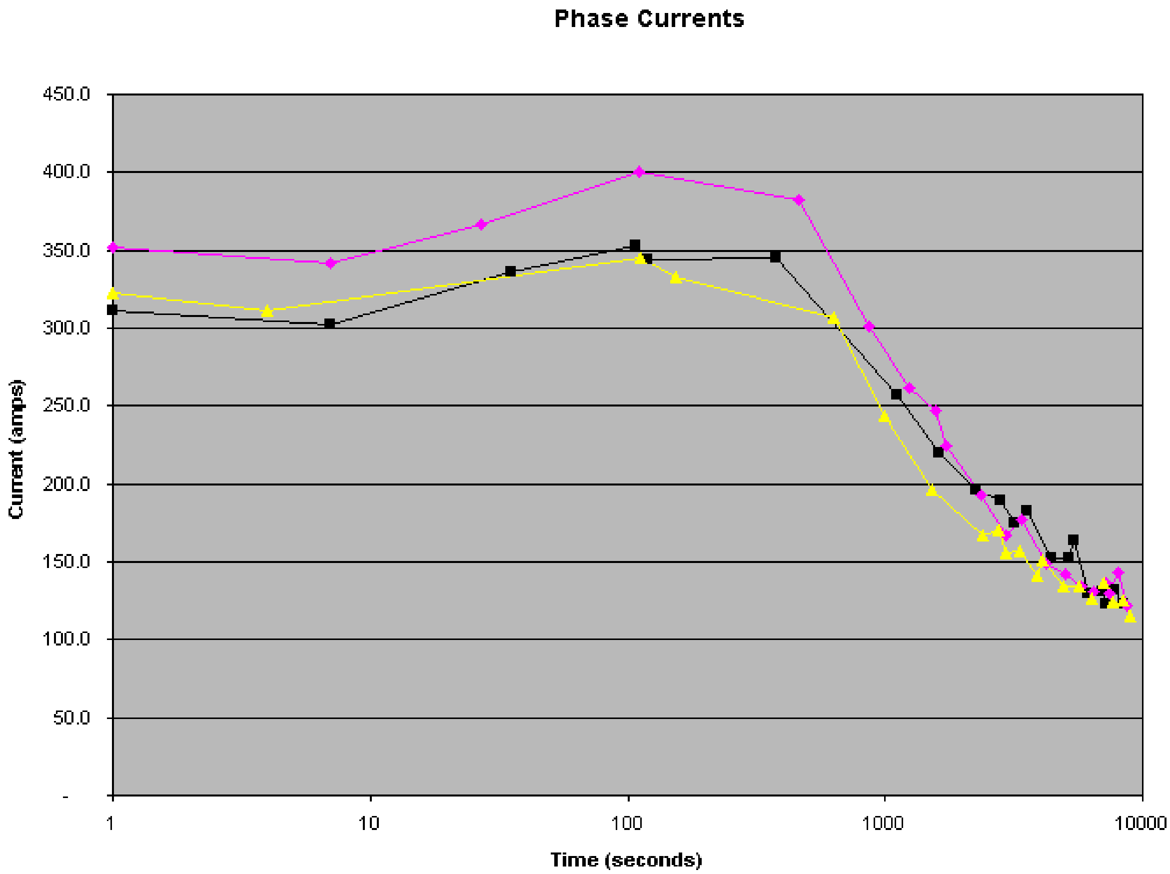

Figure 5 – Cold Load Pickup Event Current Profile

A.4 North Central United States Hot Load Pickup Events

Event 1

Figure 6 shows the current on a 35kV sub-transmission line prior to a line fault. The prefault load is approximately 170 amps. The maximum load on this line is 600 amps.

The average hourly demand readings were in the range of 350 – 400 amps range.

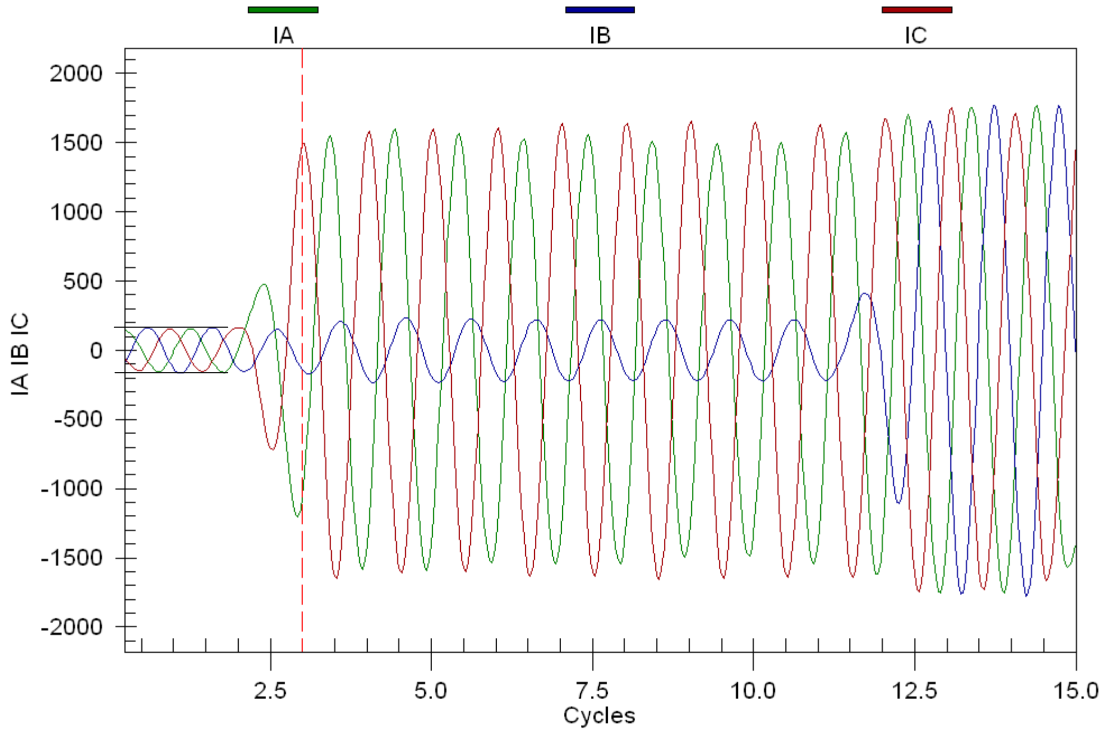

Figure 6 – Event 1: Preload and Fault Event Current

The line feeds a distribution substation with a 35,000 – 12,470 volt transformer. When the transmission line breaker reclosed the loaded transformer was energized with the line. The load connected to the transformer is a mix of residential, commercial, and industrial loads. The successful automatic reclose of the circuit breaker after a dead time of 5 seconds is shown in Figure 7.

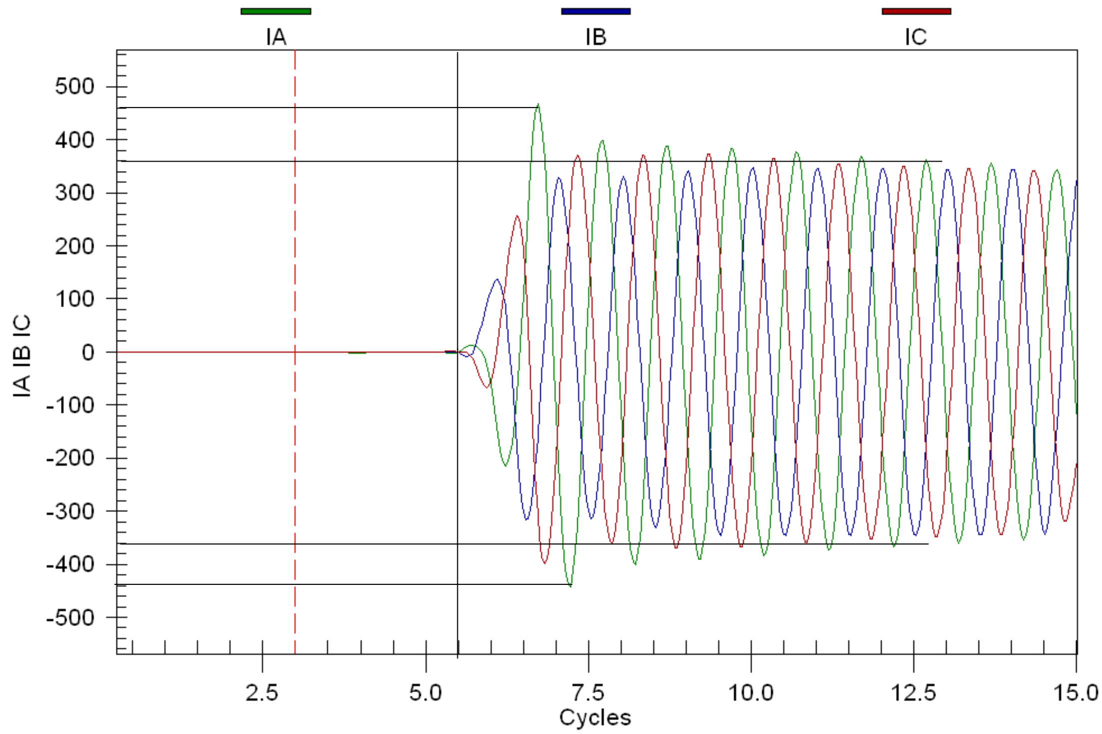

Figure 7 – Event 1: Hot Load Pickup Current

From the Figure 7 it appears that after a one cycle surge of one phase up to approximately 450 amps the hot line inrush current settled at approximately 360 amps. The current level remained relatively constant for the remainder of the record. The chart shows only 9.5 cycles (0.16 seconds) of the energization event. Figure 3 on "Example A.1" shows that the inrush current for a load with a mix of load types will start to decay at about 0.16 seconds. There is indication on Figure 7 that a reduction in current is starting at the end of the record. With the short outage, only 5 seconds, loss of load diversity should not be a factor in this example. The short outage could have caused the disconnection of some of the industrial loads. The inrush current is approximately 2 times the preload current, 170 / 360, which is about the same ratio as the inrush current is to the loss of load diversity current in the cold load pickup event shown in Figure 3.

Event 2

Figure 8 and Figure 9 show the current on a distribution line circuit for a fault and successful reclose event of a recloser out on the circuit. The system voltage is 24,940Y / 14,400 volts. The maximum load is 600 amps and the average hourly demand ranges from 200 – 575 amps. The load is primarily residential and commercial. The pre-event load current on the circuit was approximately 180 amps.

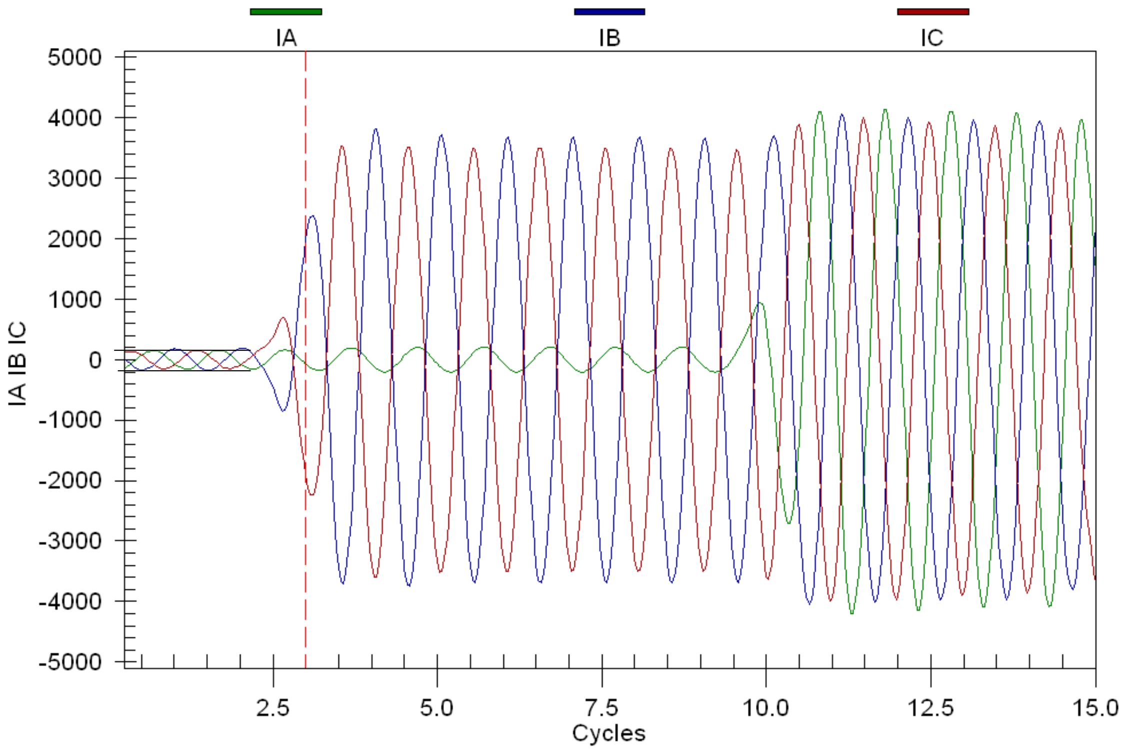

Figure 8 – Event 2: Preload and Fault Event Current

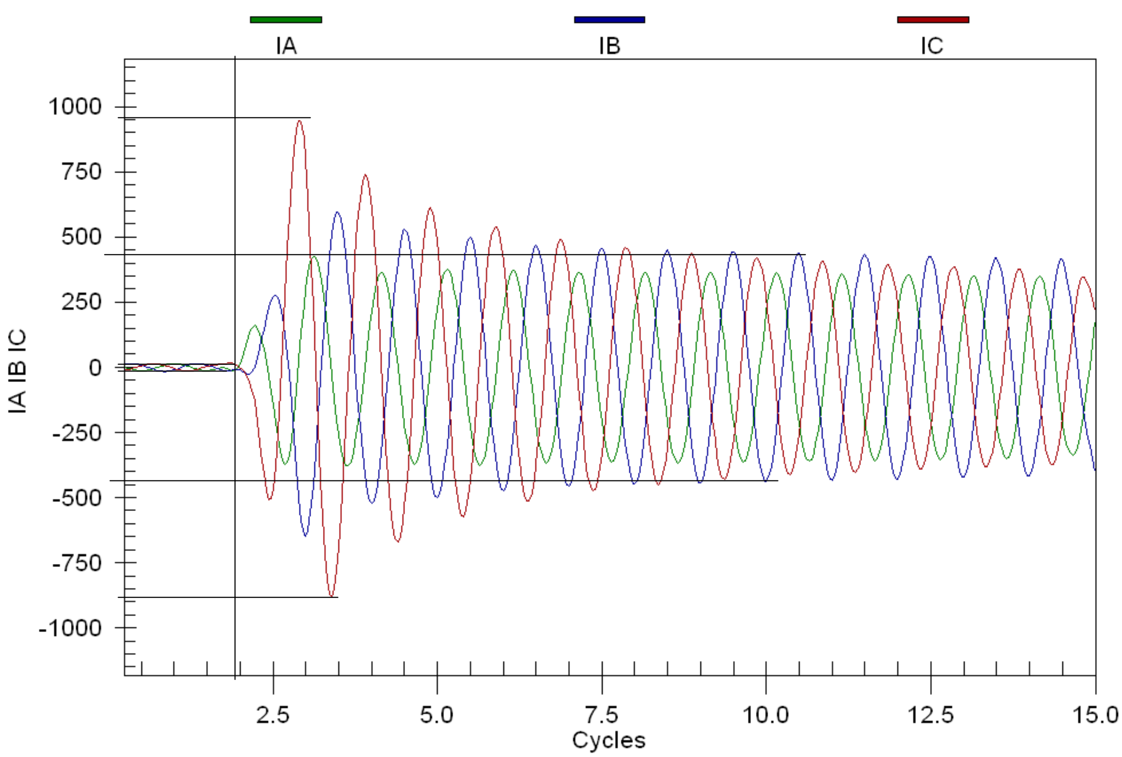

Figure 9 – Event 2: Hot Load Pickup Current

The load on the circuit shown on Figure 9 prior to the re-energization of the previously faulted section of the circuit was the load not interrupted by the fault. This load appears to be approximately 15 amps. The pre-event load on the part of the circuit of interest could be assumed to be 180 minus 15 amps or about 160 amps. The circuit was de-energized for only 15 seconds so again there should be no loss of load diversity. The loss of industrial loads because of the outage was not an issue due to the makeup of the load mix on this circuit. The current declined to about 430 amps after about 4 cycles. This would be a re-energized circuit load of 420 amps so the ratio between the pre-event circuit current and the hot load inrush current was 430 / 160 or a ratio of about 2.7 times. The record ended 13 cycles (0.22 seconds) after re-energization. This would be before the circuit current returned to the normal load current level.