Cold Load Pick-Up – Theory and Industry Practices

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Abstract:
Cold Load Pick-Up (CLPU) is an issue that has been recognized for many years, at least back into the 1940s. The term "Cold Load Pick-Up" (CLPU) refers to the increased currents encountered when re-energizing a circuit after an extended outage. The short term increase in currents, due to loss of load diversity and feeder inrush, can require accommodation in the protective relay settings, or affect performance of the protection scheme. CLPU also has been handled differently by different power companies. It may cause challenges over time as circuits are reconfigured, or if protection settings are not reviewed routinely as system expansions occur. The different approaches and lessons learned in protection and control have provided an opportunity to review the concepts of cold load pick-up, and investigate how CLPU is generally dealt with in protection and automation schemes. This paper discusses the concepts of cold load pick-up, the causes and effects, and investigates how CLPU generally is handled in protection schemes. The paper reviews past studies and an informal survey of a number of power companies conducted for the paper.

This paper reviews CLPU characteristics and describes practical solutions offered by manufacturers and power companies to address the protection set points and protection coordination challenges. A summary survey of industry practices, the types of problems encountered by industry, and a summary of discussions with various utilities on their CLPU problems and approaches is also offered.

What is Cold Load Pick-Up?

Cold load pick-up is the loading imposed on a distribution feeder after service restoration in which some loss of load diversity has occurred. The characteristics of cold load, described by some empirical relationship of load as a function of time, $i = f(t)$, will vary according to the types of load of a particular distribution feeder. Some of the common load classifications include fossil-heating, thermostatically controlled devices such as residential ventilation systems, light industrial, and small commercial loads, each with its own CLPU characteristic. Feeder load transfer and its possible impact on CLPU is also an important consideration during service restoration.

Circuit load upon restoration is generally different than it was prior to the interruption, for a variety of reasons.

- The diversity among individual loads that exists during normal state is partially or completely lost after an extended interruption (i.e., refrigerators or air conditioners that normally cycle on and off, are now on altogether). Such events tend to cause a high transient initial load that may have motor start characteristics, with varying decays to running levels and varying delays to normal diversity.

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- Similar to above, but having a somewhat different effect on load profiles, customers may have had planned tasks awaiting the return of power (i.e., run the washer or clothes dryer, cook a meal, run a periodic industrial process), and now that power is restored, these plans are starting in the short time period after restoration of power. This type of load can cause a peak a matter of minutes after load is restored, rather than the instant power is restored.
- The industrial processes that existed prior to the interruption may have stopped and need manual and gradual restart. This issue may cause a drop in load after restoration. This type of load can result in varying degrees of load restoration minutes to hours after restoration, and that never peaks beyond pre-interruption levels.
- Some loads have different restart/recovery characteristics compared to normal running conditions. For instance, during interruptions water or chemical levels may have changed and a motor might need to push against a larger, or lower, head until a tank is brought back to normal levels. Again, it is difficult to offer generalities on whether the restoration load will be higher or lower than pre-interruption loading.
- Single phase load interruption can have a notably different effect on loads than three phase load loss, and an associated different load restoration profile.

Hence, the load of a circuit when energized after a prolonged interruption may differ substantially from its pre-interruption loading level. In addition, the time constants of different types of loads will impact the rate of regaining normal diversity and steady state running characteristics.

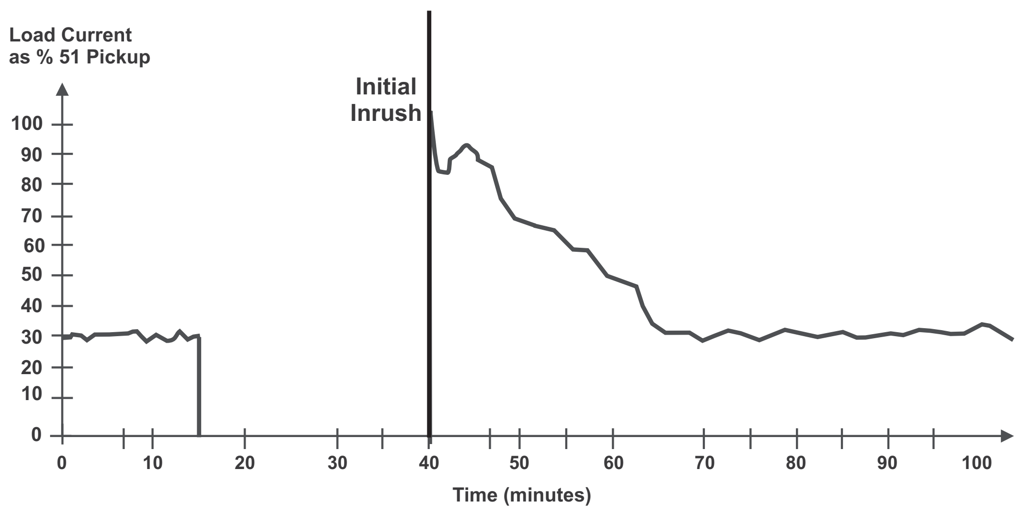

Fig. 1. Conceptual Cold Load Pick-Up Current vs. Time Profile

The first recognized phase of the CLPU problem was reported as caused by very high inrush and motor starting currents, which interfered with the normal operation of protection equipment. Enduring current, which is the result of loss of diversity, did not capture attention in the 1940s and 1950s. Partially, this was because the current was not as high as inrush and motor starting currents. Also, long duration of enduring current did not force the thermal limits of distribution equipment because of large margins between substation capacity and system load. Large margins were necessary for high system reliability since the distribution systems were in their infancy, and ties to other substations were either very limited or nonexistent.

Application of very inverse characteristic relays or sectionalizing the distribution systems were some of the solutions engineers used to overcome the initial peak and enduring high currents.

As thermostatically controlled devices in distribution systems increased, these types of enduring currents were found to be able to cause restoration problems even though they do not cause serious overload problems in normal operation. The sustained CLPU load after restoration is an important issue for thermal and loading limitations of distribution equipment.

Several aspects of the CLPU profile can be seen in Figure 1. The figure's time scale is too long to clearly show the initial inrush lasting only 1-2 seconds that is involved in starting many motors all at the same time, as well as the 2-10 cycles of excitation inrush to the large collection of distribution transformers that may exit. This current can be quite high, maybe reaching 4-5 times pre-interruption current levels. After this period, current multiples of 2-3 times the pre-interruption loading are somewhat representative of common cases, though a 2x factor is likely the more common level. The curve shows a slight delay in the peak current a minute or two after the restoration, which is an effort to represent a case where many loads are off, then manually switched on after customers realize power has been restored. The figure shows current returning to normal on the order of half an hour after restoration, but the time of restoration to normal can vary widely.

Operational constraints that may restrict the load restoration process that need to be considered during the CLPU normalization period are:

- Restoration problems due to unanticipated load characteristics (e.g., high currents causing relay tripping or device damage),
- Insufficient reserve transformer capacity in the substation,
- Possible transformer loss of life due to transient overheating, and
- Load transfers without considering adjustments to protection settings.

Key challenges associated CLPU include:

- Determination of appropriate pick-up points of various overcurrent elements, based upon necessary margins above load but below equipment damage points,
- Associated protective relay TOC curve selection, especially involving coordination at the low multiples of pick-up associated with CLPU,
- Voltage deviations (and on islanded systems, frequency deviations) and possible associated protection set point impacts,
- Thermal and loading limitations of distribution equipment during the time constant associated with the feeder becoming diversified, and
- Insufficient reserve capacity of every effected system device to supply the undiversified load.

Since CLPU is one of the most severe non-fault conditions that a distribution system experiences, restoration capabilities of the system and procedures to return the distribution system to normal operation as fast as possible will benefit not only the operation engineers but also the design engineers. Fast restoration of electrical energy to consumers and decrease in the interruption duration of customers also increase the reliability of the system. Therefore, a good concept of load behavior during CLPU is important.

Cold Load Pick-Up Modeling

The measurable parameters that determine the shape of the CLPU characteristics for different types of customer loads have been studied by many researchers, manufacturers, and power system companies. Mathematical models have been developed to aid in identifying the magnitude and duration of the CLPU for homogeneous as well as diversified feeder loads. The authors of these papers have described computer-aided modeling techniques [1, 2, 3, 4, 5], heuristic methods [6], knowledge-based approaches [7], and a network flow approach [8]. A selection of papers about system modeling for distribution circuits also can be found in [2]. All of these articles address the issue of CLPU, transformer thermal behavior, and search for the best switching strategy to maximize the number of sections restored and to minimize the time to supply power to the unaffected areas.

Today's technology provides ease of capturing high resolution data from the field recordings during actual restorations that will help validate and improve the CLPU models. The protective relay manufacturers also have been developing concepts to help power company engineers overcome the challenges of feeder restoration following extended interruptions.

In general, CLPU currents can be categorized into four phases according to the load current levels and durations. These phases are inrush, motor starting, motor running, and enduring current phases. Motor starting refers to the first second it takes most motors to accelerate to rated speed, and motor running refers to the initial high-powered period required to start processes. The first three phases last approximately less than 15 seconds and the current may reach 5 to 15 times of the pre-interruption current [9-12], especially in the first 10 cycles. The enduring current phase follows the third phase and continues until the normal diversity among the loads is re-established. The load in this phase may vary from 2 to 5 times of the diversified load level, though less than 3x is likely the most common level. This phase may last for several hours depending on interruption duration and outside temperature. The magnitude and duration of load during CLPU will depend on:

- Outside temperature
- Duration of interruption
- Type and ratings of connected load

Two basic CLPU regions are transient and enduring demands. Feeder power system characteristics in the CLPU transient region are most influenced by transformer and motor starting characteristics, and to some degree loss of load diversity. Several studies and system modeling have been conducted to determine the effects of CLPU on transformers and whether the CLPU characteristics of a feeder can be accurately predicted. Quantitative methods and simulation programs compute the dynamic characteristics of thermostatically controlled loads and combine the data with load patterns on customer appliances under starting conditions to derive restoration loading curve. There also are field measurements and recordings of feeder loads to validate the load pattern recognition algorithms. The parameters that attribute to the field recordings include:

- Date and time-of-day when service is restored; gives an implicit knowledge of the ambient temperatures,
- Duration of preceding interruption,
- Voltage and current levels of the feeder just prior to the interruption, and
- Knowledge of restoration time as a reference to the time load has dropped to about the pre-interruption load.

Since the characteristics of CLPU vary according to the nature of the load on a particular distribution circuit, the magnitude, shape, and duration of the increased load (caused by cold load) needs to be adequately defined (or known for protection studies). The design of the feeder, the protective relaying application and set points, fusing practices, and methods of service restoration may be significantly affected by the characteristics of CLPU.

Thermostatically Controlled Loads
One key in CLPU analysis is the techniques used to model thermostatically controlled heating and air conditioning loads. Accurate load representation and modeling is generally a difficult task. This is because the model needs to consider the aggregate effect of a large number of customers that have a wide range of equipment and thermostatic set-points, each making individual decisions. Figure 2 shows the basic model for a thermostatically controlled electric heating system.

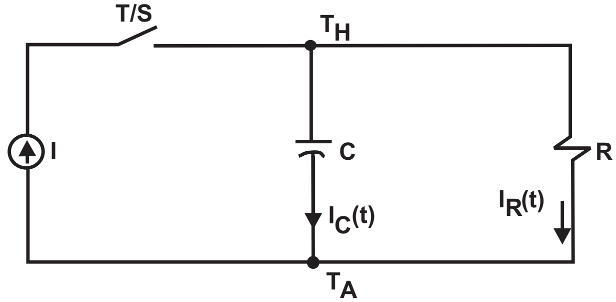

Fig. 2. Simplified model of a thermostatically controlled electric heating system

The parameters are defined as follows:

T/S	Thermostat On-Off switch
T_{H-A}	House temperature - Ambient temperature (^OF)
T_H	House temperature (^OF) =(1/C) $\int(I-I_R)dt$
C	Equivalent thermal mass of house (kWh/^0T_H)
R	Equivalent thermal resistance of house (kWh/ $^OdT_{H-A}$)
I	Rate of heat injection into the house (kWh)
I_C	Heat/(unit time) flowing into the thermal mass of the house (kW)
I_R	Heat/(unit time) loss to the outside environment (kW)

The thermostat T/S operates within a pre-set deadband of about 2^O F, giving a hysteresis characteristic. Figure 3 shows the typical characteristic of a heating unit for a residential thermostat with hysteresis. For the purpose of representation, thermostat anticipator effects in lowering the deadband are neglected. The dashed line occurs only if the thermostat fails to open. In that case, the building temperature increases until the house heat injected, I, equals the heat loss through the insulation.

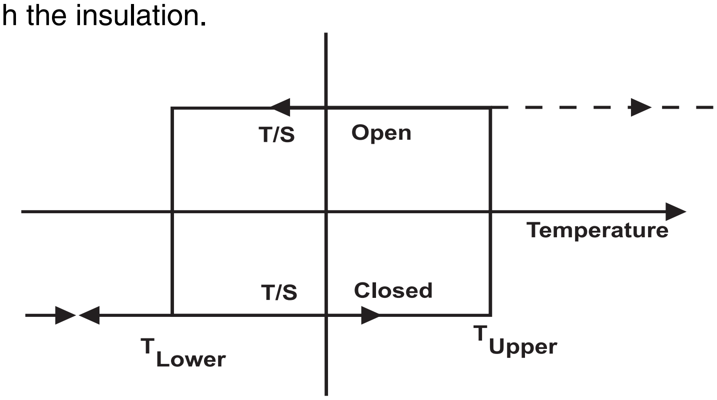

Fig. 3. Residential Thermostat Characteristics of a Heating Unit

Representative values of other structure parameters also can be modeled in a similar manner. Figure 4 shows variation of building temperature during one cycle of thermostat operation under normal conditions.

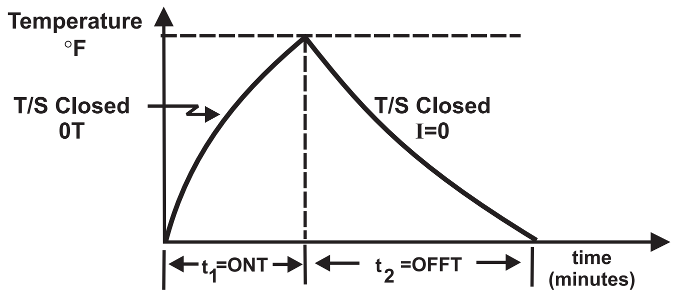

Fig. 4. Building temperature during one operational cycle of a heating unit thermostat

For a typical feeder residential load, since the structures of different homes vary, each house will be at a different temperature when interruption occurs. Upon restoration of a feeder, there will be some time before the diversity of thermostatically controlled loads is stabilized. The temporary overcurrent condition created by re-energizing a feeder or lateral that has been out of service for some period is a constraint to distribution system overcurrent protection and coordination, due to cold-load pick-up.

In 1976, the Electric Power Research Institute (EPRI) in cooperation with University of Texas at Arlington (UTA) concluded that a composite model can be developed by combining the load characteristics of individual loads that are “on” at the time of interest. Experimental and theoretical studies on individual electrically heated homes were used to validate the joint EPRI – UTA study [14].

There are CLPU software tools that estimate a time duration versus current curve for a feeder at restoration following an interruption. The estimation is based on the composition of the loads on the feeder, the duration of the interruption, and the ambient temperature.

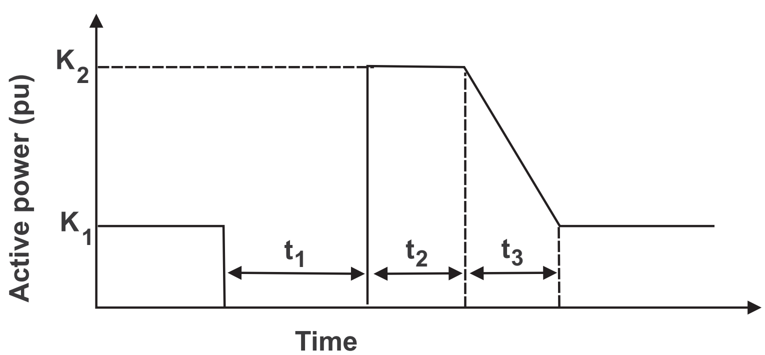

Fig. 5. Example of a load model for cold load pick-up [16, 17].

Figure 5 shows a generic CLPU model [16, 17]. For this model, K1 is the pre-interruption load; K2 is the magnitude of the CLPU overload. Time t1 is the interruption duration, t2 is the time for the CLPU overload, and t3 is the time until load diversity is restored. Studies can determine appropriate constants for the model. Distribution restoration studies in conjunction with distribution automation will further allow the distribution systems to be operated optimally by finding, for a given feeder, the values for the model above, by measurement.

Load Behavior After a Circuit Interruption

Individual loads on residential feeders can be categorized into two different groups; thermostatically-controlled and manually-controlled. In general, thermostatically-controlled devices such as air-conditioners, heaters, and heat pumps provide the largest contribution to the total load in a typical home. Feeder loads that are predominantly homes with low R factors (as defined in Figure 2), such as mobile homes, the low R value results in very high loads after an extended interruption.

Manually-controlled loads are switched on and off by occupants of the house in undetermined patterns, but are part of the cause of a transient delayed peak that can occur roughly a minute after restoration. During normal conditions, diversity among loads is present; therefore, the aggregate load of a number of homes is less than the connected load. When an abnormal condition such as an extended interruption occurs in a distribution system, some or all thermostatically-controlled devices will be on as soon as the power is restored. Similarly, the aggregate load of manually-controlled devices will be higher than normal upon restoration, but after a short delay. Many people may be in a darkened house waiting to turn on the washer or dryer or cook dinner. As soon as power is restored, these normal activities resume, but after a short delay while the customers rejoice at the return of power.

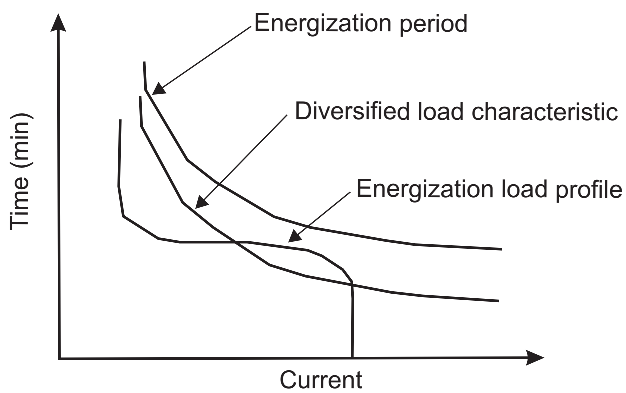

Fig. 6. Feeder Protection Coordination Against CLPU Characteristics

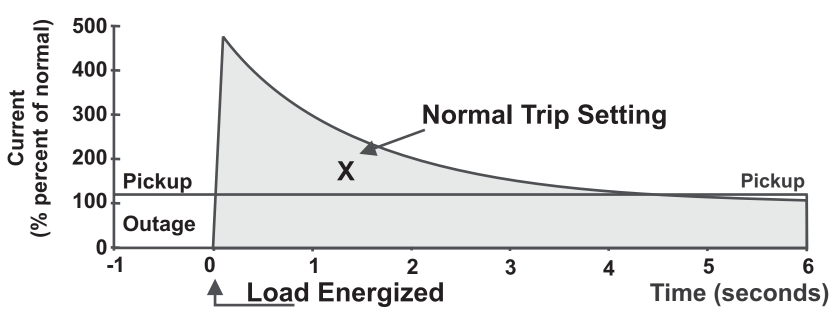

Fig. 7. CLPU Characteristics Detected by Feeder Protective Relay

Power company strategies and the type of system load patterns also can complicate the CLPU problem. For example, delayed capacity expansions cause reduction of capacity margins on feeders. Reduced spare capacity on feeders produces higher loaded systems, which ultimately makes CLPU and restoration efforts more difficult. The application of variable speed heat pumps and AC units has also complicated the process. These units will come on sooner after an interruption and, therefore, demonstrate a different type of load pattern than heating and air conditioning loads with across-the-line motors that are automatically started, but sometimes with deliberate delays built into the element controls.

One of the traditional ways of dealing with the CLPU problem is sectionalizing the system and restoring power to the sections using manual switches. For example, manually-operated sectionalizers have been used successfully to deal with the enduring portion of CLPU. However, this practice is not strictly followed. In some circumstances, personnel have bypassed the recloser instead of picking up the load in sections, thus tripping the entire feeder due to cold load current or phase imbalance. Application of automated sectionalizing also may be a consideration.

In some feeder applications, and many recloser applications, the use of fast TOC curve (first trip usually) followed by slow TOC curves (subsequent trips usually) is a common “fuse-saving” practice. In some recloser designs, if the recloser Close Switch is held closed, the recloser operates on the Slow curve, which helps the recloser ride through the magnetizing current of distribution transformers and motor inrush currents. If the recloser operates, load restoration is made in sections. Most power companies also provide annual training for the operating personnel, on the energization of feeders experiencing cold load pick-up problems. Furthermore, careful protection studies are critical in terms of planning and identifying the location of line reclosers or fuses to minimize any potential for failure to trip when the fault duty goes below 'margin of detection', as result of CLPU set points on protection devices (e.g: raising the phase pick-up for a CLPU). Some power companies use 1.5 times for a phase-to-phase fault and 2 times for a SLG.

With application of Supervisory Control and Data Acquisition (SCADA) systems and newer devices with multiple group settings, some power companies have implemented operating procedures as to when the alternate set point on a protective relay is activated for CLPU on heavily loaded feeders. Use of alternate protection set points relaxes the time elements and increases the pick-up of the feeder phase and ground over current relaying, while maintaining coordination with the transformer protective devices.

Industrial/Commercial Loads

Industrial and commercial loads have a notably different load restoration profile. These loads, especially industrial ones, will likely be lower for a period after restoration. Such facilities have processes that do not restart automatically and may need to be ramped up through an extended process. Lighting contactors may need to be manually closed. Motors that move products could result in dangerous conditions if they restarted automatically.

In areas that are a mix of industrial, commercial, and residential, the net CLPU may be flat relative to pre-interruption loading, because as one load type rises, another drops down. Hence, severe CLPU tends to be more of an issue to residential areas with extensive amounts of loads that are automatically restarted.

Ground Relay Pickup Issues

Related to single CLPU as examined on a three phase basis, there are some issues associated with single phase CLPU that cause ground relay problems. These problems can arise when heavy unbalance is seen due to inrush into single phase loads.

Single Phase CLPU

Single phase CLPU on line to ground connected loads causes a unique problem with ground relays. Heavy line to ground unbalanced loading is seen as a line to ground fault. The pickup of neutral overcurrent relays is typically set to 1/2 to 1/3 of feeder phase relays, so these relays can be armed by the CLPU of a large single phase lateral.

Single Phase Hot Line Pick Up

This problem is closely related to the single phase CLPU problem. When a single line to ground fault occurs on a feeder, the fault can cause a voltage dip on that phase over the entire feeder. The voltage dip can cause all motor loads on that phase to stall, even if the fault is cleared in a matter of a fraction of a second. When voltage is restored, all the motors on that feeder are effectively in a CLPU inrush condition. This causes high ground current at the source substation and in reclosers on the line.

Unequal Phase Restoration Time and Load Magnitude During CLPU

Phase loads tend to be independent of one another. During a load restoration process, if one phase returns to normal loading sooner than the other, or if motors on one phase come out of the acceleration mode sooner than the others, the result is high ground current at the source substation and in reclosers on the line.

Techniques for Mitigating Cold Load Pick-Up Effect on Relaying

There are several actions that can be taken to ensure that protective systems do not incorrectly trip during CLPU conditions. These include reconfiguring the actual distribution feeders, so the relay does not see CLPU problem at all, and reconfiguring the protective relaying scheme so that it will not trip for the CLPU condition. Both techniques can be performed manually or automatically, depending on the system capabilities.

Reconfiguring the Feeders

During the past decade, an increased level of distribution system automation has been seen [1-14], and penetration of distribution automation will only increase. Feeder deployment, substation transformer load balancing, voltage/VAR control, automatic sectionalizing, and load control are some of the functions that can be implemented in an automated distribution system. Automation will result in economic savings, higher revenue, and improved system reliability indices. For example, the faulted parts of the power distribution system can be identified with the aid of computers using the methods suggested by several authors [15-19]. In automated feeders, load is restored more quickly where possible, and less of the system sees a sustained interruption. This, in turn, reduces CLPU issues.

Quick identification of the faulted parts increases the system reliability. Also, automatic load transfer capability allows distribution systems to work with fewer margins between supply and load during normal operation. In general, distribution automation reduces the need for redundancy, defers construction of new facilities and maintains reliability with fewer resources [9]. Occasional system conditions such as CLPU can be easily accommodated with automated systems, allowing the possibility for optimized protection system configuration during normal operating conditions.

During an interruption, the feeder can be reconfigured to decrease the impact of the resulting cold load phenomena. Distribution feeders can be configured with sectionalizing devices or with load transfer capabilities. A line sectionalizer detects when a feeder has been de-energized, and open, to segment to load. Sectionalizing schemes may automatically connect the isolated segment to another available source. This automatic sectionalizing and load transfer is known as "Loop Reclosing Scheme". Figure 8 shows a loop reclosing scheme through independent operation of 3 sectionalizing devices each designated by an encircled "S".

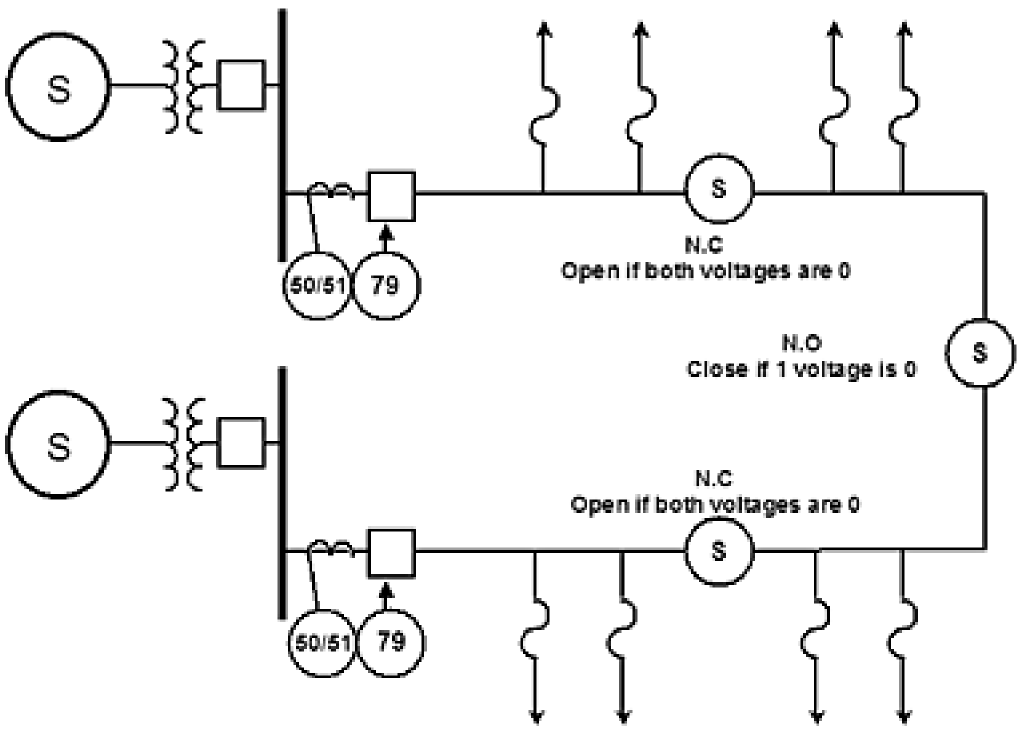

Fig. 8. Loop Reclosing Scheme

Feeders also can be manually reconfigured during interruptions, using field tie switches. This is primarily done as a load transfer function to minimize interruption time to segments of the feeder, but it also serves to decrease the load, which is picked up when restoring the de-energized feeder.

There are myriad variations of load restoration schemes.

- Many utilities have field ties that are operated by SCADA only and, when coupled with remotely readable fault indicators at select locations, the operators determine where the permanent fault is located and manually isolate the section.
- Some radial systems simply drop loads starting from the most remote load until the point when the line is restorable.

- In some applications, as crews repair failed system components, they operate manual field ties to restore power to loads as much as possible, thereby reducing the amount of load that is restored in the final load restoration steps.

Each of these processes effectively mitigates the effect of CLPU. In each case, there is a reduced CLPU effect that a relay must withstand.

Accommodating CPLU in Standard Relay Schemes

As an alternative to load sectionalizing, the protective relay scheme can be designed to accommodate CLPU conditions. This could be through normal settings that accommodate expected cold load conditions or through settings modifications (manual or automatic) when cold load conditions are expected.

In order to be secure for CLPU conditions, overcurrent relays must be set above CLPU peaks, or with sufficient time delay to coordinate above the expected CLPU condition. A time overcurrent relay (51 element) may be allowed to pick up, as long as there is sufficient time delay to accommodate the current. This may be more practical for magnetizing inrush type currents, which return to normal more quickly. For example, with a large load base of air conditioning units, there is a surge during restoration of the accumulated compressor motors, followed by the larger-than-normal load due to all of the units being on (due to loss of load diversity). If the normal overcurrent setting can accommodate the maximum loading, then a time dial setting can be determined to “ride out” the initial surge and ensure security. See Figure 9.

It is a practice of some utilities to set an instantaneous (50P and / or 50N) element on each feeder to sense faults in the near vicinity of the substation, as a protection for the transformer. This 50 element, if set too sensitive, could trip for CLPU conditions. If 50 elements need to be set below expected CLPU levels, a fixed time delay can be added to ensure security, making them effectively a definite time delay element, 50TP or 50TN.

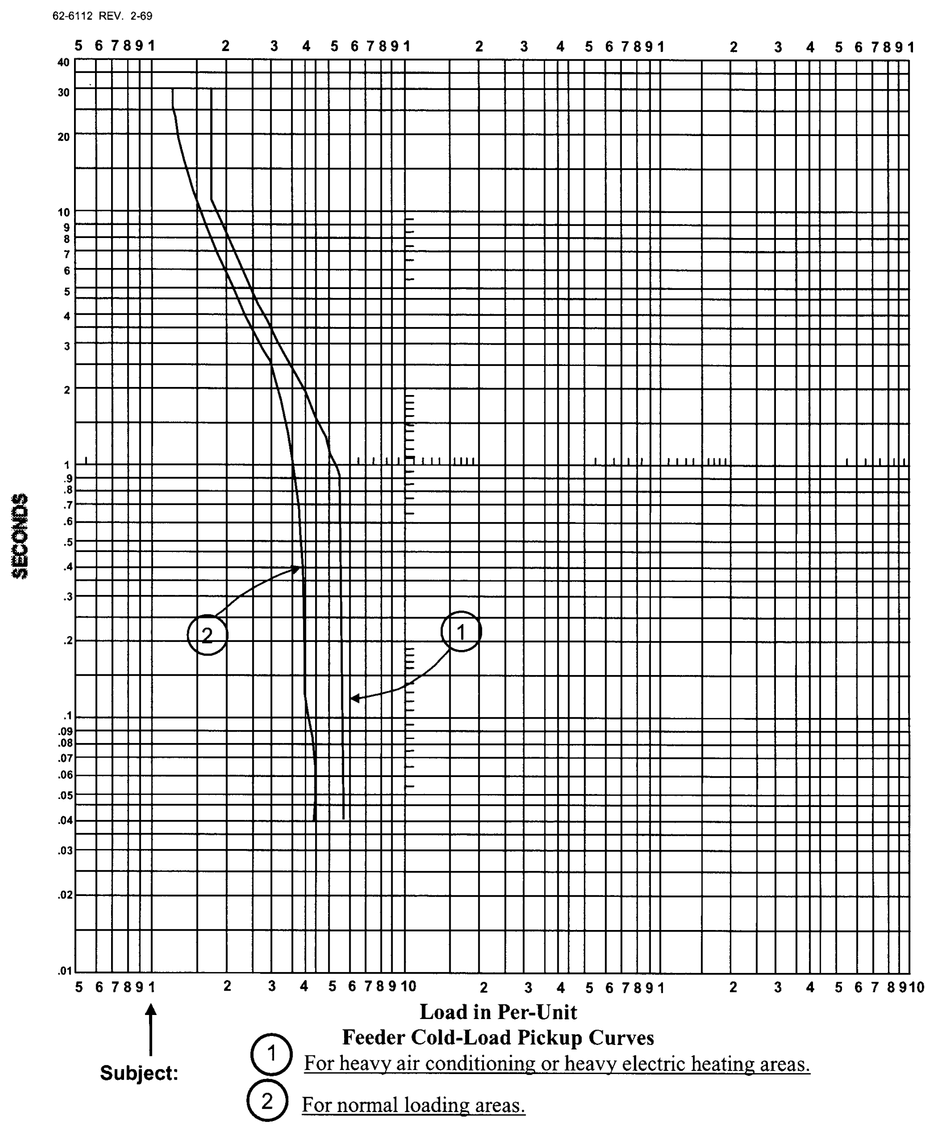

Fig. 9. Accommodating CLPU in Standard Relay Schemes

Adaptive Relaying Schemes to Accommodate CLPU

Relay settings seem to be largely based on "rule of thumb" criteria that usually enable the circuit to be secure for "worst case" non-fault conditions, including CPLU. The advent of numeric relay systems and improved communications schemes has allowed the capability to create relaying schemes that adapt themselves to accommodate CLPU conditions. Essentially, the relay changes its performance to ensure security during CLPU conditions, either automatically or through a communications network such as SCADA. This allows the possibility for more sensitive relay settings during normal conditions, while maintaining security for the times when CPLU is expected.

In modern numeric-based relay systems, adaptive relay schemes are easily implemented. Individual elements can be blocked through contact inputs or commands through a communications network. Or, a range of changes can be implemented through the use of alternate setting groups. An alternate setting group represents an additional, complete group of protection settings, including the ability to select different pick-up levels, time delays or time curves for each element in the protective scheme. By selection of alternate setting groups, the protection scheme can be reconfigured and optimized relatively simply for any specific condition such as CLPU. Modern numeric relays may have several alternate setting groups, allowing the system to be configured for multiple conditions (emergency loading, disable fuse saving, CLPU, etc).

Numeric relay systems can switch setting groups based on a variety of parameters, including contact input, front panel access, or automatically, based on system conditions. For example, for a cold load pick-up scenario, a user could configure a numeric relay system to switch into an alternate setting group when the sensed current drops to zero for a predetermined amount of time, representing a circuit outage. The alternate settings may include time delay (or higher pick-up) on instantaneous overcurrent, higher time dial (or pick-up) of time overcurrent, and / or disabling low set instantaneous overcurrent element.

The approach of handling CLPU issues by enabling an alternate setting group after an extended time of “current = 0” could result in a relay seeing very low, but normal, load current as an interruption of load, so a certain amount of intelligence has to be used on the implementation of the scheme and the determination whether the effect of transitioning to an alternate setting group during very low load conditions would be detrimental. To improve reliability of this logic, one could supervise the logic with ”Did I see a fault prior to current going to 0?” or “Is the breaker I am monitoring open?”

It might be noted that some manufacturers’ relays cannot change settings “on the fly,” and effectively must reboot themselves to change settings groups, thus limiting the usefulness of using setting groups to addressing CLPU problems. Other relay manufacturers’ relays can change settings groups on a single relay logic scan; hence, can implement CLPU settings instantaneously, as fast as users can send the commands, making changing setting groups a useful approach to CLPU problems.

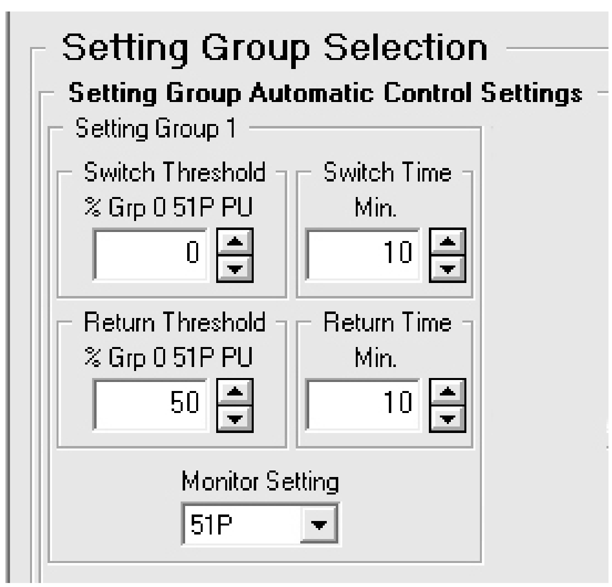

Fig. 10. Automatic Setting Group Screen

Along with the switch into an alternate group, the automatic setting group function must define the parameters to return to normal. In this case, when the current returns to a predefined value (as determined by % of 51P setting) for a defined time period, the relay system reverts to the base setting group. This is just one example of how automatic setting group changes could be applied to optimize the protection scheme for both normal operation and CPLU conditions.

Adaptive Relaying for CLPU in Fuse Saving Schemes

The practice of fast clearing of a fault in order to save a fuse has ramifications on cold load pickup practices. In fuse saving practices, the first trip tends to not only be fast, but it sometimes involves a low set 50 element. This low set 50 element is highly sensitive to CLPU issues. Companies that use fuse saving logic tend to be aware of CLPU issues and will block this 50 element during feeder restoration processes.

Adaptive Ground Relaying for CLPU

As previously mentioned, unequal restoration time of loads results in current unbalance. There will be two stages of two different magnitudes: acceleration stage, and the extended. Motor starting times may vary by phase (e.g., maybe a heavier loaded phase will have more voltage drop, causing a less rapid acceleration of motors). The ground relay, as a result, may need to be adjusted just as the phase relay to accommodate CLPU conditions.

IEEE Power System Relay Committee Survey, 2002

In 2002, The Power System Relay Committee (PSRC) of the IEEE released a paper summarizing its utility survey of Distribution Line Protection Practices [19]. This summary included a section on cold load pick-up that also discussed Magnetizing Inrush. The periodic survey of the utility industry was performed by a working group of the Line Protection subcommittee, following 3 previous surveys during the previous 20+ years. Forty-nine utilities responded to the 2002 survey.

Forty-three of the 49 responding utilities answered the section on cold load pick-up. More than half of the respondents (55%) reported experiencing cold load pick-up problems “in the last few years.” Only a third (33%) reported no cold load pick-up problems, and another 12% were unsure.

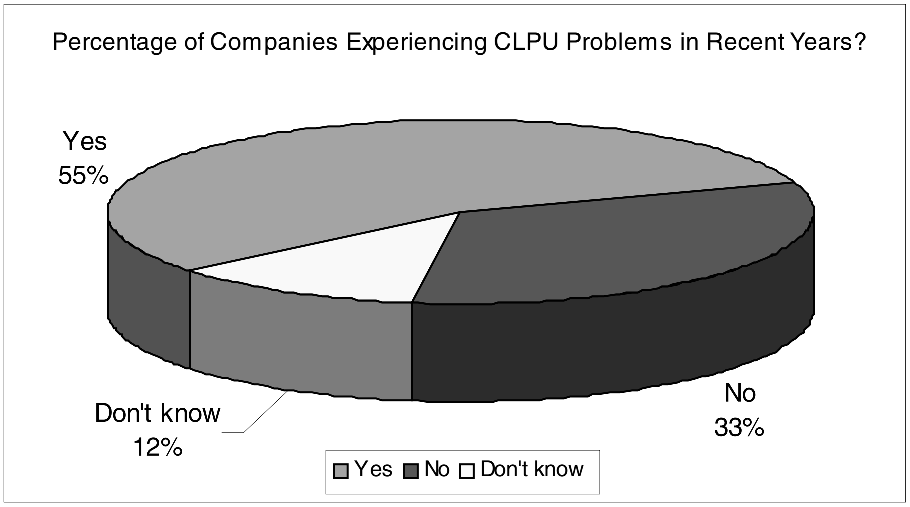

Fig. 11

Virtually all reported CLPU tripping was due to feeder protective relays, with phase relay trips slightly more frequent than ground relay trips. Only one utility specified “Other” as a trip source. Transformer protection was not reported to be affected by any respondents. The majority of CLPU issues were reported on feeders with predominantly residential loads. Commercial and Rural feeders showed CLPU related problems about half as often as the residential feeders. This corroborates expectations described in the paper. Feeders with predominantly Industrial loading were less often reported to have CLPU problems.

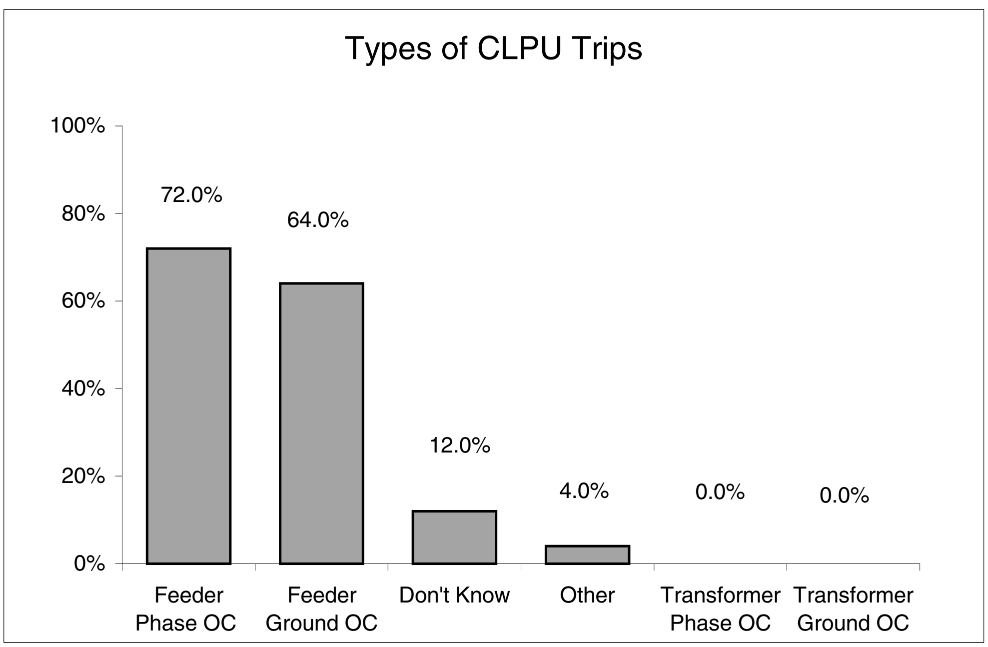

Fig. 12

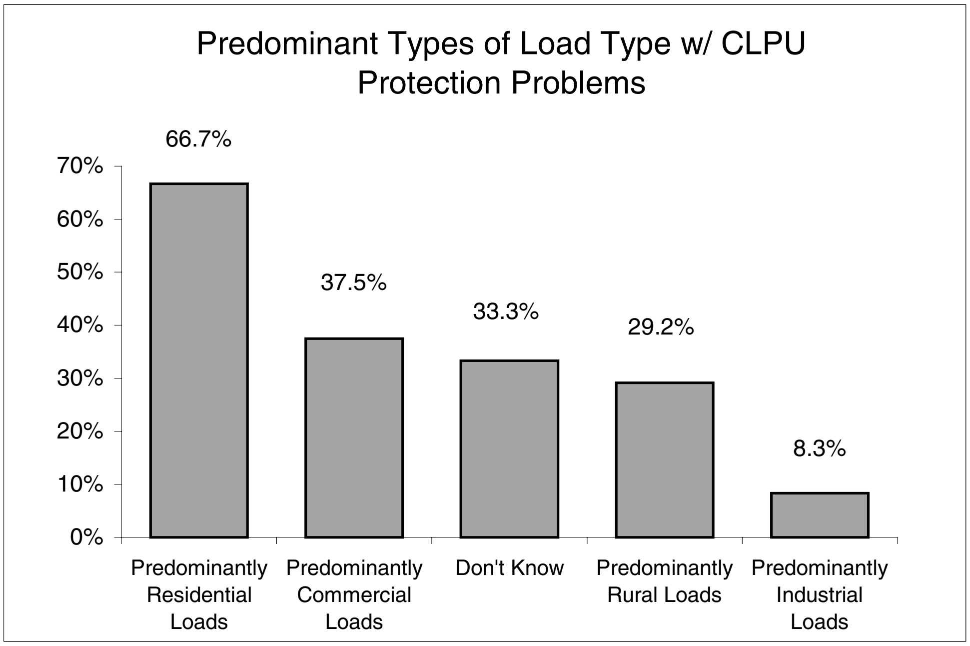

Fig. 13

By a wide margin, the most common corrective practice to relieve CLPU problems is sectionalizing the feeders, which reduces the percentage of the load at each picked up. This method was reported by 83% of the respondents. Around a third of the respondents reported blocking instantaneous elements or fast tripping, or raising phase overcurrent pick-up levels. Smaller percentages reported increasing the ground overcurrent pick-up, increasing the phase overcurrent time dial, increasing the phase overcurrent time delay, or increasing the phase instantaneous pick-up. None of the responding utilities reported increasing the ground overcurrent pick-up or time delay, or the ground instantaneous pick-up.

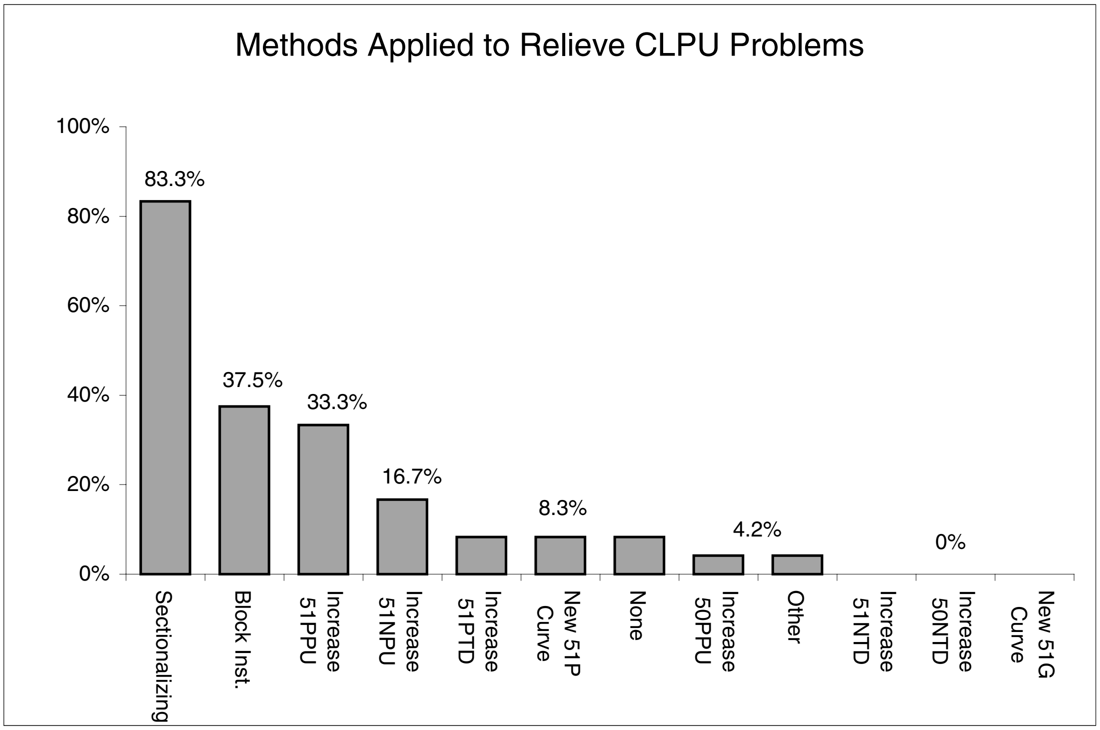

Fig. 14

A large majority of the respondents (88%) reported that they have not attempted to quantify cold load performance, either magnitudes or durations.

The report notes "the trend through the last several surveys is to resolve the CLPU issues with increased sectionalizing and/or increased relay settings and away from disabling tripping" [17].

The cold load pick-up section of the PSRC survey also included several questions on magnetizing inrush. Just more than 20% of the respondents reported feeder trips due to magnetizing inrush, and almost all of them (18.6%) reported magnetizing inrush problems as rare. In comparison to CLPU, magnetizing inrush problems were reported to be much more prevalent on feeders with industrial and commercial loads than residential feeders.

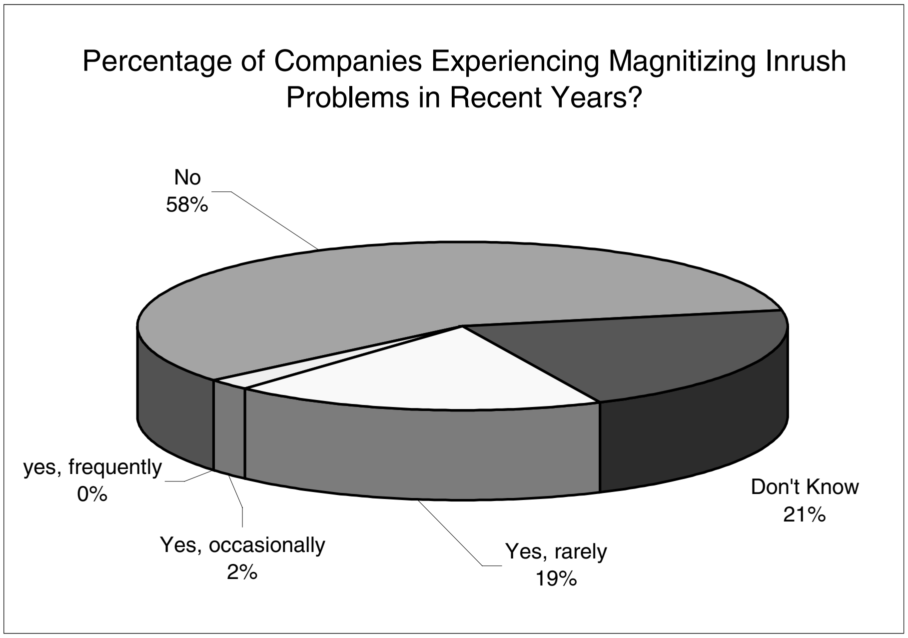

Fig. 15

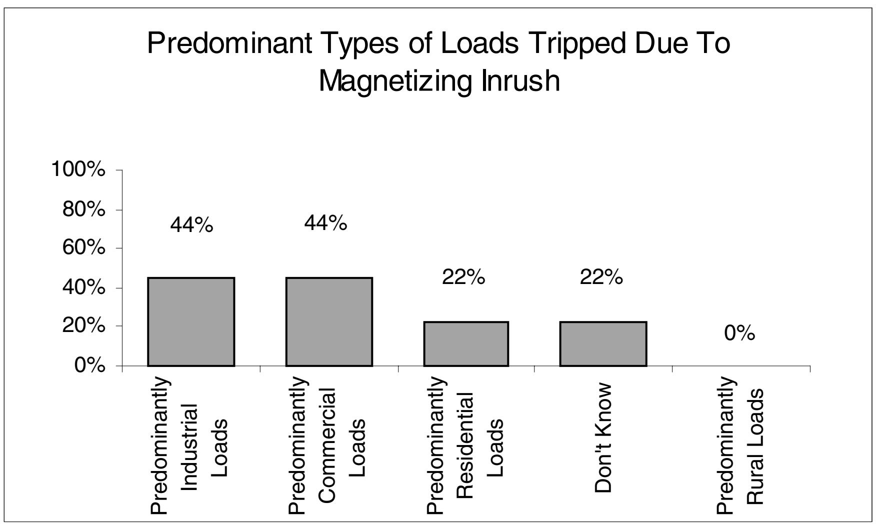

Fig. 16

There was not a strong consensus on the response to address magnetizing inrush problems. Increasing pick-ups, adding time delays and blocking instantaneous were all reported as corrective actions. Notably, no users reported using harmonically restrained relays or impedance relays to address magnetizing inrush.

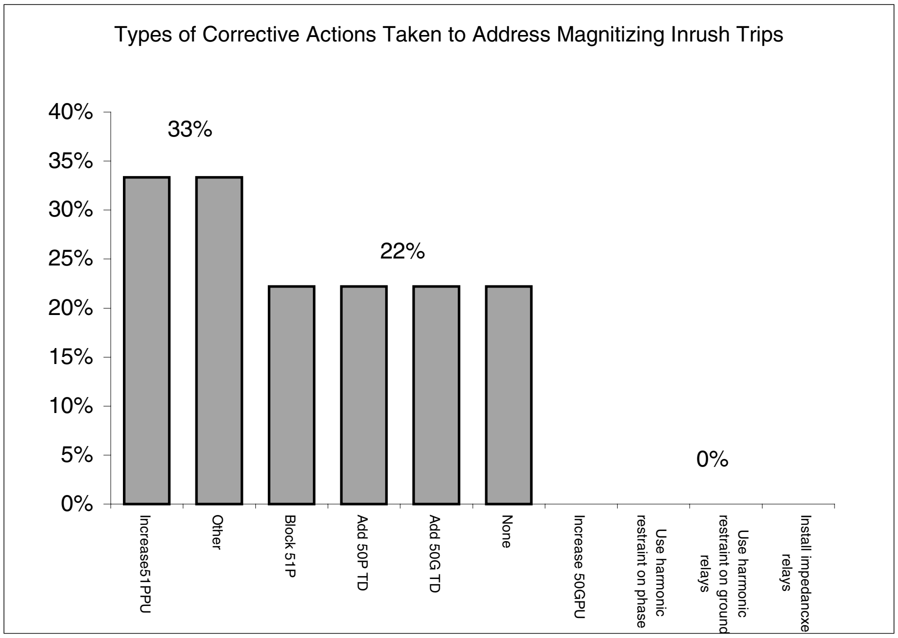

Fig. 17

CLPU Practices Survey by Authors, 2005

In the process of preparing this paper, we hoped to gain additional insight by undertaking another less formal survey of utilities, to gather additional information on cold load pick-up issue. We had a series of conversations, either direct, via telephone, or email, where we covered a series of questions relating to cold load pick-up and inrush concerns. See the references for a listing of most of the companies that were talked to. Those that had minimal information to report or asked not to be mentioned are not listed in the reference.

Virtually every company surveyed accommodates expected cold load pick-up conditions through normal relay settings. The leading factor appears to be the margin the utility has between 51 phase pick-up and load. Most utilities calculate the time overcurrent pickup value based on line emergency capacity and/or fault calculations. Using this practice, the normal peak load currents usually fall in the vicinity of 50% of the overcurrent pickup value, which seems to provide sufficient margin to withstand cold load conditions.

Another significant aspect that surfaced in these discussions is the role of sectionalizing. While only 3 companies reported automatic sectionalizing or load reallocation programs, manual sectionalizing or load reallocation is part of normal attempts to keep as many customers as possible energized during an extended equipment repair. The practice of switching loads to maintain service reliability inherently lessens the impact of cold load pick-up, since only a portion of the load is left to re-energize.

Only 3 of the responding utilities are using the capabilities of numeric substation relays to modify settings for CLPU conditions. Only one utility is using the feature extensively.

The survey began with a form that was sent via email to various utility personnel. It was discovered that response to such a request for information was relatively low, and interpretation of the form by those that did respond was inconsistent. For instance, a question such as “Do you take CLPU into account in protection?" could correctly be answered Yes or No by the same utility if they have embedded CLPU solutions into their standard feeder settings so that they do not need to look at CLPU issues on a per-feeder basis. Therefore, it was decided to change the direction of the survey by directly calling personnel. Adding together both the survey forms that were received and those that were spoken to directly, 25 companies participated in the survey.

As a side note, surveys and discussions with anyone can be misleading: The personnel spoken to are in varying degrees of knowledge of company-wide practices. A substation engineer may not know how the reclosers in the company are being set. An employee may be new to a department. A person may surmise an answer. Rural, urban, industrial, overhead, and underground feeders, all within the same company, each can have varying practices. Company practices can be experimental, single feeder specific, or change with time, which can give misleading answers.

The following is offered about what was learned from the survey, presented in a Q/A format.

1) Do you have cold load pick-up problems?

100%: No

This is a trick question. Everyone has a cold load pick-up problem if they configure their system improperly. However, if the company finds a problem, they change their practices until they have a program that works and the problem is handled in a satisfactory way, so that, effectively, there is no problem. Over the many decades that all power companies have been in operation, they have all moved toward a process that works for their employees and customers, and since they have a process to address the issue, CLPU is not a problem. A more pertinent question to ask is "How do you run your system in such a way that allows you to pick up cold load?" The following questions give insight on the matter.

2) Do you have a fuse saving (fast first trip, slow subsequent trips) scheme in place?

Yes from 10 companies, about 40%. Due to the incomplete level of information available from any one individual, it might be estimated that on the order of 50% of the respondents had some version of fuse saving in place at some location in their system. The fuse saving schemes came in 4 varieties:

a) Substation with an instantaneous that is blocked after the first trip (2 respondents)
b) Substation with classic fast/slow curves similar to that found in reclosers (2 respondents)
c) Substations with reclosers, where fast/slow curves are in use (4 respondents)
d) No slow/fast curves in substation, but reclosers in field used fast/slow curves (5 respondents)

The number adds to more than 10 due to duplicity of practices.

It might be noted that several of these respondents mentioned that their company was moving away from fuse saving schemes because too many customers were seeing short interruptions from fuse saving operations.

2a) Does the fuse saving scheme affect your ability to handle CLPU?

Yes from 60% of those using fuse saving, but to very different degrees.

The use of fuse saving schemes is important to CLPU practices. Slow curves tend to ride through CLPU, but fast curves have more of a tendency to trip for CLPU.

Of particular concern to CLPU is fuse saving scheme 2a above. In each case, the company reported instantaneous settings that were so sensitive (minimally above 51PU) that the 50 was very subject to tripping for CLPU. Hence, both of the respondents that use this practice block the instantaneous on the close after a lockout condition.

At least 4 of those using reclosers with fast/slow curves reported that they are aware of the feature of the recloser to start at the slow curves setting when manually closing the breaker (a feature in newer reclosers), or to go to the slow curve when the close handle is held in the close position (older style reclosers). However, all said, this is a feature that seemed of little importance. All of those having the older reclose feature (hold the handle in the close position to force slow curves) reported that they were unaware of the use of the feature.

3) Do your standard settings allow you to pick up cold load?

100% reported yes. However, those with fuse saving schemes did report some issues, as seen in item 2a.

For those not using a fuse saving scheme, the follow-up questions reveal the practice that allows them to avoid the CLPU problem.

4) Where is your typical peak load relative to the phase 51PU setting?

The typical response was that peak load current is on the order of 50-70% of the phase 51PU.

This is the important question that answers why a utility can handle CLPU without special considerations or actions by the operators. The typical CLPU, in a residential area with high levels of thermostatically controlled loads, will have a peak current in the minute after closing that is about 2 pu (or possibly more in some cases, but the currents are falling as time progresses) of final long term load, as discussed earlier in this paper. The ratio between 51PU and normal peak load is a strong measure of how well a feeder can handle CLPU without encroaching on the 51PU curve long enough to generate a trip. Typical feeder loads are notably less than the peak feeder current, so one can extrapolate fairly easily to see that CLPU has limited ability to cause enough current to create a trip when the peak load is in the range of 50-60% of the 51PU.

5) Where is your typical Phase Instantaneous (Device 50) setting?

This question was not asked of every participant, but of those that were asked, three variations were seen:

a) No Instantaneous, 20%

b) Phase instantaneous (Device 50) set to trip for close in-faults (3-8 times 51PU), 70%

c) Phase instantaneous (Device 50) set sensitive, first trip; then blocked or raised on reclose, 10%

The significance of this question is whether the initial inrush associated with CLPU is an issue for the phase instantaneous (Device 50) setting. No respondent felt that the phase instantaneous (Device 50) element had a tendency to trip for CLPU, except those that used a sensitive phase instantaneous (Device 50) element as part of a fuse saving scheme.

6) Where is your typical load relative to feeder ratings?

This question was only asked of a few respondents; in general, all respondents said that feeders had notable reserve capacity. One utility reported that virtually all feeders were loaded at less than 50% of rated capacity.

The significance of this question is related to the ability of a utility to transfer load to adjacent feeders during an extended interruption of load. When load is transferred from the feeder that has the interruption, there is less load on the feeder when it is re-energized, reducing the impact of CLPU.

7) Do you have any automatic sectionalizing or re-allocation of load during an outage or interruption of a feeder?

Two of the respondents reported a sizable automatic or remotely operable scheme for reallocation of load, and another reported a sizable automatic sectionalizing of feeders as part of the reclosing process. In the remainder of the utilities, sectionalizing and load re-allocation during an extended outage is up to the discretion of the linemen, but many felt that linemen would move loads routinely. However, as the survey did not speak to linemen, it is uncertain how much load transfer is occurring. No utility reported a regular practice of sectionalizing or load reallocation solely for the purposes of addressing CLPU issues, though a couple acknowledged it could be occurring without the respondent knowing about it.

The significance of this issue is that sectionalizing and load re-allocation serves to reduce feeder load prior to closing. To the extent that load is reallocated, there is less of a risk of CLPU issues.

8) Do you use alternate settings at the substation that are enabled for the purpose of alleviating a cold load pick-up problem?

Three utilities reported yes to this question. Only one reported any extensive use of the feature, where the alternate settings were automatically enabled after a line lockout. The alternate setting in the other two required manual intervention, but the respondent felt the alternate setting was almost never utilized.

This option is available only for substations with numeric multifunction relays. It might be noted that a cold load pick-up setting group option is available in the latest recloser controls, but the survey did not obtain a clear picture on how much this feature is being utilized.

9) Do you have any guidelines for feeder settings that you use where the main purpose is addressing CLPU problems?

Three utilities reported that they had a guideline for the time dial and pick-up setting that the engineer needed to address for the purpose of accommodating CLPU. Only one could give the specifics (in terms of an anticipated CLPU coordination curve). The other two could only say that they believed guidelines existed somewhere in the company.

10) Is CLPU a topic of concern of yours or your company?

Approximately 75% of the respondents thought the topic was a non-issue at their utility. Only 5 of the respondents could be classified as being interested in talking about the topic at any length and discussing how they felt the problem should be addressed. Only a couple of these respondents could be classified as thinking of CLPU as a notable issue in their utility, and each of these felt the problem was addressed adequately in their system.

11) Do you have any comments that you wish to share?

About 5 respondents mentioned occasional problems with ground relay tripping during cold load pickup conditions. Particularly, 4 brought up the topic of recovery after a single line to ground fault (SLG). This is effectively CLPU of a single phase line, but where power had been only transiently interrupted on that phase. As mentioned earlier in the paper, when the SLG fault occurs, it causes a voltage dip on that phase on every feeder out of the substation. This can cause all of the motors on that phase to stall. When the fault is cleared, the re-energization of that phase results in an apparent SLG fault on every feeder served from that substation bus. Details of their ground relay setting practices were not obtained during the interviews. The matter was more of an issue that they were aware of and how they mentally interpreted the cold load pickup concept, and, as best the interviewer interpreted the responses, it was not a huge cause of repeated trips in their system.

Conclusions of the Survey

CLPU was not a large concern to most of those interviewed, but some reported it to be an occasional concern in peak loading times, especially the peak of summer mid-day heat in desert areas, and the peak of some very cold winter storm conditions.

CLPU can be an issue for those with a fuse saving scheme, especially if the fuse saving scheme uses instantaneous elements set to a low level. These elements must be blocked when picking up the feeder after an extended interruption.

All utilities have migrated to feeder protection practices where CLPU is generally handled well. It appeared that a practice of designing feeders to handle nearly twice the load on the feeder has a major impact, allowing CLPU to occur without tripping the 51P or 51N relays. The ability to ride through CLPU in this design is likely, in part, due to the reduction in load that occurs due to sectionalizing and reallocation of load during an extended load interruption.

Summary

The paper

- Discussed the nature of the profile of cold loads,
- Discussed the difficulties that CLPU has on system operation,
- Reviewed the role of feeder automation and either automatic or manual line sectionalizing in maintaining loading; hence, reducing CLPU issues,
- Discussed relaying practices that utilize the capabilities of numeric system relays to optimize relay scheme performance during CLPU,
- Reviewed the CLPU section of a formal 2002 IEEE PSRC survey on utility distribution practices,
- Reported on a 2005 informal survey of CLPU practices made by the authors, and
- Provides a substantial list of references on the topic.

Acknowledgement

The authors would like to express their sincere appreciation to personnel in the following companies that provided information during our informal interview and survey process:

Aquila, Avista, City of Fort Collins, Intermountain Rural Electric Association (IREA), Los Angeles Department of Water and Power (LADWP), MidAmerican Energy, Nashville Electric, Nevada Power, Northwest Energy (Montana), PacifiCorp, Pacific Gas & Electric, Platte River Power Authority, Public Service New Mexico, Puget Sound Energy, Salt River Project, San Diego Gas and Electric, Seattle City Light, Sierra Pacific, Snohomish County PUD, Southern California Edison, Tucson Electric.

Survey Form used for 2005 data

Dear -----

We are working on the IEEE Power System Relay Committee's (PSRC) working group studying Cold Load Pick-Up (CLPU) issues, and are also writing a paper on the subject for this Fall's Western Protective Relay Conference (WPRC). Would you be willing to provide some information on your company's philosophies with regard to CLPU, in support of our efforts? Would you be willing to fill out the short survey (below), or direct it to the appropriate person in your group? If you could simply reply to this email, with your information added, that would be great. Any support would be greatly appreciated.

\- - - - - - - - - - - - - - - - - -

Can we include your company's name in the report's appendix, as a responding source? (Y / N)
Can we include your company's name in our report, specifically referencing your practices? (Y / N)
Would you be willing to discuss in more detail? (please include contact info)

\- - - - - - - - - - - - - - - - - -

Does your company take Cold Load Pick-Up (CLPU) into account in your protection philosophy?

If so, do you use:
- Normal overcurrent settings which accommodate expected CLPU? (How do you determine the required setting?)
- Sequential loading after extended interruptions?
- Modification of relay settings? (See follow-up questions below)

If you modify relay settings to accommodate CLPU, can you provided a short summary? Do you:
- Defeat instantaneous (phase, ground)
- Raise PU (phase, ground; how much)
- Add time delays (phase, ground; how much)
- Defeat neutral elements
- Use alternate setting groups in numeric relay systems?
- Are changes made manually or automatically? (What is the logic for automatic?)
- How do you return to normal operating mode?
- Other

Comments:

Has your company made an effort to analyze Cold Load Pick-Up?
- Can you characterize when you expect CLPU to be an issue?
- Is there a feeder loading level where you expect to see the problem?
- Do you find CLPU to be more of an issue with seasonal loading?
- Do you find CLPU to be more of an issue with time of day, or weather conditions?
- Do you find CLPU to be more of an issue depending on load type?
- Do you have a load model that helps explain and predict when cold load pick-up issues will arise, and how long after energization that you need to utilize the alternate setting?

THANK YOU for taking the time to respond

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John Horak received his BSEE degree from the University of Houston in 1988 and his MSEE degree, specializing in power system analysis, from the University of Colorado in 1995. He worked ten years with Stone and Webster Engineering and was on assignment for six years in the System Protection Engineering offices of Public Service Company of Colorado. His work has included fault calculations, relay coordination settings, control design, and equipment troubleshooting. John joined Basler Electric in 1997 and is a Senior Application Engineer. He has authored, coauthored, and presented technical papers at a variety of industry events and conferences. John is a member of IEEE-IAS and –PES.

Vahid Madani, IEEE SM, is a Principal Protection Engineer at Pacific Gas and Electric Co. (PG&E). His responsibilities include 500kV transmission, reactive compensation, series capacitor protection and controls on EHV systems, single-phase protection and operation, transient and real time simulations, wide-area disturbance monitoring and prevention, protection and control equipment evaluation, substation integration and automation, and standardization.

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Vahid has been a member of several investigative and restoration recovery task forces including the 1989 San Francisco and 1994 Los Angeles Earthquakes and the 1994-1996 Western Interconnection Disturbances. Additionally, Vahid has several years of distribution protection engineering and planning experience.

Mr. Madani has various technical, advisory, and leadership roles within the North America and Internationally. He is Chair of the Remedial Action Scheme Reliability Subcommittee in the Western Electricity Coordinating Council (WECC), Chair of the IEEE Working Group on the global industry practices with system integrity protection schemes (SIPS), Chair of the Power System Protection testing, a member of CIGRE Study Committee (SC) B5 in Protection and Control Standards, and CIGRE SC C2 (Power System Operation) for "Design and Deployment of Defense Plans against Extreme Contingencies."

Vahid has been an invited author, speaker and panelist for CIGRE, DistribuTech, EPRI, IEEE-PES, and International Institute for Research and Education in Power Systems (IREP). He has authored numerous paper and articles and has been invited to publish in IEEE Spectrum and contribute to the 2006 McGraw-Hill Yearbook of Science and Technology on topics related to blackout prevention.

Mohammad Vaziri received a BS EE in 1980, MS EE in1990, and Ph.D. EE in 2000 from University of California at Berkeley, California State University at Sacramento, and Washington State University at Pullman, respectively. He has 19 years of professional experience at PG&E, and CA ISO, and more than 12 years of academic experience teaching at CSU Sacramento and WSU Pullman. Mohammad has authored and presented technical papers and courses in the U.S., Mexico, and Europe. He is an active member and serves on various IEEE and other technical committees. Currently, he is a Supervising Protection Engineer at PG&E, and a part time faculty at CSU Sacramento and San Francisco. Dr. Vaziri is a registered professional engineer in the state of California, and his research interests are in the areas of Power System Planning and Protection.

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