Back to Table of Contents

Protective Relaying Issues in Low Voltage Systems as Addressed in the National Electric Code

John Horak, David Beach
Basler Electric

Presented before the
32nd Annual
Western Protective Relay Conference
Spokane WA
October 25-27, 2005

Blank page for back of cover sheet

Protective Relaying Issues in Low Voltage Systems as Addressed in the National Electric Code

John Horak, David Beach
Basler Electric

This paper provides some background on low voltage (LV) design practices, as mentioned in the National Electric Code (NEC), especially for the protection engineer who normally only works in high voltage (HV) and medium voltage (MV) systems. Such engineers may never have a reason to work with low voltage systems, and may never pick up the NEC and be quite unaware of its content. Hence, when asked for guidance on a LV application, may simply extrapolate HV/MV practices to the LV system, and give inappropriate advice. The background information herein may assist such engineers in having some basic ideas on some major differences faced in protection of LV systems.

On the other side of the same issue, the title of this paper might also be “Protective Relaying Issues In Low Voltage Systems as *Not* Addressed in the National Electric Code.” The NEC’s main interest, as far as topics that a protective relay addresses, is overload detection and fault detection on solidly grounded systems, using fuses and low voltage circuit breakers. Many other issues that one would address using a classic protective relay are not directly covered by the NEC. This paper will discuss some of these issues.

The paper will address the topic of low voltage systems from the perspective of the United States’ National Electric Code (NEC), for voltages <=600V. The NEC has variations of its concepts for voltages >600V, but they will not be addressed herein. Also, while the concepts are similar everywhere, no attempt will be made to represent the content of worldwide codes and standards.

Low Voltage Protection Practices That Vary from HV/MV Practices

While there is a large difference between the protection of HV/MV systems and LV systems, there might be some tendency to extrapolate HV/MV practices to LV protection. The topics below discuss some areas where this extrapolation does not hold well. These will be the talking points for the balance of the paper:

1) Overload protection vs. Fault protection
    - In LV systems, overcurrent pickup (OCPU) and fuse sizes are commonly based on overload protection, as compared to HV/MV systems where the main concern is that a relay can sense faults, and in addition, HV/MV relays normally are configured to allow large overload.
2) Ground Fault Tripping
    - In LV systems, Neutral and Ground are carried on separate conductors, where in HV/MV systems, the neutral and ground are effectively the same and one cannot separate ground current from neutral current. The neutral/ground OCPU setting approach is therefore different in HV/MV and LV systems.
    - For low impedance grounded systems, 480V, on feeders >= 1000A, the NEC requires ground fault protection in a manner that creates coordination difficulties.

Prepared by Basler Electric for presentation to the
Western Protective Relay Conference, October 2005; Revision Date 09/23/05

3) Low Voltage Breakers Design is Much Different than HV/MV Breaker Design
While not a protection issue directly, the HV/MV protection engineer needs to have some concepts on how HV/MV and LV breakers differ from one another.
    - There are various LV breaker designs (MCCB, ICCB, LVPCB, and designs within each of these categories)
    - Interruption rating is not what it might appear at first.
    - The common LV MCCB breaker lacks features that a HV/MV engineer might expect to be included without asking, such as trip and close coils, CTs, auxiliary status contacts, and draw out construction. The ICCB and LVPCB may or may not have these features.
    - The overcurrent response of LV breakers is much different than anything seen on HV/MV system designs.
    - In almost all LV breakers there is a high set magnetic instantaneous current level that cannot be overridden, which prevents coordination at these current levels.

4) Fault Level Range Difficulties
    - The ranges of fault current, especially compared to load level currents, can be much greater in LV systems
    - In some applications where load current and fault current are extremely different, CT based current monitoring becomes ineffective, so overload and fault sensing with a classical relay may produce difficulties.
    - Similarly, sensitive ground fault systems can be compromised by high phase faults.

5) LV Systems Tend to Use MCCBs and ICCBs with Standard Trip Units
    - A LV engineer might tend to use a MCCB/ICCB where a HV/MV engineer would apply a protective relay.
    - The NEC is aimed at the mainstream radial overcurrent protection concepts. It does not directly address the niche issues where a protective relay is required.
    - The NEC makes little attempt at addressing generator protection.
    - The NEC makes little attempt at addressing issues associated with IPPs that have island and are at risk of back-feeding the utility
    - The NEC does not address advanced concepts in protection such as negative sequence voltage or current monitoring for phase loss detection
    - The NEC does not discuss methods for ground fault detection on impedance grounded systems.
    - The NEC does not discuss advanced motor protection schemes found in modern motor protection packages, and simply requires overload protection.

1) Overload Protection vs. Fault Detection

In utility feeder applications, overload protection is not typically part of the protection engineer's criteria for phase OCPU settings. As a disclaimer, in some utilities, the phase OCPU is sometimes based on the current rating of the distribution feeder at the exit from the substation or some known other point, plus some margin. In general, if you examine the overcurrent settings throughout various utilities, a large majority of the average utility's equipment could be heavily overloaded, even to the point of destruction, without a relay trip. To a high degree, it is the job of system operators, not relays, to monitor and respond to overloads.

For instance, in a utility distribution system environment, the criteria for OCPU decision is based on factors such as:

- Xfmr Primary Phase OCPU: Set as high as possible to allow coordination with Xfmr damage curve, or 130% of secondary, or 175% of Xfmr FLA (peak rating) whichever is less

- Bus Phase OCPU (=Xfmr Secondary) PU = 140% of Xfmr FLA (peak rating)
- Bus tie Phase OCPU, =120% of Xfmr FLA (peak)
- Feeder Phase OCPU = 140% of feeder rating at exit from the substation.
- (Next Feeder Recloser or fuse installed where line fault duty drops to 125% of feeder phase or ground OCPU)
- Feeder Ground OCPU: Set at about 1/3 of phase OCPU, except delta Xfmr main, set at 10% of Xfmr FLA (peak). Set high time dial for good downstream fuse coordination.
- Fuse sizes selected to protect cables from damage due to faults, not overload.
- Distribution Xfmr (MV to LV) fuses set at 150% of xfmr FLA (which effectively allows unlimited overload)
- etc.

Note these guidelines are not providing any substantial overload protection.

Similarly, transmission lines have minimal overload protection. In some instances, zone 3 impedance relays can provide some overload protection, but today's common practice is to limit the use of zone 3 relaying, or decrease its sensitivity, due to system stability concerns. If a transmission line is overloaded to the point of damage, it likely means this is a bad time to trip the line. The assumption is that the system is highly stressed and the line must stay in service in order to prevent a system collapse.

The NEC has a different perspective for OCPU settings. It has extensive rules on phase OCPU and fuse selection that ties back to equipment ratings. While the NEC contains many exceptions and "if ... then ... else" statements that only an experienced NEC expert will have a good grasp on, there are some generic rules worth considering. On LV system wiring, the general concept is to first size conductors to handle the respective worst case load, and then size the breakers and fuses to protect the conductor against overload just in case someone puts on more load than system design allows. For example, suppose a feeder is supplying a sub-panel that has branches to a variety of loads. (Generally speaking, a feeder is the conductor between panels, and a branch is the conductor from a panel to a final load.) To determine the current the feeder must be rated to carry, determine the net load on a feeder by adding:

- 125% of all continuously running loads on the sub panel. Continuous is defined as a load that might run more than 3 hours at a time.
- 100% of all non-continuous loads on the sub-panel.

Now select the conductor rated to carry at least this much current. Next, if the conductor rating is < 800A, round the conductor rating up to the next standard size circuit breaker or fuse, and then use that size, or lower, breaker or fuse. If the conductor is rated >= 800A, round the conductor rating down to the next standard size fuse or circuit breaker and use that size or less.

For example, suppose a panel has branches feeding loads that add to 36A continuous (*1.25=45A), and 70A non-continuous. The net load per NEC is 115A. For the feeder to that panel, select a conductor rated for 115A or greater. Suppose one decides to use a 130A conductor. The standard breaker (or fuse) sizes per NEC 240.6 are ...110A, 125A, 150A ... Hence one must use a breaker or fuse rated 150A or less. The approach is not really a guarantee that no overload will occur, but it will be limited in magnitude. e.g., a 150A breaker or fuse will allow only a moderate overload.

The above statement, however, is based on the normal 80% rated circuit breaker. The standard circuit breaker is actually rated to continuously carry only 80% of its nameplate current continuously. If one obtains a circuit breaker that is rated to carry 100% of its nameplate continuously, the calculated load is equal to 100% of the continuous load plus 100% of the non-continuous load.

One should not set a relay without consulting the appropriate section of the NEC that might address special issues for a given piece of equipment. Articles 400-490, “Equipment for General Use” covers special rules for common equipment, such as motors, transformers, generators, lighting, and refrigeration. Articles 500-590 cover special allowances for “Special Occupancies” such as health care facilities and mobile homes, and Articles 600-695 cover “Special Equipment” such as cranes and fire pumps.

For instance, suppose one is working with a motor circuit, an important topic. In Article 430 the NEC separates the issue of overload detection and fault detection. The section has instructions on determining FLA for a wide variety of possible motors and system configurations. The conductors are sized for 125% of the motor FLA. The NEC allows the circuit breaker OCPU to be set very high, in order to allow successful motor starts. However, motors must have a means of protection against overload, such as a thermal overload relay, and the section has some options on how the motor overload protection may be configured. Because there is separate overload protection, the circuit breaker or fuse on the branch circuit is allowed to be set above the conductor rating, but fault detection is still expected, and the NEC supplies guidelines on where this overcurrent element should be set. The NEC makes allowances for issues with high starting current that can add complexity to the selection.

2) Ground Fault Sensing

2a) Low Impedance Grounded System Design

In the great majority of the HV/MV power systems, in the United States at least, the three phases are referenced to a neutral conductor that is multipoint solidly grounded, and where all generation sources, at the point where they connect to the transmission lines, are solidly grounded. On HV transmission lines, the loads tend to be phase to phase (e.g., delta windings of distribution transformers) so the normal (unfaulted) system ground current tends to be low. This allows the transmission system to be relatively sensitive to ground faults compared to distribution lines. On MV distribution lines, where loads are connected line to neutral, ground fault current cannot be differentiated from phase to ground load imbalance, which limits how sensitively one can set a ground fault relay. A typical ground OCPU on a distribution line cannot be set much below 1/3 of the phase OCPU.

The great majority of LV systems in the United States, and the main type of construction that the NEC addresses, are solidly grounded facilities where loads are line to line or line to a dedicated neutral, and where a ground conductor is carried with every power conductor, as seen in figure 1. The ground is not utilized as a load current carrying conductor. The neutral bus is connected to ground at only one point in the system, in the service entrance panel and accessible to the customer.

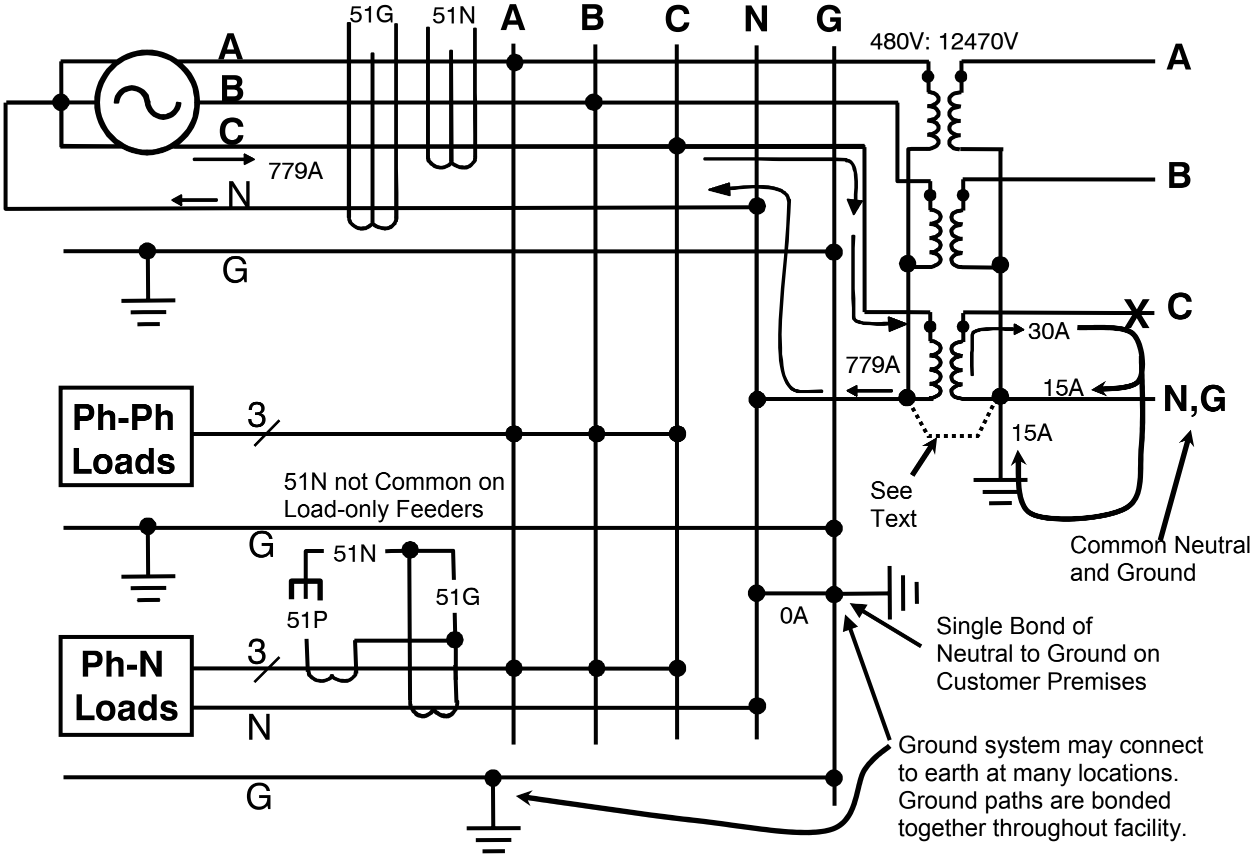


Fig. 1. Neutral vs. Ground in Low Voltage Systems.

The basis of the NEC's approach is that when a ground fault occurs, if a solid continuous conduction path through metal enclosures, conduit, and ground wires exists back to the source service entrance, then high currents will exist that will lead to tripping of the phase overcurrent elements. At the same time, personnel in contact with the grounded elements will not see excessive voltage. The solid connection of the conduit and metal enclosures to ground is an extensive topic of the NEC. In wet locations where personnel could be in touch with the faulted equipment, additional sensitive ground fault circuit interrupter (GFCI) devices are mandated. In other areas of the world, the service entrance (entire building) might have sensitive ground fault protection. GFCI specifically refers to 4-6ma devices used in the US for personnel protection. In the IEC world 30ma protection is used in some applications, which is considered equipment protection (GFP) by the NEC.

Another basis of this design is that since the neutral load is separated from the ground, a ground fault relay (51G in Fig. 1), which is a summation of A, B, C, and N currents, can be sensitive to ground faults .The 51G in this application can sum the 4 CTs shown in the bottom of the figure, or can use a window CT that encircles the A, B, C, and N buses. A 51N that sums A, B, and C, as utilized in a utility system, cannot be set as sensitive as a 51G due to load currents normally flowing on the N bus.

An interesting aspect of Figure 1 is how a ground fault at 12.47kV is seen by the ground/neutral relays at the generator. One might at first think that because the 51G at the generator is set sensitively, the relay can easily see the utility fault. However, if one traces out the currents, one sees that ground current in the utility system becomes neutral current at the generator. Only the 51N can see the utility fault.

On systems where line to ground voltage is above 150Vln (e.g., a 480Vll system but not a 208Vll system), the NEC requires ground fault detection schemes on feeders rated 1000A or above. This system must have a trip level of 1200A or less, and a trip speed of 1s or less for a current level of 3000A. Unless ground is isolated via a delta-wye transformer, a 1000A feeder is likely to have a large number of downstream loads, so for proper coordination every downstream feeder will need to have ground coordination that is faster than the upstream breaker. Many ICCBs have a special ground trip function with Zone Selective Interlocking where the downstream breakers, upon sensing a ground fault, block tripping of the upstream breaker, hence reducing the time delays needed coordinate multiple levels of ground fault protection. These schemes of course add cost to the installation.

The connection between the 12.47kV neutral/ground and the 480V ground, shown via a dotted line, may not exist (especially if the primary is delta) in a given installation. The connection adds extra reliability to the ground system, but the connection cab also be seen as a safety hazard because the connection makes it feasible to have a phase to ground fault on the primary enter the ground wires, and hence the neutral bus, of the facility.

2b) High Impedance Grounded Systems

The NEC mentions impedance grounded neutral systems as acceptable designs (e.g., Article 250.36) where continuity of service is important, but does places the engineering for such systems into the realm of the end user. It says the system must be maintained only by qualified personnel, and that ground detectors shall be in place. It does not address how the ground detector should be designed. This is an area where protective relaying, monitoring line to ground voltage or zero sequence voltage, may be used, though a more low-tech scheme using of a series of light bulbs between phase and ground works well too. The NEC does not relieve one of the need to carry a well designed ground system throughout the facility and maintain solid grounding on all metal conduit, panels, etc .Suggested reading on high impedance grounded systems is in reference [7].

3) Low Voltage Breakers Design is Much Different than HV/MV Breaker Design

The NEC does not offer standards on breaker design; it simply says that it must be able to interrupt current in the environment in which it is applied. There are many design variations in LV breakers and a good description of the various types of LV circuit breakers may be found in IEEE 1015, the “Blue Book” [2]. The standards that describe breaker design are UL-489 (NEMA AB-1) [3], applicable to Molded Case Circuit Breakers (MCCB) and Insulated Case Circuit Breakers (ICCB); and IEEE C37.13 [4], applicable to Low Voltage Power Circuit Breakers (LVPCB). Below is a comparison of these classifications, largely taken from table 4-2 of [2], but with a few extra pieces of information that reflect modern design.

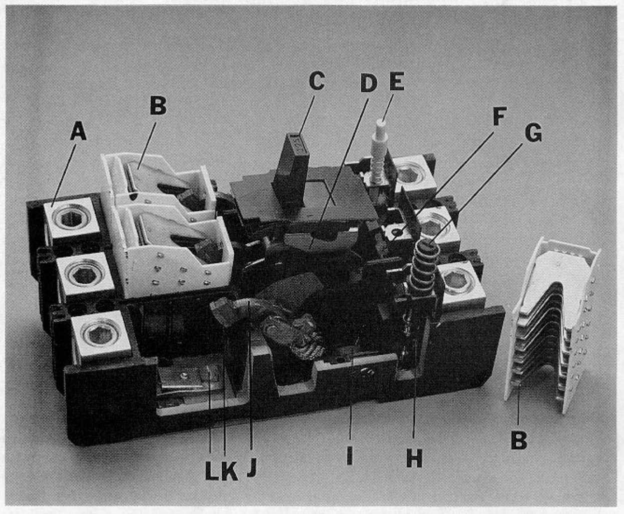
A caveat, though. The line between LVPCBs and ICCBs is becoming increasingly blurred. Some manufacturers are producing products that it appears almost as if the only difference between the two products is the nameplate.

LVPCB	ICCB	MCCB
Maintainable; Solid stat trip units; Always 100% rated; 75^0C lugs; PU Tol. ~105%-125%; Rated at V_{MAX}; One style per Mfr. 30cycle short time rating on some designs	Possibly maintainable; Solid stat trip units; Usually 100% rated; 75^0C lugs; PU Tol. ~105%-125%; Rated at $V_{NOMINAL}$; Limited styles available; High end MCCB or low end LVPCB	Sealed package, not maintainable; Thermal/magnetic tripping or solid state trip units; Usually 80% rated; 60^0C or 75^0C lugs; PU Tol. ~105%-125%; Rated at $V_{NOMINAL}$ Many styles available
Types of operators: mechanically operated, two-step stored energy, and electrical two-step stored energy	Types of operators: mechanically operated, two-step stored energy, and electrical two-step stored energy	Types of operators: mechanically operated, over-center toggle or motor operator
Selective trip over full range of fault currents up to interrupting rating	Selective trip over partial range of fault currents within interrupting rating	Selective trip over a smaller range of fault currents within interrupting rating
Remote trip and close coils standard	Trip and close coils generally available	Shunt trip available in some designs
Aux status (52a, 52b) contacts standard	Aux status (52a, 52b) contacts available	Aux status (52a, 52b) contacts not generally available
Friendly to adding CTs in breaker cabinet	Friendly to adding CTs in breaker cabinet	Cabinet designs usually make adding CTs an issue.
Available in draw-out construction permitting racking to a distinct "test position" and removal for maintenance	Available in draw-out construction permitting racking to a distinct "test position" and removal for maintenance	Some are available in plug-in design allowing removal for inspection and maintenance. Large frame sizes may be available in draw-out construction
Operation counter is available	Operation counter is available	Operation counter is available
Interrupting duty at 480Vac; 22-100kA without fuses and up to 200kA with integral fuses. More recent design offer 200kA without fuses.	Interrupting duty at 480Vac; 22-100kA	Interrupting duty at 480Vac; 22-65kA without fuses and up to 200kA with integral fuses or for current-limiting type
Current limiting available only with fuses	Current limiting with fuses long available; recently current limiting without fuses has become available	Current limiting available with and without fuses
Usually most costly	Usually mid-range cost, but depends on the enclosure selected	Usually least costly
Small number of frame sizes available	Small number of frame sizes available	Large number of frame sizes available
Extensive maintenance possible on all frame sizes	Limited maintenance possible on larger frame sizes	Limited maintenance possible on larger frame sizes
Used in enclosures, switchgear and switchboards	Used in enclosures, switchgear and switchboards	Used in enclosures, panelboards, and switchboards
Not available in series ratings	Not available in series ratings	Available in series ratings
100% continuous-current rated in its enclosure	80% continuous-current rated unless specifically stated to be rated 100% in an enclosure	80% continuous-current rated unless specifically stated to be rated 100% in an enclosure
IEEE Std. C37.13	UL 489	UL 489

Table 1. Comparison of LV Breaker Features

.

The MCCB is the mainstream breaker found in standard practice. These breakers are hard plastic boxes that cannot be disassembled after construction and that tend to have very limited functionality or flexibility. They are typically thermal-magnetic trip devices. The ICCB is an upgraded version of the MCCB that makes the device somewhat field maintainable and adds the ability to have more complex trip units and features such as trip coils and close coils. The LVPCB is a high amperage full feature breaker, except it lacks certain current limiting features that can be obtained in small molded case breakers.

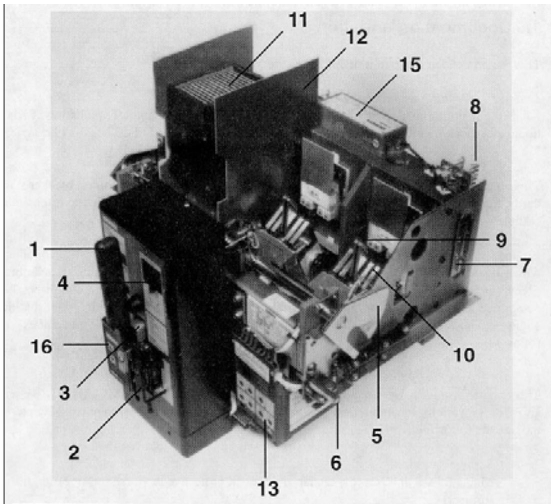


LEGEND

A.	Wire connector	G.	Instantaneous trip level adjustment
B.	De-ionizing arc stack	H.	Electro-magnet
C.	Handle	I.	Bimetal
D.	Operating mechanism	J.	Moving arm
E.	Test trip actuator	K.	Moving contact
F.	Common-trip bar	L.	Stationary contact

Source: Square D Company.

Figure 1-1—Cutaway view of a typical MCCB



LEGEND

1. Manual spring charging handle	9. Main contacts
2. Open (push-to-trip) lever	10. Arcing contacts
3. Close (push-to-close) hood	11. Arc chute
4. Racking crank access opening & interlock	12. Interphase barrier
5. Racking (drawout) mechanism	13. Electronic overcurrent trip device
6. Drawout interlocks	14. Current sensors (on rear—not shown)
7. Breaker frame size interlock	15. Voltage sensor (optional)
8. Primary disconnect finger assembly	16. Breaker display unit (current, voltage, and power measurements) (optional)

Source: Siemens Energy & Automation, Inc.

Figure 1-2—Low-voltage ac power circuit breaker—drawout type (shown partially disassembled to show internal features)

Fig 2a, 2b. Circuit Breaker Cutaway [2]

The figures above are from IEEE 1015, the “Blue Book” [2], offering some comparison of the breaker types. The figure numbers are as found in this source.

3a) Continuous Current Rating of LV Breakers

The continuous rating of MCCBs and ICCBs is not exactly what one would expect at first glance. These breakers are rated to continuously carry only 80% of their nameplate current, unless a 100% rated device is purchased. The NEC’s “FLA is based on 125% of continuous current” and the UL489’s “breaker continuous duty is 80% of nameplate” are “two sides of the same coin.” Is the NEC responding to how breakers are built, or are the breaker manufacturers taking advantage of NEC FLA calculation procedures? Once one reaches the high end products associated with ICCBs, 100% ratings become more common. LVPCBs always are 100% rated.

3b) Interrupting Ratings of LV Breakers; Series Ratings, Testing

In HV/MV systems, an engineer would never install a breaker rated to interrupt less current than the available current. However, in LV systems, an MCCB breaker, or a fuse, can be applied in applications where the available short circuit current is higher than the rating of the breaker or fuse, if the underrated device is in series with an approved MCCB breaker or fuse that can interrupt the available fault current. Series rated MCCB/MCCB, fuse/MCCB, and fuse/fuse systems must be approved and tested in accordance with UL489. Series ratings of MCCB/MCCB are always within one manufacturer, but fuse/MCCB and fuse/fuse combinations will cross manufacturer lines. The fuse in series ratings is always a current limiting type. Series ratings generally involve upstream breakers with thermal magnetic trip operations, and not adjustable solid state trip units.

Relying on series ratings means that one has forgone device coordination at the current levels where the upstream device is being relied upon to clear a fault. However, making both MCCBs fully rated does not give one selective coordination either. Two fully rated breakers will both trip if current rises beyond the default high set instantaneous of both breakers, and hence give no selective coordination.

Another issue that might seem strange to a HV/MV engineer is that MCCBs and ICCBs are not actually tested at their rated interrupting duty. For the interrupting capability test, a source capable of providing the rated current is connected to the breaker via a length of cable. The cable adds impedance to the circuit. Per [5], for example, a 22kA circuit breaker, is actually only tested to 9,900A. The test may be reflective of reality, however. Fault analysis software is calculating the worst case scenario for fault current, and this will generally be directly at the terminals of the source transformer. Some argument can be made that the small impedance between the transformer terminals and the breaker load side will reduce fault duty to less than the worst case, and further that faults do not happen often directly at the terminals of a breaker, but there is the case of an electrician working in a live panel, or faulty wiring leading to a fault at the breaker terminals.

Another typical practice that might be strange to a HV/MV engineer is the use of fuse/breaker combinations to obtain increased fault interruption ratings. In order to achieve high interrupting capacity, MCCBs and ICCBs may have an integral fuse designed to clear the highest level fault currents, relieving the robustness to which the circuit breaker interrupting mechanism must be built. This scheme forgoes some level of automatic or remote closing of a tripped breaker, since the fuse must be replaced.

3c) MCCB Circuit Breakers Auxiliary Features

An engineer accustomed to working with HV/MV breakers may be surprised to find many features that are normal on HV/MV breakers become a costly or unavailable adder on a LV breaker, especially when working with MCCBs. If these features are required, the design may need to graduate from MCCBs to ICCBs and a major price increase will be seen. The typical MCCB is just an overcurrent sensing and tripping device. It has

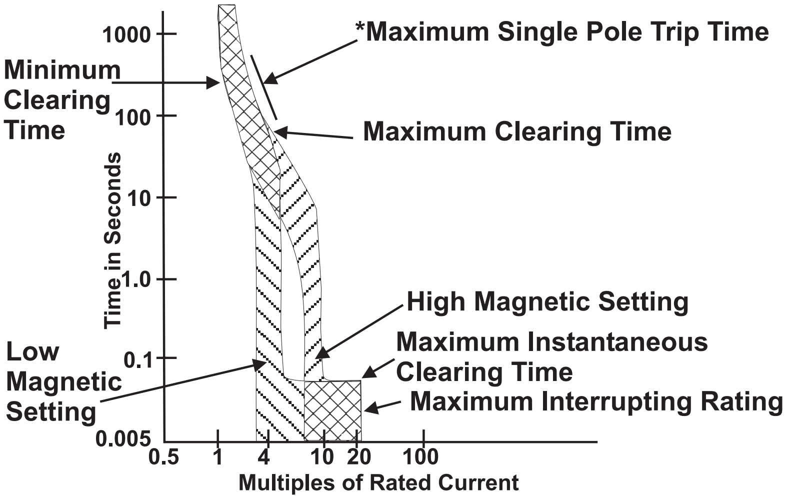
- no trip coil (shunt trip can be obtained on some styles)
- no close coils (motor operators that operate the toggle switch can be obtained on some models)
- no allowance for CTs (might be able to install them in the bus work leading to the breaker)
- no auxiliary status contacts (available on some models)
- cannot be drawn out as a means to completely isolate downstream equipment
- no operations counter (might be obtainable on some models)

These features can be obtained in ICCBs to a large extent, but one might need to buy a LVPCB if all the features are needed. One could be asking the facility to add 10s of thousands of dollars to a project by what seemed to be a simple request for a feature. “The event reports would be a little easier to read if we had an auxiliary contact off the breaker" could translate into a major expense for the facility.

3d) The Overcurrent Response of LV Breakers

The HV/MV engineer is accustomed to inverse time response overcurrent elements that trace their roots back to electromechanical induction disk relays. The low-budget mainstream LV circuit breaker is based on the thermal (long time) and magnetic (instantaneous) response characteristics. If one graduates to the more expensive ICCB or LVPCB, then one has a wider curve shaping control, but again, the response is different than the response to which the engineer is accustomed.

Below are some typical curves seen in the trip units seen in MCCB, ICCB, and LVPCBs. While these curves tend to be generic, they are essentially redrafts of curves seen in [6], the IEEE 242, the Buff book .As a caveat however, one manufacturer provides options Medium Inverse, Very Inverse, and Extremely Inverse in the long time delay portion of the breaker curve .An other replaces the Long Time Pickup and Long Time Delay portions with a single, curved, segment that looks like a Very or Extremely Inverse curve



***Single pole test data at 25°C Based on NEMA AB4-1991**
Note: Shaded band allows for manufacturing tolerances

Fig 3. MCCB with Adjustable Magnetic Trip Inst., Fixes Thermal Long Time [6]

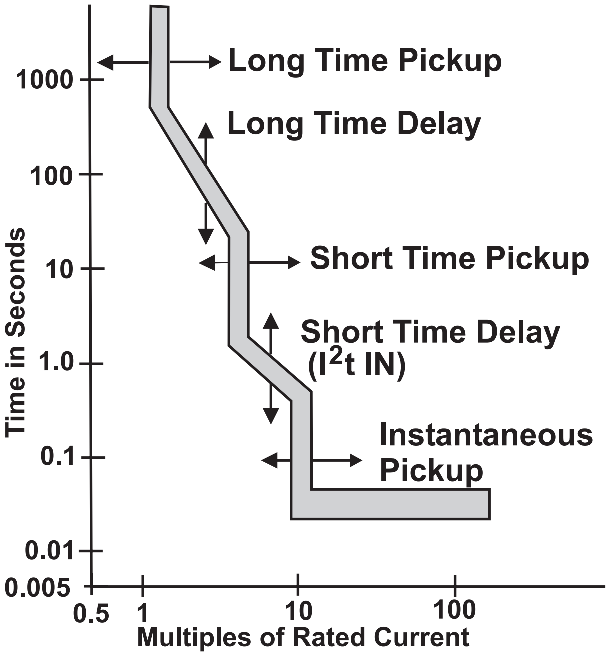


Fig. 4. Typical TCC Curve for Electronic Trip Circuit Breaker, (I^2t IN) [6]

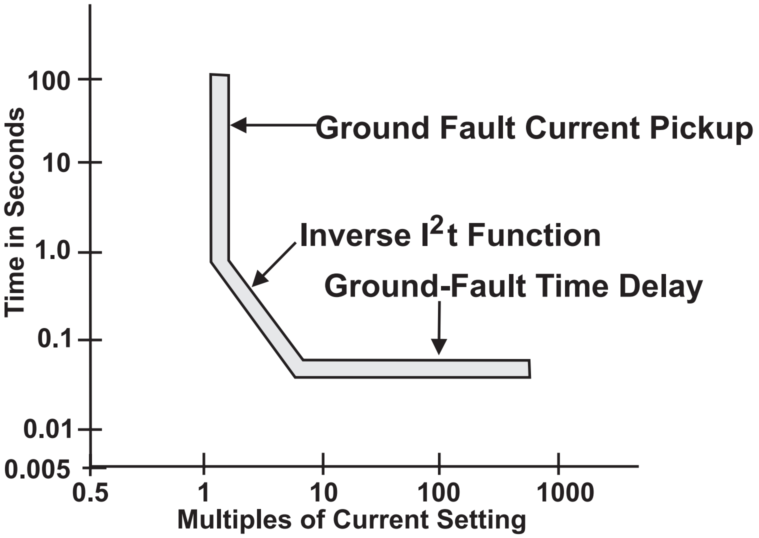


Fig. 5. Ground-fault TCC curve (I^2t IN) for Electronic Trip Circuit Breaker [6]

3e) High Set Instantaneous on LV Breakers

It is typical that on a LV breaker there is a level of current where the breakers will always trip with no time delay. This feature is needed so the breakers can be self protecting. This feature is not always shown in electronic trip unit response curves, such as seen in section 3.d above, but it is generally there. For currents above this fixed instantaneous current level, there is no coordination with downstream overcurrent devices. In the majority of cases the instantaneous trip current is high enough that the current level will not be reached in actual practice, but the problem of a possible miscoordination is still there.

4) Load vs. Fault Current Range in LV Systems

An engineer accustomed to working in HV/MV systems may be a bit surprised at the high fault currents and high dynamic range of currents that are experienced in LV systems. In HV/MV distribution systems maximum load currents for both distribution substations and transmission lines will likely be in the range of 200-3000A, though of course values outside this range are found. The fault duty typically will be on the order of 5,000 to 30,000A, in most applications. While these ranges are large, fault currents, in general, are on the order of less than 30 times load current. This has ramifications on CT selection. If the CT ratio is selected so that secondary current during peak load is 5A, the peak current during faults is a manageable 150A, but usually much less. While 150A is high amount of current for a CT to push, it is doable, and in most applications the current is lower.

In LV systems the load current range is a little wider. The load can vary from the low end breaker of 15A, all the way to the maximum breaker available of 6000A, though 6000A is an extreme design, and 4000A is likely a more common peak breaker rating in use. To achieve good voltage regulation, transformer impedances are very low, possibly fed from transformers oversized for the facility’s true power needs, or from a network of transformers. The result can be fault duties that can be very high. Fault currents approaching 200kA are reported in extreme designs, especially networked systems. The more common designs with a single moderately sized (<1MVA) transformer feeding a load will have fault duties less than 50kA. Also, the dynamic range of currents that can be seen in LV systems is very high. A 200A breaker fed from a 2000A bus, which in turn has 50kA fault duty, means the breaker will see fault current that is 250 times its nameplate. Even if the breaker were rated 1000A, a fault would push 50 times its rating through the breaker. The situation serves to make a point on CT sensing. Classical CTs cannot respond well to such dynamic range. It might only put out blips of current at each zero cross. When a CT saturates, it does not simply put out a maximum current and no more; the output becomes so distorted that the relay starts to see less current the more the actual current rises. This puts a handicap on classic protective relaying. One may need the trip units that are supplied with such breakers to respond to the highest currents, even if a protective relay is installed.

5) LV Systems Tend to Use MCCBs and ICCBs with Standard Trip Units

The great majority of work in LV systems only involves overcurrent monitoring where an MCCB, ICCB, or at times a LVPCB, is sufficient. When applications arise where the advanced techniques of a protective relay may actually be more appropriate, the system design, lack of guidance from the NEC, and lack of experience of the engineer tends to limit the protective relay option from immediate consideration.

The NEC does not address custom relaying schemes for such applications as generators, IPP interconnects, phase loss detection, and schemes to detect ground faults on high impedance grounded systems

- Generator protection and control is beyond its scope. In Article 445 it says the generator shall be protected against overload. That is about all.
- The interconnection of a generator to the bulk power system is addressed in Article 705. Here it says overcurrent protection is required, that the system must shut down on loss of the primary source (utility).

- As previously mentioned, the NEC only lightly touches on ground fault detection processes in high impedance grounded systems.
- The NEC does not directly address that application of negative sequence current or voltage and the advances that can give for system protection.
- The NEC does not discuss advance motor protection schemes found in modern motor protection packages, and simply requires overload protection.

Each of these schemes could use a protective relay. Given the breaker designs described above, the relay could be incorporated into a low voltage network by:

- Obtain an ICCB or LVPCB with the lowest cost possible trip unit. (An MCCB without a trip unit (molded case switch) with a shunt trip is possible too). These breakers cannot be bought without at least a basic trip unit. Obtain a breaker model with a trip coil and a close coil and the appropriate CT placement. It is likely that you will obtain CTs mounted loose/separate from the breaker. Install a relay to monitor the CTs. The basic trip unit will be needed for the case where the current rises to extreme fault levels, where a CT might not be able to perform, but we will allow the relay to do the other tripping functions, still maintaining conductor protection per the NEC.
- Install a protective relay. Not all 480V panel boards have space to mount a relay, but some relays are smaller than others and available in a variety of case sizes.
- Allow the protective relay to add all the myriad of features, yet still perform the overcurrent protection as called for by the NEC. The average relay can do many things the typical 480V trip unit cannot.

The cost differential of the most basic trip unit, with ground protection, and the approach above, is likely in favor of installing the relay, and one obtains more functions than the most capable trip unit.

Conclusion

The paper's intent was to let the HV/MV engineer become more aware of a few important aspects LV design that differ from HV/MV design, including some concepts out of the NEC, a few critical concepts on LV system design practices, and some concepts where classical protective relaying fits into this environment. The breadth of this topic will not be gained entirely from this paper, but the concepts herein are important building blocks that must be part of one's work in the LV environment.

References

1. The National Electric Code, NFPA 70
2. IEEE Standard 1015, IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems ("Blue Book")
3. UL 489 (NEMA AB1), Molded-Case Circuit Breakers, Molded Case Switches, and Circuit-Breaker Enclosures
4. IEEE Standard C37.13, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures
5. Cooper Bussmann, "Fuseology", available at http://www.bussmann.com/apen/pubs/spd/index.asp
6. IEEE Standard 242, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems ("Buff Book")
7. David Beach, Negative Sequence Relaying Applications in Ungrounded and High Impedance Grounded Industrial Systems, Western Protective Relay Conference, October 2005; available at http://www.basler.com

Biography

John Horak received BSEE degree from the University of Houston in 1988 and his MSEE degree, specializing in power system analysis, from the University of Colorado, Denver, 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. Previous employers include Houston Light and Power and Chevron. John joined Basler Electric in 1997 and is a Senior Application Engineer. John is a member of IEEE-IAS and -PES and has P.E. licenses in Colorado and California.

David Beach received a BS degree in Electrical Engineering from California State University, Fresno in December of 1982 (and is presently progressing toward an MSEE from Idaho State). Since that time, David has become a Registered Professional Engineer, licensed in the states of California, Oregon, and Washington. David worked in the Consulting Engineering business until February 2005 when he joined Basler Electric Company as a Senior Application Engineer. David is a Senior Member of the IEEE, a member of the Industrial Applications Society and the Power Engineering Society of IEEE, and represents Basler on the work groups extending IEEE Standard 1547.

Back to Table of Contents