Technical Considerations in the Specification of LV Switchboards

The following subject headings provide a list of technical considerations, which should be applied to the specification of LV switchboards. The information provided is not exhaustive, but is intended to give a basic understanding of the requirements.

AF Switchgear will be pleased to assist in the specification process and to provide more extensive technical data. Please write, call or e-mail our Sales Department at the addresses and numbers provided below.

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Standards:

The basic standard to which designs and assemblies shall comply, is BS EN 60439-1 1999 - Low Voltage Switchgear & Control Gear Assemblies (part 1 - specification for type testing and partially type tested assemblies).

The standards listed below are also relevant:

BSEN 60947-1 : 1992 Low Voltage Switchgear & Controlgear (part 1-general rules)

BS EN 60529: 1992 - Degrees of ingress protection.

BS 7671: (IEE Wiring Regulations 16th Edition)

E.U. Directives:

Low Voltage Directive 73/23/EEC

Machinery Directive 89/392/EEC

Electromagnetic Compatibility (EMC) Directive 89/336/EEC

Cabling Facilities:

This aspect of Switchboard and MCC design is often the least considered – but is of paramount importance to the installer.

The key issues to establish are:

- Type and size of cables.
- Whether single or paralleled cables are proposed.
- Whether trench depth or ceiling height allows the cables to assume not less than their minimum bending radius beyond the bottom or top of the cubicle.
- Whether non-ferrous gland plates are required (for high current single core conductors).

The Switchboard layout design is now evolving **inwards** from the cable entry, glanding and connection restraints, thereby establishing the available space for "all other items".

Access:

Cubicles may be front access only, rear access only or front & rear access. This has clear ramifications with regard to cable accommodation and access. What should not be overlooked with the **Front access only** configuration, is the fact that rear access may be available during the factory build period and that components - such as fuses, CT's etc, are located such that they can be accessed when installed on site and in service.

Forms of Separation:

This essential aspect of switchboard design deals with the separation of live parts, functional units, terminals and glanding facilities and is defined in BS EN 60439.

Detailed information is also available in the BEAMA Installations' "Guide to Forms of Separation".

Fault Rating/Fault Level:

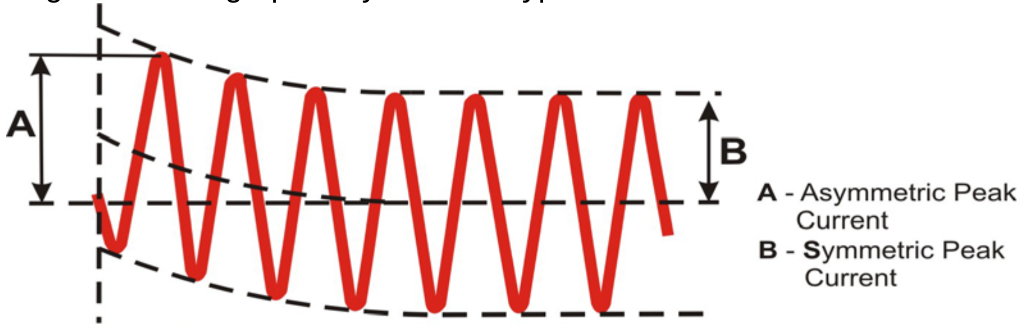
A typical specification requirement where the supply is derived from transformer/s up to 2 MVA would be 50KA RMS sym 1 sec.

Specifiers often state a fault rating of equipment considerably above that which can arise in the system – this is their prerogative. Sometimes however, there is "more behind this" – the consideration of other power sources, which may parallel with the system – and a little known subject – **motor contribution**. If a load has a large motor content this may become a source of regenerated energy during a short circuit fault on the system. The effect is that certain sections of the switchboard busbars have to carry the fault current "expected" from the supply source plus the regenerated (reverse current) from the rotating machines.

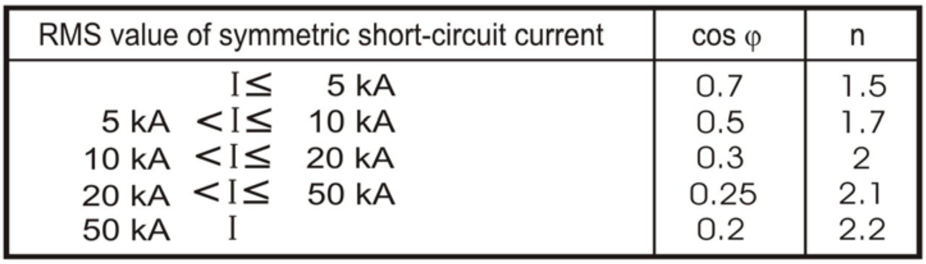
Fault rating or fault withstand capability is a safety statement that the equipment or device can without hazard to personnel, or equipment damage, operate or be operated up to that fault level and be suitable thereafter for further service, albeit in some cases at reduced load level.

In order to appreciate what has to be considered in the selection of components and the design of equipment to cater for the above requirements, it helps to have an understanding of what happens during a fault current transient period and the terminology used.

The following illustration graphically shows a typical short circuit current transient:



Measurement of prospective current



RMS value of symmetric short-circuit current	cos φ	n
I≤ 5 kA	0.7	1.5
5 kA <I≤ 10 kA	0.5	1.7
10 kA <I≤ 20 kA	0.3	2
20 kA <I≤ 50 kA	0.25	2.1
50 kA I	0.2	2.2

Relationship between RMS symmetric short circuit current, power factor and asymmetric peak current to RMS symmetric current multiplier, n

When a short circuit fault commences, an asymmetrical condition of the waveform initially occurs. A DC component, proportional to the **fault circuit** power factor effectively raises the sine wave zero axis thereby increasing the Peak Value of the current wave relative to the original axis during the first few cycles.

The “normal” peak value (if the wave is sinusoidal and symmetrical) will be 1.414 x the RMS value. As can be seen from the illustration, the low power factor of the **fault circuit** (not to be confused with the distribution **system** power factor) brings about an increase @ 0.25 PF to 2.1 x RMS.

From the above, it can be seen that measurements of RMS and peak can either be made relative to the displaced zero axis or to the “original axis” during the early cycles of a fault current transient. In the “early days” much confusion arose due to this.

Convention now established and generally adopted is that Peak value is stated as Asymmetrical – i.e. that as experienced initially (during the first cycle) and that RMS is expressed as the “normal” symmetrical value.

The asymmetrical Peak value is also sometimes referred to as the Peak Making Current, particularly when associated with switching and protective devices.

Why the two separate measurements of fault current ? The reason is very sound and relates to the separate and potentially damaging electromechanical and thermal effects of the pattern of change during the transient period.

Mechanical forces of considerable magnitude occur resulting from opposing magnetic fields between parallel conductors during the fault/transient and directly relate to the **square** of the **peak** value (asymmetrical peak). Such conductors require to be suitably restrained from movement and distortion.

During the duration of the fault period, which will tend to be dictated by the protective device operating time, which may be graded in a discrimination system, **thermal** stresses occur which relate to the **square** of the **RMS** value of the fault current and the time duration, I^2t. The temperature rise resulting from this "let through energy" must be limited (by appropriate selection of conductor cross section) to that which will not cause damage or deterioration to the insulated supports, other insulation in close proximity and connected devices.

From the foregoing, it can be seen that the **Mechanical** forces (which may reach several tonnes in magnitude) are at their maximum during maximum asymmetry, i.e. during the first half cycle. If the restraining/bracing techniques adopted, successfully maintain the stability and alignment of the conductor system (Bus bars, interconnections etc) during the first half cycle, they will then be subject to considerably lower forces and stresses during the remainder of the fault “experience”.

The stresses building up in the conductor system during and after the first half cycle are the **Thermal** effects of the “let through energy” (I^2t measured in Joules). This manifests its self as a rapid temperature rise, and may apply further stresses to the mechanical support system due to distortion and expansion of the conductors.

The points highlighted in the preceding three paragraphs are the principal features focused upon in an independent sequence of proving tests carried out on Busbar systems at short circuit testing establishments. The oscillograms produced and supporting photographic evidence of system configurations tested, serves to verify the:

a) Asymmetry (Peak)
b) RMS symmetrical
c) Time interval
d) Temperature rise (above declared ambient)
e) Evidence of extent of any distortion and/or support/bracing failure.

The use of designs of busbar systems in configurations that have such proof of integrity under fault conditions shall be adopted whenever feasible and appropriate to the application. A further factor that must not be overlooked is verification of temperature rise at normal assigned full load current.

TTA’s and PTTA’s:

These are categories within BS EN 60439, differentiating between Fully Type Tested FBA’s (Factory Built Assemblies) and Partially Type Tested FBA’s.

Bespoke, custom built, Switchgear and Control Panel Assemblies are by essence likely to be PTTA’s. The manufacturer should include Type Tested components and sub assemblies within the design.

PTTA’s are not inferior to TTA’s. They are usually the outcome of a different concept of applications to suit a specific installation.

Operating Temperature and Environment:

BS EN 60439 states a maximum indoor ambient temperature of 40ºC, a maximum daily average of 35ºC and a minimum ambient of -5ºC.

As a general guidance rule, the temperature within the FBA should not exceed 50/55ºC. If Switchroom/Plant room ambients are typically considered to be up to 25ºC this relates to a 25/30K rise above ambient. In the maximum ambient condition of 40ºC, this relates to a 10/15K rise above ambient. Natural ventilation facilities will be required in the design of the switchboard to ensure the maximum internal temperature is not exceeded.

The sources of heat within the FBA will be:

a) Heat liberated by the copperwork and cabling.
b) Heat liberated by the devices.
c) Heat liberated by eddy currents and magnetic losses.

A Factory Built Assembly accommodates a number of devices in a configuration that relates to the scheme requirements. The enclosure and compartments within it provide the operating environment for each device. Most devices e.g. circuit breakers, fuse switches, contactors etc. have been Type Tested in **free air** or **“other enclosures”.**

When enclosed within an FBA compartment the heat liberated may adequately dissipate by convection and radiation from the “walls” of the enclosure and by heat sink via the conductors. It may however be necessary to assist the liberation to atmosphere by forced ventilation. Devices, which invariably require such measures, have by experience been found to be:

(a) ACB’s above 2,500A
(b) PFC Capacitor Banks
(c) Variable Speed Drives
(d) Motor Starting Resistors
(e) Power Transformers

Natural ventilation via louvres and/or mesh screens are the simplest and most cost effective measure of controlling temperature rise provided that I.P. ratings are agreed with the client. Considerable investigation has been carried out by AF Switchgear, to establish a relationship between watts dissipated and Inlet and Outlet louvre free area required.

The problems arising from eddy currents and magnetic losses are generally overcome by common good practice in the selection of appropriate non-ferrous materials and the avoidance of ferrous metal “magnetic loops” being created in structures in close proximity to conductors or groups of conductors where phase/neutral balance may not prevail.

The subject of these sources of heat is often considered as one but is in fact two separate issues. **Eddy Current** heating results from the I^2R losses of induced currents circulating in metalwork, which is not part of the defined conductor system. The use of non magnetic, low resistance materials such as Aluminium and Brass for single core cable gland plates and equipment mounting back plates (e.g. for circuit breakers above 630A) will reduce this source of heat and is advisable. **Magnetic** Heating results from the energy dissipated through each cycle of magnetization and de magnetization of a ferrous material (hysteresis loss) and relates to the metalurgical specification of the material used. Both these issues and the losses associated with them are **frequency related** and will be adversely affected at frequencies above the fundamental (50Hz).

Ferrous metal “magnetic loops” around single conductors or groups of conductors that do not produce a magnetic nil balance can bring about additional problems to those mentioned above by virtue of the fact that currents are circulating in metallic structures and joints in them that are not designed as conductor systems. These currents can be of extremely high magnitude, particularly during short-term load inrush transients and during short circuit conditions. Such high current circulations through joints in the structures can result in arcing / sparking at such joints. The arcing can produce an ionised gaseous state in a region close to the main conductors / busbars and precipitate a most catastrophic flashover and destructive failure in this zone of the switchboard. In situations where mechanical support is required between conductors, non-magnetic materials and sometimes non-metallic materials, have to be applied.

Forced ventilation via fan(s) will have to be considered if natural ventilation will not adequately maintain an acceptable environment for the device(s). Fans should be arranged to provide positive pressure (blowing in at low level) with exhaust air discharging at high level. It is generally advisable to use fans with integral louver/filter housings regardless of the I.P. requirements.

In situations where the I.P. rating of fan ventilated systems is not acceptably high enough or the temperature rise cannot be adequately controlled by this method – Refrigerated (A/C) cooling techniques must be employed.

Anti-condensation control may have to be incorporated either resulting from specified requirements or if the operating environment requires it. This may be catered for by thermostatically controlled heaters and/or ventilation. Special anti-condensation paint on internal surfaces is also effective in some cases.

Selection of Devices and Components:

i) Circuit Breakers & Switch Disconnectors

With confident knowledge gained from the fault rating/fault level and applied in this area, the information stated by suppliers/manufacturers resulting from their type testing, can be appraised and related to the particular application.

The incoming device shall be capable of:

a) Making on to the maximum prospective fault current available at this point in the system.
b) Interrupting the fault current or in the case of a non auto/isolator (switch disconnector), withstanding the through fault current until the up stream device operates or for the specified time – say 1 sec.

c) Make and break normal full load current an adequate number of times consistent with the application.

ACB's (Air Circuit Breakers) are designed to close on to a short circuit fault at Peak Asymmetrical Current (within the limits of their assigned rating), the mechanism will "latch closed" and hold the contacts together until such time (up to 1 sec) as the trip unit or protection relay initiates the release process of the mechanism. It follows therefore, that when used in Auto or Non-Auto (Isolator) mode, these devices totally fulfil the requirements a), b), c) stated in the previous paragraph.

MCCB's (Moulded Case Circuit Breakers) are **not** through fault rated devices. A value of short time current rating is generally available, which will be **considerably** lower than the breaking capacity of the device. MCCB's are designed to open under short circuit conditions (above a certain threshold) during the first half cycle, thus the reason for their compactness and style of mechanism. This fundamental feature must be clearly understood when considering ACB versus MCCB in discrimination selections and particularly when considering the use of Non-Auto MCCB's, (Isolator's or Switch Disconnector's).

Switch disconnectors now exist which still retain a tripping function at a pre determined high level (below that which would damage the device) but which may provide adequate discrimination usually 10/15kA dependant on rating. This is a useful safeguard if details of the upstream device cannot be established.

ii) Fuseswitches

These devices embody energy limiting HRC fuse links which satisfy the requirements of a) & b) above. They will generally be reduced in load switching capability than circuit breakers.

Particular caution should be applied with the consideration of fuse switches fitted with solid isolator links in terms of fault making and through fault capability.

Energy Limitation (Current Limiting)

This has traditionally been the significant feature of HRC fuse links whereby the "cut off" characteristic of the element gives an assured maximum I^2t and **Peak current** value for all values of fault current above the cut off level (up to 80kA with BS88 links).

Some circuit breakers are now able to achieve high degrees of energy limitation with published and certified evidence of limitation of I^2t and peak current.

If the incoming device demonstrates an ability to limit Peak Asymmetrical Current, then a benefit may be available in that the busbars and outgoing devices may be able to be selected at reduced fault rating. A further benefit may arise with certain **cascade** conditions whereby the **mutual** operation of incomer and outgoer will significantly enhance the **apparent** fault capability of the outgoing device. This latter technique however **may** compromise discrimination.

In summary it should be remembered that whilst all automatic circuit protective devices have a declared or calculable value of I^2t – they are not deemed to be **energy limiting** unless they operate with sufficient speed, above a declared threshold, to be able to interrupt the fault current **before** the first half cycle **peak.**

Controls, Monitoring Devices and Instrumentation:

The selection of these items is invariably contract specific and related closely to the scheme philosophy.

Most A.C. monitoring and measurement devices rely on the accurate measurement of the RMS value of the current or voltage waveform. Some measure Peak Value and "calculate" the RMS from this, others accurately and rapidly scan the wave and calculate **True RMS.** The latter is the only faithful method as it is not "mislead" by high Crest Factor (the ratio of Peak to RMS), which can be prevalent with non-linear loads.

For generator control systems, the wide frequency and voltage variations may have to be "accommodated" from start up to shut down of the plant. DC voltage if derived from the starting batteries will vary considerably from cranking level, to "on charge" level.

Power Interconnections – Conductor Size:

Manufacturers when type-testing devices such as Fuse Switches and Circuit Breakers to establish temperature rise limits (measured at the terminals) adopt cable or copper bar sizes as stated within the product standard (e.g. BSEN60947-1). The conductor acts as a "heat sink" to the device.

A study of the permitted conductor sizes shows these to be "on the generous side". The conductor sizes selected for interconnections by the switchgear builders, or by the contractor for outgoing cables are sized from other criteria and **may** be smaller that those used in the type test situation. This could result in a higher temperature rise being experienced.

High ambient temperature, restricted internal air circulation movements and the likelihood of high Harmonic Distortion, are all factors that may require special design consideration and discussion.

Protection:

1) General Principles:

In distribution systems, devices are required to protect cables against thermal and mechanical damage resulting from excess current flow. The excess current may result

from a fault, phase to phase, phase to neutral or phase to earth – or a combination of more than one of these.
The nature of the supply source, the fault location, the impedance of the fault circuit and that of the "seat of the fault" will determine the magnitude of current flow. Prospective fault current calculations always assume zero impedance at the "seat of the fault" and generally relate to the **theoretically worst situation** – that of a phase to phase fault wherein the resistance and if appropriate, reactance of the cable/s in **one line** only are considered. In practice, fault currents seldom, if ever, reach these levels as for example, phase/neutral faults require the neutral conductor impedance to be taken into consideration (which will approximately half the fault current) and the "seat of the fault" will often present a considerable impedance.

The higher the **actual** fault current, the **better** it is for protective systems to operate **as designed** and to **discriminate** – particularly with **HRC fuses.** "Events occur" in practice however, from time to time, which reflect the practical "facts of life" expounded in this and the previous paragraph.

Protection is deemed to be correctly established if the protective device operates within an inverse time/current curve that ensures that conductor and insulation damage is not sustained.

Within a manufactured assembly it may not always be possible to provide over current protection to certain conductors. These should be kept to the minimum and treated as within **"fault free zones"**. Control and instrument feeds from busbars and/or copper interconnections should wherever practical be fed via HRC fuse fittings directly attached to the copperwork.

2) Earth Fault / Leakage Protection:

This is a specific area of protection consideration that extends the "responsibility" to excess current or leakage current to earth. If current flow to earth is of sufficient magnitude to be "seen" as overcurrent, the "normal" protective device will operate, defined parameters of acceptance of this principle are stated in the IEE Wiring Regulations/BS7671.

Leakage currents to earth may give rise to the likelihood of non-conducting metalwork being at a dangerous potential thereby presenting a risk of electric shock or other hazard depending upon the specific environment. Should such leakage currents be of insufficient magnitude to operate the "normal" protective device – they will continue undetected. Should this potential situation be required by the system designer/specified to be protected against, special detection equipment must be embodied in the scheme.

Forward looking, **UNRESTRICTED,** (downstream from the device) Earth Fault protection whether it be a simple RCD (Residual Current Device) or more sophisticated Relay and CT's system, works on the simple (and old) principle of "core balanced protection". With a supply, which has neutral earthed at source, the vector sum of the Phase and neutral currents will be zero. Should this be detected not to be so, the current "measured" is deemed to be earth current flowing to the earth reference point at the supply source. A threshold value has to be established as to the acceptable tripping level in order to avoid "nuisance tripping". A time delay may also be required/specified.

The provision of **UNRESTRICTED E/F (UREF)** protection is usually associated with outgoing and/or downstream Switchgear devices.

RESTRICTED E/F (REF) protection adopts the same core balanced principles in operation and caters for the LV Zone between the transformer LV winding and the LV Switchboard Incomer. This zone "escapes" any other form of earth fault protection i.e. the MV (high voltage) earth fault protection equipment cannot take account of core balance reference due to the galvanic isolation inherent within the transformer. The MV source star N/E has no reference in the LV system. Earth faults in this zone without REF protection can, only be detected in the MV system as excess/overcurrent and this becomes "difficult" from a protection point of view in that the "arithmetic" involves the complex vector relationship of *asymmetrical* faults in the **LV Star** system and how they relate to the **MV Delta** system. Asymmetry here is used to describe a fault that may not be evenly balanced across the 3 phases.

REF protection can be achieved with either integral trip units in LV ACB's or with dedicated protection relays, both requiring the appropriate configuration of CT's, particular care needs to be taken with the correct location of the 4th (neutral) CT. If the integral trip unit option is pursued, two important caveats must be observed:

a) ACB's by some manufacturers require a special external power unit for this mode of operation to enable "low value" fault currents to be detected.

b) If the ACB is a withdrawable unit, it should be noted that the REF protection is rendered inoperative in the Disconnected (and Test) positions. A label must be fitted clearly stating this in order that the duty holder can ensure that the MV equipment is isolated prior to withdrawal of the LV breaker.

Whilst the fault condition is **detected** in the restricted LV zone and tripping is **initiated** here, an **intertrip** with the **MV circuit breaker** must take place in order to interrupt the fault. This will require details to be known of the tripping battery and circuit arrangements of the MV equipment.

REF protection is not commonly seen with Transformers up to 1.0/1.25 MVA unless the LV tails are "long" say over 10m or the tails are considered to be vulnerable with regard to likelihood of physical damage. Above this rating it tends to be more "the norm" – but is a specifier driven feature.

Transformer L.V. Star Point/Neutral Earthing:

This is a vitally important aspect of system integrity and the fundamental requirement of a system conforming to the TN-S configuration as defined within BS7671 (IEE Wiring Regulations).

Whilst it may be considered to be a client/specifier design matter on the face of it, the switchgear designer must ensure **how** and **where** this **has** been accommodated. It is often convenient to provide a N/E link within the switchboard.

If a scheme involves a **step up** transformer, it should be noted that unlike a “normal” step down distribution TX, the LV winding will be **Delta** and the MV winding will be **Star** thereby creating a N/E reference point at the origin of the “new MV system”.

Buchholz Relay Protection:

This is a **mechanical** device, which is optionally fitted externally to the tank of oil/liquid filled transformers. It has two functions. The first, initiating an alarm contact, is sensed by a float which senses a build up of gas caused by a minor insulation fault within the windings of the transformer. The second, initiating a trip contact, is sensed by a steel vane sensing a high flow of oil from the transformer tank to conservator, caused by a major fault within the transformer windings or internal connections. It is the trip contact, which is used to trip the MV circuit breaker, which in turn trips the LV circuit breaker.

HRC Fuses:

This very traditional method of protection provides a secure cost effective system of protection with confidently predictable discrimination and energy limitation.

In spite of the worldwide move towards the adoption of MCCB’s, fuse technology and application (both British BS88 and European/Continental types) still continues. The application initiative however, is very much specifier driven.

Fuse application is seldom seen above 800A where the cost and availability of switching hardware becomes prohibitive.

A common misconception regarding HRC fuses is that they **always** demonstrate energy limiting “cut off” characteristics under short circuit conditions. This is **not** necessarily the case. This feature of their characteristic is dependant upon the **value** of prospective fault current. e.g. a 400A fuse link (BS88) does not reach cut off (less than 10 ms) with fault current less than 10 KA. At 9 KA the total operating time is 20 ms (one cycle) and at 2 KA is over 10s.

Motor Fuses are to be considered with considerable caution. There is wide misunderstanding as to what they are. A 100M200 link is a **200A** element in a **100A** barrel. The time/current **characteristic** is that of a **200A link.** This allows the economic use of a 100A carrier and base should the normal running and full load current **not exceed 100A.** It is imperative therefore, that this fact is clearly established. So called “nuisance” blowing of fuses being resolved by the use of “motor fuses” must only be considered with a full understanding of the foregoing facts.

Semi conductor fuses are designed as the name indicates, to give special energy limiting short circuit protection to semi conductor devices such as Thyristors and assemblies such as Soft Start Units etc. These are **not** designed or intended to provide

overload protection and may have manufacturers **embargoes** applied such that they shall not be called upon to operate **below** a prescribed current level.

Circuit Breakers:

These devices are widespread in their application worldwide in the form of ACB's, MCCB's and MCB's as reliable protection choice options.

The protection time/current characteristic of these devices is provided by an integral thermal/magnetically or electronically actuated release mechanism. Some MCCB's and all ACB's have replaceable integral trip units.

Some specifiers prefer to use ACB's without the trip unit (non auto) and rely upon a separate Protection Relay arranged to remotely trip the ACB via a shunt release (shunt trip coil). This stems from the days when integral trip units were "no match" for the well-proven dedicated specialist relays, which offered an extremely extensive choice of inverse time/current curves to satisfy the most fastidious protection engineers, thus the practice still to some degree continues.

The use of separate protection relays, if specified, requires special considerations such as choice of appropriate protection class CT's, high integrity of the shunt trip cabling, possible use of DC tripping batteries and associated charging and alarm systems.

ACB manufacturers argue that "modern" electronic trip units are "a match" for separate protection relays and that by virtue of the lack of dependence on external CT's and trip circuit wiring, are less likely to fail. The integral system, no matter how it is adjusted/set automatically ensures that any through fault limitations of the device are not exceeded. This philosophy is supported by the writer, furthermore the **cost effectiveness** of this option is **significant**. The subject of selection is often however specifier driven, the option however, if open to choice should go to the application of the integral unit.

All ACB's and most MCCB's are available in fixed and withdrawable form, the withdrawable option being specifier driven. It should be noted that in withdrawable form, the power loss dissipation of the unit (internal watts loss) is generally about **twice** that of the fixed pattern unit.

ACB Earthing Kits or Earthing Switches may be specified in certain applications. This facility is a safety precaution adopted during system or equipment maintenance periods wherein; i) the LV switchboard busbars are connected to earth via the ACB or; ii) the transformer tails are connected to earth via the ACB. The kits for conversion of ACB's also render the protection inoperative and dependant on the configuration of links and attachments can provide the appropriate orientation for either busbar or transformer earthing as required. Some manufacturers provide a "special" earthing switch version of the ACB. In all cases, the fixed portion (chassis) must be suitably equipped for this option from the outset.

With reference to the example statement made in a previous paragraph, relative to a 400A HRC fuse, it should be noted that an MCCB of the same rating can achieve a total break time of 20 ms for fault currents of 4 KA and above, whilst at 2 KA giving similar performance to that of a fuse.

Some MCCB's (dependant on manufacturer and type) are Current Limiting and achieve a high degree of energy limitation having breaking capacities beyond that achievable with HRC fuses (up to 180 KA).

Discrimination and Co-ordination:

Discrimination:

This is an important aspect of system and equipment design. Within a switchboard or control panel assembly we should ensure that the incoming device, or upstream device (if incomer is an isolator) discriminates with all outgoing devices. By definition, the lower rated device only, should operate for all values of overload and fault current in the immediate zone down stream.

The incomer should only operate in the event of busbar overload or busbar zone fault. The incomer sometimes is relied upon to also provide overload protection for the transformer, if this is the case it may have to be set lower than its nominal assigned rating, e.g. 1600A set to 0.9 for a 1 MVA TX. If the supply source is a Diesel Alternator – special characteristics may be required.

With HRC fuse systems discrimination is assured if a factor of 1.6 x is applied between successive "stages" in the ratings of fuses that are in series. This practice should also be observed with control circuit fusing, particularly with supplies derived from Bus Bar mounted fuses, which may not be readily and safely accessible in service.

With circuit breakers and combinations of CB's and HRC fuses, manufacturers characteristics must be compared and evidence studied of any test data available from actual tests carried out of such combinations.

Total discrimination throughout a distribution system is a fine objective for the designer to strive to achieve, but in practice from time to time, **compromise** will have to be faced. This may be up stream in the MV network or at some stage down stream.

Where compromise is unavoidable – it can often be controllable to some degree as to the "range" or "band" of prospective fault currents within which the discrimination loss may occur. This control by means of adjustment setting or selection of tripping curve profile can be made with consideration of the likely magnitude of fault currents at particular points in the distribution system.

It is important to be able to establish the values of theoretical maximum prospective fault current throughout a distribution system and there are sophisticated software packages available which assist in this endeavour. At the planning stage where the feasibility of various options are being considered and discussed with the client, it is often helpful to use a simple graphical guide to prospective fault currents available from various transformers and the decrement curves relating to circuit resistance/impedance.

Co-ordination:

This subject “naturally” follows on from discrimination and is sometimes confused with it. Co-ordination is in fact a controlled loss of discrimination where by the up stream device “takes over” from the down stream device by **intention/design.**
The application of this is most commonly seen in (but not limited to) the application of motor starting systems. This is defined within IEC 947-4-1 and has two categories – type 1 (previously type “a”) and type 2 (previously type “c”).

Type 2 co-ordination, is assured when the up stream device is so selected that the contactor and overload device are uninhibited in the handling of overload and stalled motor conditions and the combination of devices utilizing the up stream energy limiting protection handle short circuit conditions without deterioration or **altered settings** of the **overload device.** This latter point is most important, as the **future** overload protection to the **motor** and **cables** is reliant on the integrity of this device. No danger to personnel or installations must be assured, although “light welding” of contactor contacts is permitted if easily separable.

AF Switchgear always ensure that Type 2 co-ordination is embodied within all designs, and equipment shall only be used from manufacturers who can show evidence of tests which substantiate conformity to IEC 947-4-1.

Similar philosophy applies with the use of co-ordinated up stream energy limiting devices to enhance the fault capability of MCB’s.

Harmonic Distortion and High Frequency Applications:

The presence of harmonic frequencies in addition to the fundamental 50Hz, bring about distortion of the fundamental sine wave. Considerable problems may arise dependant upon the level of this distortion.

Sources of harmonic distortion can be:

(a) Variable Speed Drives
(b) UPS equipment
(c) Non Linear Load (switch mode power supplies)
(d) Special Industrial Processes
(e) Resonant conditions with PFC capacitors
(f) Diesel generated supplies, cyclic engine/flywheel irregularities and full pitch winding alternators.

A particularly problematic manifestation of the presence of harmonic currents is the reduced level of current depth of penetration in all conductors (switchgear, transformers, cabling etc) known as Skin Effect at the higher frequencies.

The Copper Development Association has produced two useful documents (publications 22 and 123), which include information relating to power quality and system reliability. The following formula, taken from publication 22 can be used to establish the depth of penetration in flat copper bar for various frequencies:

$$\text{Depth of penetration, } d = \frac{1}{2\Pi}\sqrt{\frac{pX10^{5}}{f}}$$

Where d = depth of penetration. mm
ρ = resistivity of copper. μς cm
f = frequency. Hz

Example at Fundimental, 50hz:

$$d = \frac{1}{2\Pi}\sqrt{\frac{pX10^{5}}{f}} = 0.159\sqrt{\frac{1.72X10^{5}}{50}} = \underline{\underline{9.32\text{ mm}}}$$

Examples at some harmonic frequencies

3rd	f = 150Hz	d = 5.38
5th	f = 250Hz	d = 4.18
7th	f = 350Hz	d = 3.52
11th	f = 550Hz	d = 2.81
13th	f = 650Hz	d = 2.58

It can be seen that at 50Hz the penetration depth is just over 9mm therefore with conductors (or solid laminations) greater than 18mm thick, the centre of the conductor starts to be "void" of current. As the higher frequencies are considered e.g. the 13th (650Hz) the centre of 6mm thick conductors is not being "reached".

This definitely results in higher conductor temperatures than those expected under true sinusoidal conditions, encourages the use of conservatively rated copperwork and the adoption of **air spaced** conductor laminations rather than solid, butt-up, formations.

A further problem arises with harmonic currents in that unlike "normal" fundamental currents, the <u>odd numbered</u> i.e. 3rd, 5th, 7th etc. etc. harmonic currents do not vectorially add with a resultant as the neutral current - they arithmetically add and summate in the neutral. This can result in neutral currents **exceeding** those of the phase currents.

Power Factor Correction Equipment:

This equipment, comprising capacitor units, with appropriate switching contactors is frequently built as an integral part of FBA's. The operation is controlled by a dedicated control relay, which brings in the capacitors in stages as the load and PF of the load demands, in order to satisfy the target level of correction required. Manual override of each stage is a facility normally provided.

It is necessary to ensure that capacitors are **not** in circuit when standby generators are first presented with load as this gives rise to Alternator AVR instability. Unless the uncorrected PF of the load is less than 0.8 lagging, there is no technical or economic merit in having the capacitors in service when the load is generator fed.

It should be noted that in-rush currents of up to 22 x normal current can be expected with a **single** capacitor unit. With multi-stage arrangements each subsequent capacitor switched in, is seen initially by the previously switched unit(s) as a short circuit. The "new" capacitor is subject to the **mains** in rush **plus** a similar in rush from **each** of the preceding stages. After only a few stages, contactors rated adequately for the **one** stage they control are presented with making currents beyond their design limits and contact welding or disastrous emissions of arc products result.

Systems have been developed utilizing in-rush reactors, limiting resistors with pre-making special contactor auxiliary contacts etc. to limit the rate of growth and magnitude of in-rush currents to manageable levels for the contactors to be able to handle. Such composite sub assemblies are available as Type Tested functional units and only these are used by AF Switchgear.

A further problem of past years, was the disastrous end of life display demonstrated by certain capacitors. This could lead to a serious switchboard internal flashover. The current IEC specification (IEC 831) contains an End of Life test condition, which serves to define the limits of any explosive emissions. Only capacitors compliant with this specification are used by AF Switchgear.

The presence of harmonics above certain levels will impose stresses brought about through both voltage rise and excess current in the capacitor elements. This may require as a minimum, that higher voltage grade elements be used or dependant on the level and nature of the harmonic distortion, that de-tuning reactors be installed in addition to higher voltage grade elements.

This is a specialised subject, requiring appropriate advice and if possible a site analysis survey of Power Quality.