Best practices for designing low-voltage switchgear to reduce size, costs, and CO_2 footprint

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Executive summary

Electrical equipment optimization is a top priority for Process Industry operators (Oil & Gas, Petrochemical, Chemicals, Mining, Minerals, & Metals, Water & Wastewater, etc.) and Engineering, Procurement and Construction (EPC) contractors. This paper reviews practices for IEC low-voltage switchgear and discusses key design choices and best practices to help reduce size, costs, and CO_2 footprint by up to 10% as part of operators' sustainability agenda. It will focus on circuit breaker/fuses selection impact at the switchboard level, nominal voltage selection, and enhancements digitization and Intelligent Electronic Devices (IED) can provide.

Presented conclusions are qualitatively applicable for other geographies and standards, even though voltages, ratings, and quantitative estimations will differ.

Reduce footprint and costs up to 10% by switching from fuses to circuit breakers

Electrical equipment optimization is a constant interest to Process Industry operators (Oil & Gas, Petrochemical, Chemicals, Mining, Minerals, & Metals, Water & Wastewater, etc.) and Engineering, Procurement and Construction (EPC) contractors. There is specific attention to low-voltage (LV) switchgear as end users, specifiers, and designers have several alternatives to choose from, which can significantly impact the desired outcome.

This white paper will discuss some key LV switchgear design choices and present best practices to help reduce footprint, costs, and CO_2 footprint, as part of operators' sustainability agenda. It will focus on the impacts of circuit breaker/fuse choice at the switchboard level, nominal voltage selection, and other design considerations.

This paper reviews practices for IEC switchgear, but conclusions would also make sense qualitatively for other geographies and standards, even though voltages, ratings, and quantitative estimations will differ.

Fuses are legacy designs with good performance in overload and short-circuit protection. Circuit breaker design and performance have been drastically improved since the introduction of Molded Case Circuit Breakers (MCCB), reaching similar and, at times, superior electrical performances to fuses. In addition to providing protection, circuit breakers can be fully connected with electrical digital systems to offer:

- Circuit breaker health and status monitoring
- Metering
- Power systems monitoring
- Advanced protection and alarm response

Note:
In this document, MCCB refers to current limiting circuit breaker selectivity category A per IEC/EN 60947-2 or 4-1.

Circuit breakers enable Process Industry operators to benefit from smaller switchboards and to digitize their power system while ensuring an equal or superior protection level as fuses.

Fuses have often been perceived as an economical alternative to circuit breakers. That could be challenged from a total cost of ownership (TCO) or total expenditure (TotEx) perspective, but end-user projects clearly show that the Motor Control Centers (MCC) footprint is smaller with circuit breakers when dealing with mid to large-size MCCs.

This leads to up to 10% cost reduction, lower electrical room costs, and reduced CO_2 emissions.

Fuse switch and circuit breaker alternatives: designer choices

LV circuits must be protected against overcurrent such as overload or short-circuit. In addition, the most common protective measure against electric shock – an automatic disconnection of the supply – also relies on overcurrent protection, particularly in the TN system. IEC 60364 series "Low-voltage electrical installations" and related national electric codes recognize circuit breakers equally according to IEC/EN 60947 or IEC/EN 60898 and fuses according to IEC/EN 60269 series to perform such overcurrent protection.

This paper aims not to reopen the debate between fuses and circuit breakers as products, as their differences are known.

Instead, it aims to complete this comparison with a more holistic assessment by including additional criteria such as switchboard size, costs, sustainability, and reviewing some common myths.

Cable protection and cable sizing

Myth 1 – fuses allow smaller cross-sections for cables.

According to IEC 60364-4-43 and related national rules, cables must be protected against overload and short-circuits. The cable cross-section and its related current carrying capacity and overcurrent protection characteristics are required to meet the following rules:

For overload:

$I_n \leq I_z$ — I_z is the continuous current-carrying capacity of the cable
I_n is the rated current of the protective device

Note: For adjustable protective devices, the rated current I_n is the current setting selected.

$I_2 \leq 1{,}45\ I_z$ — I_2 is the current ensuring effective operation in the conventional time of the protective device. The current I_2 ensures the effective operation of the protective device shall be provided by the manufacturer or as given in the product standard.

For short-circuit:

$LT \leq k^2\ S^2$ — S is the cross-sectional area in mm². k is a factor taking account of the resistivity, temperature coefficient, and heat capacity of the conductor material and the appropriate initial and final temperatures. For common conductor insulation, the values of k for line conductors shown in IEC 60364-4-43 2008 Table 43A.

LT: the let-through energy (I^2t) provided by the manufacturer of the protective device for the maximum short-circuit current.

I_2 is the main difference between fuses and circuit breakers, according to IEC/EN 60947-2:

- I_2 for fuse = 1,6 In
- I_2 for circuit breaker = 1,3 Ir (even 1,2 for electronic release)

In other words, the accuracy of overload tripping characteristics of a circuit breaker is better than a fuse allowing a cable current carrying capacity closer to the circuit breaker rating than the fuse rating (**see Figure 1**).

Let’s consider a 3-phase circuit supplying a 150A load.

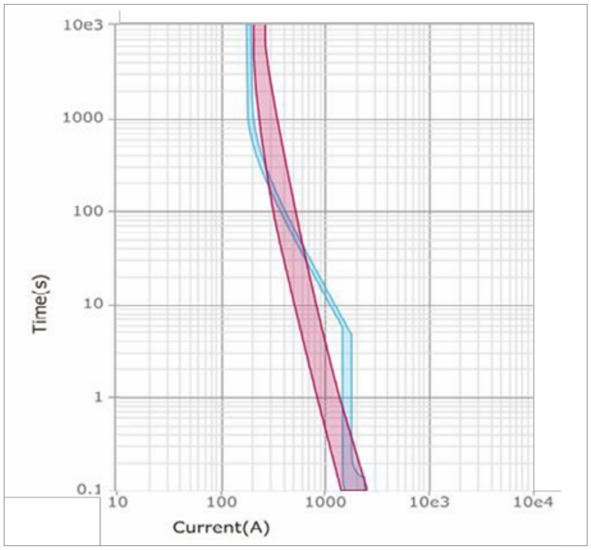
The circuit is made of three cooper single core conductors PVC 70°C on a perforated tray: IEC 60364-5-52 Table B52- 10 Column 6 Method of installation 31-F.

The cross-section area of such a circuit protected by a 160A circuit breaker must be 50 mm^2 Cu (Iz = 174).

The cross-section of such a circuit protected by a 160A fuse must be 70 mm^2 Cu (Iz = 225).

Figure 1

gG160 fuse time versus current curve (red) compared to 160A MCCB with an electronic trip unit (blue)

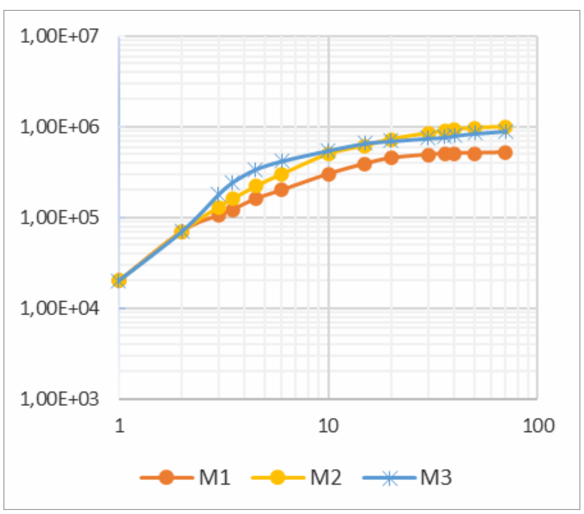


When considering short-circuit protection for such a cable k = 115, the maximum let-through energy for MCCB must be lower than $50^2 * 115^2 = 3.3\ 10^7\ A^2S$.

A 160A MCCB frame will limit the energy far below this value. See **Figure 2** showing let-through energy curves from three different manufacturers for 160A MCCB frame (2021 IEC catalogs), where they are all below $1.10^6\ A^2S$ and far below = $3.3\ 10^7\ A^2S$ calculated for $50mm^2$ Cu PVC cable.

Figure 2

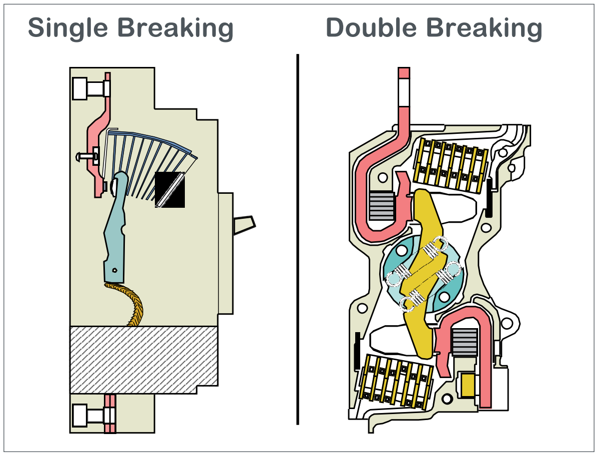
I2t limitation curve 400Vac for 160A MCCB from several manufacturers



Main MCCB manufacturers now use double-breaking technology for frames higher than 100A, providing a high current limitation. The two contacts and two arc chambers of the double-breaking capacity significantly reduce the let-through current and let-through energy, see **Figure 3.**

Figure 3

Illustration of single breaking principle versus double breaking principle for MCCB.



For smaller ratings like 32A or 63A motor MCCB, single breaking technology and internal impedance provide enough limitation to properly protect cables with these ratings.

Hence, both solutions are recognized equally to protect cables against overcurrent. But a circuit breaker will allow a smaller cross-section, or for a given cross-section, better overload protection of circuits, helping to reduce cable damages and fire risk, thanks to the accuracy of its overload protection.

Selectivity and coordination performances

Myth 2 – fuses provide better selectivity and/or coordination with contactors.

Let-through current and energy limitation performances are also linked to selectivity and coordination between short-circuit protection and switching devices like contactors or switch disconnectors.

These performances are covered by the IEC/EN 60947 series of standards:

- IEC 60947-2 Annex A for selectivity
- IEC 60947-4-1 for coordination between overcurrent protection and contactor and an overload relay for motor starter
- IEC 60947-3 for coordination between overcurrent protection and switch disconnector

These standards do not make any differentiation between overcurrent protection provided by fuses or circuit breakers.

Major manufacturers of MCCB have proposed solutions for full selectivity based on energetic coordination for high short-circuit current between MCCB's frames. Additionally, electronic trip units allow adjustments and time delays to cover situations of a long cable or weak short-circuit current.

Type 2 coordination for motor starters based on MCCB is also achieved with an optimized size of devices. If a fuse is utilized, it may be better to protect the motor starter at the maximum short-circuit capacity of the fuse, but MCCB is often better to protect the contactor for the second test required by IEC/EN 60947-4-1 at "Prospective short-circuit current Ir."

Manufacturers provide this information in coordination guides,[1] embedded in electrical design software such as ETAP, Caneco BT, and others.

However, in terms of integration, as some of this data is manufacturer-dependent, it can be complicated for an EPC contractor or final user to manage coordination when different suppliers are involved.

This issue is difficult to address, as the data results from product tests. Hence it can be time-consuming within the execution of a project, especially when the classification company requires justification.

But including tripping curves, limitation curves, and coordination performances in product description standards (such as ECLASS ADVANCED or IEC 62683-1 Low-voltage switchgear and controlgear; product data and properties for information exchange) would be a step forward for EPC tools and detailed engineering phases.

Reliability and maintenance

Myth 3 – fuses are more reliable, and installations with fuses are easier to maintain.

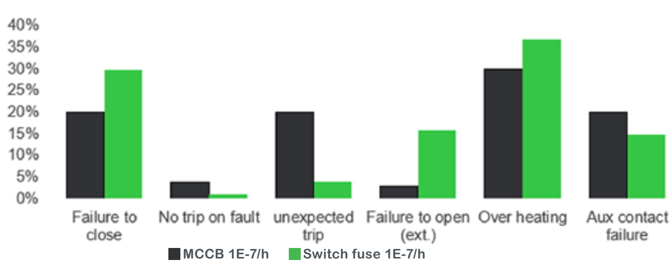
Comparing fuses to circuit breakers is often considered from the perspective of the "overcurrent" function. But this event is very rare and may never happen for many circuits. Whereas all circuits will have to carry current without excessive temperature rise, will be opened/closed/padlocked, etc.

Analysis from field return of MCCB and switch fuses demonstrates that the global failure rates are quite similar.

With different failure modes (see **Figure 4**) the probability of dangerous failure (no trip on fault) is minimal. Still, other failure modes are present, requiring maintenance for both solutions.

Figure 4

Split of failure rate by failure modes for switch fuse solution and MCCB



For example, a switch-fuse solution shows a higher probability of mechanical issues (failure to close and open) that could disturb daily operations.

Therefore, both solutions need a minimum amount of maintenance to ensure proper functioning during installation. Advanced diagnosis function in an electronic trip unit of most recently built circuit breakers can now estimate contact wear due to current breaking.

1 "Selectivity Cascading and Coordination Guide," Schneider Electric, 2021

With this trend towards obtaining aging information built-in circuit breakers will prove useful for maintenance scheduling and help minimize operators' concerns.

Operation in IT system

Myth 4 – fuses are more suitable for the IT type of earthing systems.

A fuse-based solution is inherently designed and tested with a "single pole" approach. Therefore, short-circuit breaking performances are based on a single fuse-link for a rated voltage. Then in the 3-phase system, the fuse-links are installed for one circuit, each able to handle any type of short-circuits.

A 3 or 4 Pole MCCB short-circuit breaking performance is based on the more demanding situation of a 3-phase short-circuit in a 3-phase system supply. In this case, the rated voltage is the line-to-line voltage, and the voltage applied to each breaking pole is operating underline to neutral voltage. This breaking capacity test is relevant for short-circuit situations between phases (or neutral, if any) and between a phase and earthing for all types of earthing systems (TN, TT, or IT).

IT systems are unique as a phase-to-earth fault causes no significant overcurrent so that no overcurrent protective device will trip in that case.

But this operating mode of the IT system can lead to a new situation unknown in TT or TN called the "double earth fault," meaning a first line to earth fault occurs somewhere in the installation. This fault is not cleared, and a second line-to-earth fault occurs later on another line in a separate circuit.

In this situation, a circuit breaker may have to break a current with only one pole under the line-to-line voltage. If a fuse-linked test covers this situation, a standard breaking capacity test ("Icu/Ics" of a 3P/4P circuit breaker) is irrelevant.

LV circuit breaker standards cover this situation by a test described in IEC/EN 60947-2 Annex H: Test sequence for circuit breakers for IT systems. This annex states: "This test sequence is intended to cover the case of a second fault to earth in the presence of a first fault on the opposite side of a circuit breaker when installed in IT systems."

LV installation rules such as IEC 60364 require circuit breakers compliant with this IEC/EN 60947-2 Annex H. Some national regulations may also have additional requirements.

No short-circuit calculation standard (not covered by IEC 60909-0, for example) gives rules to estimate the minimum and maximum current for such a situation.

Therefore, the breaking performances of overcurrent protective devices are not specified by the most common codes for this unique situation for IT systems.

When a first line to earth fault remains present in the system, then the two main benefits of IT systems (no automatic disconnection in the case of an earth fault, very low earth fault current) are lost.

Consequently, it is mandatory to locate and clear this first fault in a reasonable amount of time to maintain system performance and uptime. This point is enforced in standards, with the obligation to have an on-site maintenance team to correct faults when using IT systems.

Depending on the prospective time of fault clearance, even over-insulation of equipment can be required. It is therefore strongly recommended to install an insulation fault locator on feeders to ease and speed fault locaton.

Power losses

It is commonly assumed that power losses of a fuse-based solution are higher than a circuit breaker solution. When it comes to power dissipation, there is no general rule, and complete functional unit power dissipation should always be evaluated, in particular for different types of motor starters.

A simple device-to-device comparison is not always fair nor relevant, and a holistic view should be taken (see case study below).

However, a fuse switch disconnector solution in 100A to 630A will dissipate around two times more than an MCCB with an electronic trip unit.

Looking through an EPC lens, this can have a major impact on the heating, ventilation, and air conditioning (HVAC) system, which is one of the most demanding power consumers in a substation. It also impacts the operation under emergency conditions, where HVAC can be switched off, and the temperature inside the emergency switchboard can rise in minutes, sometimes faster than the required time for the evacuation of an offshore platform, for example.

Features

Circuit breakers, in particular with electronic trip units, provide more features for the same footprint: they allow digitization thanks to metering, monitoring, communication, and also additional protection (see **Figure 5**).

Figure 5

Features provided by circuit breakers and fuse switch disconnector

Features Standard X – Optional O	Circuit Breaker	Fuse Switch Disconnector
Isolation	X	X
Manual control	X	X
Remote control	O	
Overcurrent	X	X
Earth leakage/Ground fault	O	
Signaling (O/C/trip status)	X	X
Metering	O	
Diagnosis (trip history, contact wear)	O	
Communication	O	

LV switchgear footprint and costs

The width of a circuit breaker is, in most cases, smaller than for the fuse switch having the same rating. Particularly, above 15kW, drawers with circuit breakers become more compact than those with fuse switches.

For PCC or MCC feeders, the reduction is usually between 50 to 100 mm.

The **illustration below** is for a 30kW motor, in which the typical size with a fuse switch is 200mm and can be reduced to 150 mm using a circuit breaker.

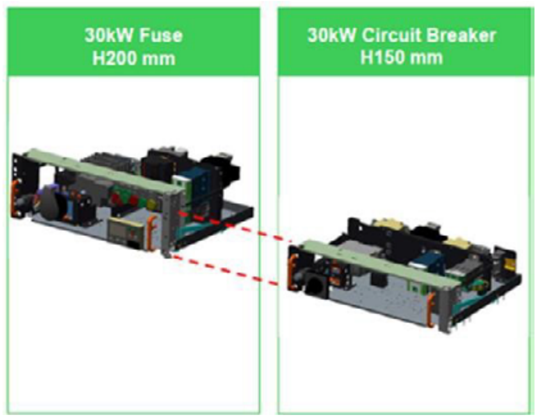


Table 1 shows that a fuse drawer is between 16% to 100% higher than the equivalent one with a circuit breaker, except for motors below 15kW. Even though small motors make up most of the load lists, the assessment at the switchboard level shows that footprint advantage remains for circuit breakers.

Table 1

Drawer size comparison

IP41/40°C
400V
COMPARISON CB vs FUSES SWITCH

PCC FEEDERS

	CB	Fuse/Switch	
100A	150 mm (3P/4P)	250 mm	+66%
200A	150mm (3P) / 200mm (4P)	300mm (3P/4P)	+100% / +50%
350A	250 mm(3P/4P)	500 mm (3P/4P)	+100%

MCC FEEDERS 3P

	CB	Fuse/Switch	
15kW	100mm	100mm	=
22kW	100mm	200mm	+100%
30kW	150mm	200mm	+33%
55kW	150mm	250mm	+66%
75kW	200mm	300mm	+50%
110kW	300mm	350mm	+16%
200kW	450mm	550mm	+22%

The above values can significantly impact the switchboard's length, as demonstrated by the below configurations comparison.

The following example is based on a switchboard with 2 sections, 2 incomers 3200A and a bus-tie 3200A, having on each side 45 feeders.

Configuration A is for a fuse switch.

Configuration A

To accommodate the different feeders, 12 feeder cubicles are needed with fuse switches.

Configuration B

Configuration B is with the same feeders, using circuit breakers.

In this case, only 10 feeder cubicles are needed for the same load list.

Hence, the length of the switchboard decreases from 9.8 m to 8.6 m (1.2 meters, corresponding to 12%), moving from 12 feeder cubicles to 10 cubicles. It is a significant saving of sheet metal, and for the copper used on the horizontal and vertical busbars in 2 cubicles.

The cost of the switchboard can therefore be reduced up to 10%.

It could be challenged whether those drawers or switchboard assessments translate into similar figures for a complete facility since many factors could affect those conclusions at the drawer level and make it more or less true facility-wide. That comparison has been made for an actual project, for a liquefied natural gas (LNG) train facility, with an LV scope of 15 switchboards, corresponding to 250 LV cubicles.

Footprint and cost differences significantly varied from switchboard to switchboard, but selecting fuses instead of circuit breakers led to switchboards 12% bigger and 8% more costly for the total project.

In conclusion, smaller drawers with circuit breakers effectively translate into tangible m² footprint savings for the electrical rooms and significantly lowers costs.

Select the most suitable LV level

The use of a higher LV voltage level, such as 690V instead of 400V, has advantages, mainly in terms of saving cost, footprint, and weight, as well as network efficiency, and CO_2 emission reduction.

The following detailed analysis has been performed using a real case example from the O&G industry to validate.

The objective was to assess the convenience of the 690V for the LV electrical network vs. 400V. The analysis includes the transfer of medium-size motors (from 200kW to 400kW) from 6.6kV to 690V, which is possible because of this higher LV level.

The below detailed comparison between the two solutions has been performed, focusing on the following items:

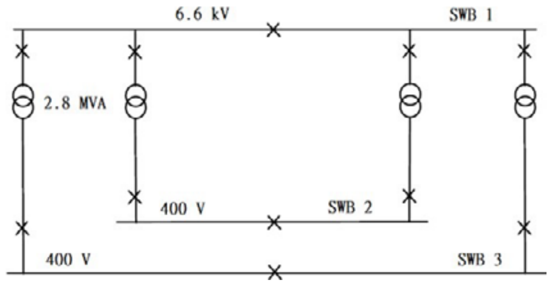
- LV switchboards
- Upstream medium-voltage (MV) switchboard
- Distribution transformers
- Cables
- Induction motors

Costs, footprint, and weight comparison will be highlighted in percentage, whereas carbon footprint saving will be highlighted in $kgCO_2e$.

This analysis is limited to the section of the electrical architecture presented below, which is the relevant part of the complete system.

Alternative 1

400V design



400V key design parameters and characteristics which have been considered:

- 1 x MV switchboard 6.6kV, 1250A, 25kA
- 2 x LV switchboards 400V, 4000A, 65kA (with circuit breakers)
- 4 x Dry-type distribution transformers 2800kVA, 6600V/420V

Load list as below:

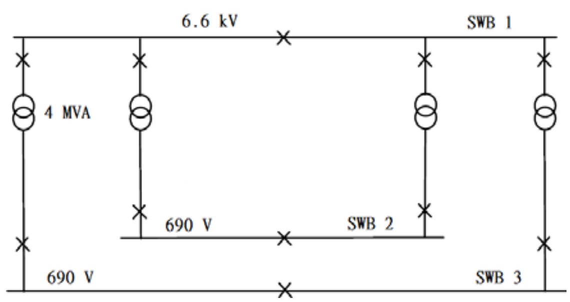
	(V)	Bus	MV Loads – PCC or MCC						
			300A	250kW	280kW	315kW	500kW	735kW	1000kW
SWB 1	6600	A	2	1	2	2	3	1	1
		B	2	1	1	2	4	1	1

	(V)	Bus	LV Loads – PCC or MCC							
			100A 4P	250A 4P	400A 4P	5.5kW	15kW	37kW	75kW	110kW
SWB 1	400	A	6	4	2	12	10	6	2	2
		B	6	4	2	12	10	6	2	2
SWB 3	400	A	6	4	2	12	10	6	2	2
		B	6	4	2	12	10	6	2	2

Small non-process loads typically below 5.5kW (e.g., heating and lighting) are powered through 400V distribution boards.

Alternative 2

690V design



The following characteristics have been considered:

- 1 x MV switchboard 6.6kV, 1250A, 25kA
- 2 x LV switchboards 690V, 4000A, 65kA (with circuit breakers)
- 4 x Dry-type distribution transformers 4000kVA, 6600V/720V

Load list as below:

	(V)	Bus	MV Loads – PCC or MCC			
			300A	500kW	735kW	1000kW
SWB 1	6600	A	2	3	1	1
		B	2	4	1	1

	(V)	Bus	LV Loads – PCC or MCC										
			100A 4P	250A 4P	400A 4P	5.5kW	15kW	37kW	75kW	110kW	250kW	280kW	315kW
SWB 1	690	A	6	4	2	12	10	6	2	2	1	1	1
		B	6	4	2	12	10	6	2	2		1	1
SWB 3	690	A	6	4	2	12	10	6	2	2	1		1
		B	6	4	2	12	10	6	2	2		1	1

MV switchboard comparison between Alternative 1 and 2

Transferring the nine smallest MV motors to a 690V LV switchboard will lead to the following savings:

- Cost saving: 32%
- Weight saving: 31%
- Footprint saving: 32%

Alternative 1 / *Front face of 6.6kV MV switchboard with a total length of 18.2 m*

Alternative 2 / *Front face of 6.6kV MV switchboard with a total length of 12.35 m*

LV Switchboards comparison between Alternative 1 and 2

By transferring MV motors, the 690V LV switchboard has increased in size by two columns. The additional length is 1.2 m. It is worth noting that without the transfer of MV motors to 690V, the 690V switchboard would have the same size as its equivalent 400V switchboard.

The overall impact on the LV switchboards is the following:

- Costs increase: 27%
- Weight increase: 15%
- Footprint increase: 15%

The front face of the 400V LV switchboard (7.95 m total length)

The front face of the 690V LV switchboard with additional motors (9.15 m total length)

If there had been no transfer of motors from 6.6kV to LV, the impact on switchboards by using 690V instead of 400V would be as below:

- Costs saving: 7%
- Weight saving: 15%
- Footprint saving: 15%

Note: In the case of 690V (without additional motors originally MV), cubicle quantity is reduced due to short-circuit reduction below 50kA and incomers and main busbar rating reduction below 2500A.

Impact on Distribution Transformers

Transfer of MV motors to 690V impacts distribution transformer size. The 2.8 MVA 6600/420V dry-type transformers proposed in Alternative 1 would then become 4 MVA 6600/720V, with the following impacts:

- Cost increase: 44%
- Weight increase: 46%
- Footprint increase: 33%

Impact on induction motors

With Alternative 2, i.e., 690V instead of 400V for LV and nine motors transferred from MV 6.6kV to LV, costs and weight savings are the following:

- Costs saving: 15%
- Weight saving: 2.4% (2.28 t)

Impact on MV and LV power cables

Induction motors are considered at 200 m from switchboards on average to assess impacts on power cables. The size of MV and LV cables has been chosen according to the recommendations from the Standards.

Costs saving associated with Alternative 2 is 17% and a weight increase of 2.4% (~1t).

Carbon footprint during the construction phase (CapEx)

The below analysis addresses the impact on sustainability Scope 1 and 2, which are the direct and indirect emissions linked to the manufacturing of product/equipment and the energy used for operations.

With the integration of 690V instead of 400V, as well as the transfer of small 6.6kV motors to LV, CO_2 footprint savings/impacts concerning the manufacturing of electrical equipment and induction motors are the following:

- MV/LV switchboards: -18% (~19tCO_2e)
- MV/LV induction motors: -3% (~10tCO_2e)
- Distribution transformers (increased power):+20% (~16tCO_2e)
- MV/LV cables: -6% (~7tCO_2e)

Thus, the total CO_2 footprint saving for the construction phase (CapEx phase) is -3%, corresponding to ~20tCO_2e.

CO_2 footprint during operation phase (OpEx)

To quantify the impact on CO_2 footprint during operations, the following key considerations on MV and LV respective motors efficiencies have been selected:

- For small MV motors energized at 6.6kV level (250kW, 280kW, and 315kW motors), the efficiency considered is 94.5% (motors close to their nominal load).
- If those motors are transferred to the 690V level, the efficiency will become 96% (under similar conditions) considering IE3 LV motors.

All other LV motors of this analysis are assumed IE3 motors, with below efficiency ratios:

5.5kW	15kW	37kW	75kW	110kW
89.6%	92.1%	93.9%	95%	95.4%

OpEx CO_2 footprint savings associated with the implementation of Alternative 2 are based on 8,000 hours/year of operation time (90% during 20 years of operation).

Results of the analysis based on new efficiencies and losses:

- MV/LV induction motors: -5% (~360tCO_2e)
- Distribution transformers (increased power): +30% (~88tCO_2e)
- MV/LV cables: +10% (~136tCO_2e)

So, OpEx's total CO_2 footprint saving is -2%, corresponding to ~136tCO_2e.

Conclusion

This analysis demonstrates the benefits of using 690V associated with transferring small MV motors to LV. In this case, the total cost savings are 11%.

If we were to limit the analysis to replacing 400V with 690V (excluding the transfer of small MV motors to 690V), the total cost savings would be reduced to 7%.

As demonstrated in sections 3.6 and 3.7, carbon footprint savings of the 690V electrical architecture is ~3% for CapEx and ~2% for OpEx. By excluding the transfer of small MV motors to LV, savings would be slightly lower.

In addition to moving to 690V instead of 400V, the recommendation is to transfer small MV motors to LV. This transfer should be limited to approximately 300kW. This limitation enables the ability to take advantage of the benefits without increasing too significantly the distribution transformers rated power and LV cables cross sections.

Other design practices

Air circuit breaker integrated control units

For process industries such as O&G, the typical legacy solution to control incomer and bus-tie circuit breakers has been to select unprotected breakers associated with external protection relays.

There have been two main reasons leading to this design:

1. Protection features requirements beyond what Air Circuit Breakers (ACB) control units could typically support
2. LV ACBs not supporting IEC 61850 communication protocol

Recent ACB technology is changing the game and enabling footprint and cost savings, thanks to extended protection features and IEC 61850 capability.

Protection plans for O&G facilities are often, and sometimes unnecessarily, complex. Tailoring the protection requirements to just enough features will allow the use of ACB–integrated trip units, and reduce engineering, commissioning, and troubleshooting time. Further, it minimizes the consequences of tripping due to non-adapted settings and implementation.

Typically, a designer could select, in most cases, the following short-circuit and overload protections:

- ANSI 50/51 Instantaneous overcurrent
- ANSI 50N/51N Earth/Ground Fault
- ANSI 86 Lockout

And *if* transformer monitoring is required:

- ANSI 63 Transformer pressure
- ANSI 49 Transformer thermal

This circuit breaker-based solution should be complemented with a programmable logic controller (PLC) to perform an automatic transfer switch (ATS) to manage change-over for incomers and bus-tie, based on the following complementary protections:

- ANSI 25 Synchro-check
- ANSI 27 Undervoltage
- ANSI 27R Residual undervoltage

As the ACB control unit is integrated into the circuit breaker, the footprint for the external relay is saved.

It can also enable having two ACBs in the same cubicle or leverage that space for other devices such as Arc Flash relay, ATS PLC, etc.

In addition, customers often require the installation of the external relay in an adjacent cubicle to the ACB cubicle. This is a common practice, leading to an additional footprint.

For a double radial typical switchboard with two incomers and a bus-tie, it generally leads to two additional cubicles (one for each incomer).

The external relay for the bus-tie can often be installed without an additional cubicle above the circuit breaker.

Figure 6

Example of footprint savings

Cost savings for Figure 6 design, leveraging an ACB control unit:

- LV ACB control unit is cheaper than the external relay.
- There is no need for external current transformers (CTs) or voltage transformers (VTs).
- Saving on the footprint and removing a couple of cubicles will make significant savings.

Digitization for more efficient operation and maintenance

Digitization is top of the agenda for all parties within our industry. Operators, owners, EPCs, and vendors are only seeing the tip of the iceberg for LV switchboards. A few revolutions ahead of us are augmented with virtual reality to support Operation & Maintenance (O&M), or moving from monitoring and control devices (appliances) to virtualized applications and data hubs.

Within this paper, we will focus on O&M support within smart circuit breakers.

For process industry switchgear, incomers and bus-tie circuit breakers are especially important to the energy availability and continuity of the process.

Those ACBs and their electronic control units have provided basic monitoring and communication features since the early 2000s. With the microcontroller's ever-increasing capabilities and more powerful algorithms, new features are now being made possible. Those features will contribute to better maintenance and less downtime.

As Process Industry operators expect to keep maintenance and product retrofitting for the turnaround typically planned every four to six years, understanding the aging of main devices is key.

Operation counters have often been implemented, but they poorly reflect the actual aging of ACBs. ACB control units can integrate those operations counters and algorithms to assess the actual aging of the circuit breakers and the control units. Those algorithms must be based on key parameter assessment campaigns on the devices, then engineered and developed to provide accurate support to operators.

To name a few parameters: load profile, number of trips in operation, contact wear, coils diagnostics (MN, MX), remaining service estimation, and maintenance scheduling information. Those data and indicators can be displayed on the control unit HMI or, more conveniently, on a handheld device for nearby operations and communicated to any asset management solution.

Operators can either rely on the alarms and recommendations provided by the ACB manufacturer or leverage the data for their assessment.

In addition, those ACBs have become event loggers: tripping events, operations, settings modifications, exceeding thresholds (alarming), etc.

These examples highlight the concrete benefits operators will experience from the current digitization trend, with major evolutions and benefits expected in the coming years.

Conclusion

This paper identifies design best design practices for LV switchgear that enable process Industry operators to reduce footprints and costs.

Highlighted best practices are :

- **Using circuit breakers instead of fuses** can typically reduce footprints and costs by approximately 10%.
- **Shifting from 400V to 690V** and transferring small MV motors to 690V motors, up to 300kW, which provides cost and CO_2 footprint saving as well as improves network efficiency.
- **Leveraging circuit breaker digital control units** for metering, enhanced communication, and improved protection.

In addition to economic benefits, the proposed design practices contribute to reducing the environmental impact for the scope assessed in this white paper: 3% carbon footprint savings for construction and 2% for operations.

About the authors

Laurent Bloch received his Engineering Degree in 1985 with a specialization in Mechanical and Systems Engineering. After a first experience at L'Air Liquide Engineering Division, he joined Schneider Electric in 1989. He worked for Schneider Electric Contracting Division in France and abroad, then moved to different marketing positions related to electrical distribution and energy management solutions. He has supported the O&G and Chemical businesses for LV solutions for the last five years.

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