Mastering All Sub-assemblies of an MV Circuit Breaker and Racking Truck System Ensures Reliability and Robustness

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Executive summary

The field experience on Medium Voltage equipment and the study of the behavior of the equipment in the environmental conditions must be taken into account in new developments. Analyses conducted through customer experience show the real conditions faced by operators. The control of sub-assemblies and interfaces of a circuit breaker is therefore crucial to ensure the reliability of the complete product.

Given all constraints, the scope of product development must ensure that performances in the areas of uncertainty are validated by simulation, testing, and mastery of industrial processes.

This paper describes the key areas that must be mastered to ensure robustness in design, validation, and industrialization, such as vacuum interrupters (VI) with compactness and performance targets to achieve, and the circuit breaker with dielectric performances in a constrained environment. A new multi-functional circuit breaker racking and disconnection racking truck associated with an earthing switch in a compact and optimized environment including interlocking safety is described.

Finally, it is shown that digitization is the key feature to move forward toward predictive and proactive maintenance.

Introduction

Electro-technical products are used in almost all areas of the world in various weather conditions and must meet the constraints imposed by severe weather with the necessary reliability. A detailed knowledge of the climatic conditions to which the product will be submitted must be available in the design phase. Although the installation and operating conditions of the environment are already taken into account in the design of medium voltage products, they must be better understood and well defined, especially for extreme environmental conditions and operation. The main environmental conditions to be considered are:

- ambient temperatures around the equipment and their variations (day, year, geographically, etc.)
- humidity conditions
- corrosive atmospheres

This design process ensures consistent performance of the product throughout its lifetime and thus provides increased reliability. It also gives a better balance between the levels of functionality and the requirements to optimize, for example, energy consumption, or operation and maintenance costs.

Advanced control and monitoring functions lead to embedding more and more electronics in the switchgear.

State of the art

The typical structure of AIS (Air Insulated Switchgear) MV (Medium Voltage) cubicle for primary distribution consists of three compartments containing the removable (or withdrawable) circuit breaker, the cable connections and the main bus-bars.

The function of circuit breaker withdrawal, by means of a racking truck, provides for an independent switching device (circuit breaker) compartment, with respect to the other MV compartments: cables and bus-bars can remain energized when accessing to the circuit breaker.

Frequent circuit breaker disconnection (withdrawal) operations can be due to the fact that maintenance operations are made necessary, for example, the extraction of the circuit breaker to clean insulating material covered with dust or pollutants. These operations can be linked to severe environmental or industrial conditions.

In this case, the more maintenance operations are carried out, the more the circuit breaker rack-in and rack-out systems are handled, the greater the risk of degradation of mechanisms and interlocks. And the risks in terms of operator safety are increased.

It is therefore crucial to provide customers with robust solutions in terms of design, able to meet the actual conditions of operation and maintenance of the products. The mastery of the sub-assemblies and interfaces of a circuit breaker is therefore crucial to ensure the reliability of the complete product.

If in addition, the same manufacturer also designs the interface between the circuit breaker and the cubicle, then it is possible to ensure the robustness of the complete system.

Compact Vacuum Interrupter (VI)

Vacuum interrupters have geometric and technical characteristics specified by the manufacturer, but their performances are fully achieved only with perfect control and optimization of the kinematic chain and of the drive mechanism.

Combining the breaking performances required by different standards lead to additional dielectric stress and to the use of high-performance vacuum interrupters.

On the other hand, optimal design studies of MV circuit breakers require very compact vacuum interrupters. The vacuum interrupter is the breaking element of the circuit breaker. In order to effectively break the electric arc in a vacuum interrupter, in the case of high fault currents, it is necessary to create a magnetic field whose effect is either to make the arc diffuse (AMF: Axial Magnetic Field) or rotate (RMF: Radial Magnetic Field). For this purpose, specific shapes of current paths to the contacts (arc controls) are used that can be located either in the vacuum interrupter itself or outside (figure 1).

Figure 1

RMF vacuum interrupter with internal arc controls

Internal arc controls of a vacuum interrupter

The AMF vacuum interrupters with internal arc controls (coils) tend to be long. The integration of arc controls in the vacuum interrupter impacts the dimensions of the circuit breakers and therefore those of the cubicles that incorporate them.

The challenge of vacuum circuit breaker design is to achieve short vacuum interrupters using internal arc controls, while guaranteeing the rated dielectric and breaking performances.

A new contact technology (netshape) for vacuum circuit breakers having a reduced contact stroke while keeping high-level breakdown performances has been developed. The principle of the netshape contact technology is that it is possible to produce the electrical contact and arc control function in a single sintered part: the gain in thickness is high compared to a two-piece assembly. This technology allows increased performance with reduced contact distance. Dimensional margins are small due to the compactness and it is therefore the optimal shape of the contact/arc control which, by its influence on the generated radial magnetic field, allows a better arc rotation, thus a better cooling of the contacts and finally extinction of the arc with less degradation of the contacts. Different contact/arc control designs have been tested to achieve the best effectiveness for the dissipation of the arc energy.

Among the constraints to be taken into account are the industrial aspects such as obtaining the contacts directly by sintering without machining and the brazing of the vacuum interrupter in a single operation: they require a complete mastery of this core component of the vacuum circuit breaker.

After making the contact by sintering, each elementary piece is calibrated and annealed, to give this part the expected material properties. The contact is assembled by brazing on a current carrier electrode, giving a complete assembly (figure 2).

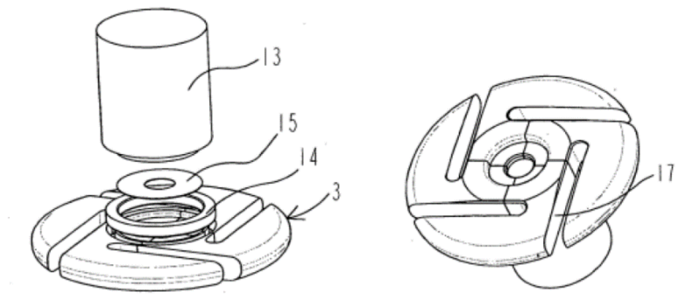


Figure 2

The RMF contact (3) is brazed on electrode (13), giving a complete assembly (17).

Circuit breaker drive mechanism: Design and constraints

Drive mechanisms for MV circuit breakers have specific requirements that are related to the physical characteristics of vacuum interrupters. The contacts being kept under high vacuum inside a ceramic envelope, the operating mechanism has to provide a high compression force on the contacts in closed position. But contacts in this position tend to be forced apart by the electromagnetic forces generated when the short circuit current passes through them. This phenomenon must be avoided as it leads to arcing, which causes contact surfaces to melt and subsequently to weld, making it impossible to separate them again[1].

Spring operating mechanism

Spring mechanisms use separate charged springs to store the energy for opening and closing the circuit breaker. The closing spring has sufficient energy to charge the opening spring and is recharged either manually or by an electric motor supplied by the auxiliary voltage source[1].

The racking truck: A new concept

The circuit breaker inserted in a cubicle compartment should allow the racking-in and racking-out movements behind a closed door. The main components of this compartment are combined in a functional module called the "cassette".

A new system has been developed to be used for rack-in and rack-out of the circuit breaker.

This new racking truck brings many improvements to existing functions and integrates new features linked with the position of the circuit breaker. The objective is to integrate as much functionality as possible into this sub-system (figure 3).

[1] Juan Tobias, Jean-Marc Biasse, Philippe Picot, Denis Perrin, Marc Bonjean, Oleg Garelli (2015) "Impact of Operating Mechanism type on MV Vacuum Circuit Breaker Reliability" CIRED conference

Figure 3

Design of the new racking truck concept

The purpose of this truck is to enhance reliability by integrating a new rack-in system of medium voltage circuit breaker in an existing AIS cubicle. Some particular points of this study were:

- implementing complex mechanical and electrical interlocks
- improving the user interface ergonomics and safety

Thanks to this racking truck, the mobile part circuit breaker moves into the cubicle from the disconnected position to the connected position while performing a series of safety features via mechanical and electrical interlocks.

The integration of this racking truck transfers a number of functions from the cubicle to the circuit breaker. This new compact truck, equipped with a motor, is not declarative. That is to say that it is not necessary to operate a selector. It is possible to perform the operations only if they are permitted through automatic interlocks. Thus, the release button ("opening push button") checks all related functional requirements.

This truck is self-supporting. There are no devices on the cubicle: for example, the plug locking the low voltage circuit breaker tripping.

For this study, the various technical functions (functional analysis) and interfaces between the circuit breaker module (incorporating the mechanical control), the truck, and the cubicle had to be identified.

The main specificities of this new racking and withdrawal truck are the following:

- Access to the actuators on the front face of the medium voltage cubicle, without having to open the door of the circuit breaker compartment (figure 4)
- Pushbutton (red) replacing the selector and giving access for the insertion of the crank to operate the racking truck
- Motorized racking truck with smart features, making the presence of the operator in front of the MV cubicle not compulsory
- Handles (green) for locking
- Low Voltage socket on the circuit breaker (figure 5)

Figure 4

Access on actuators through the door

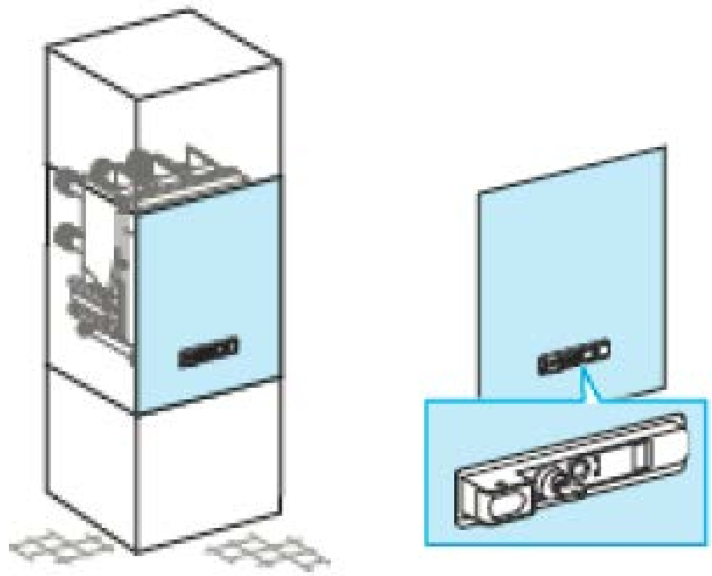
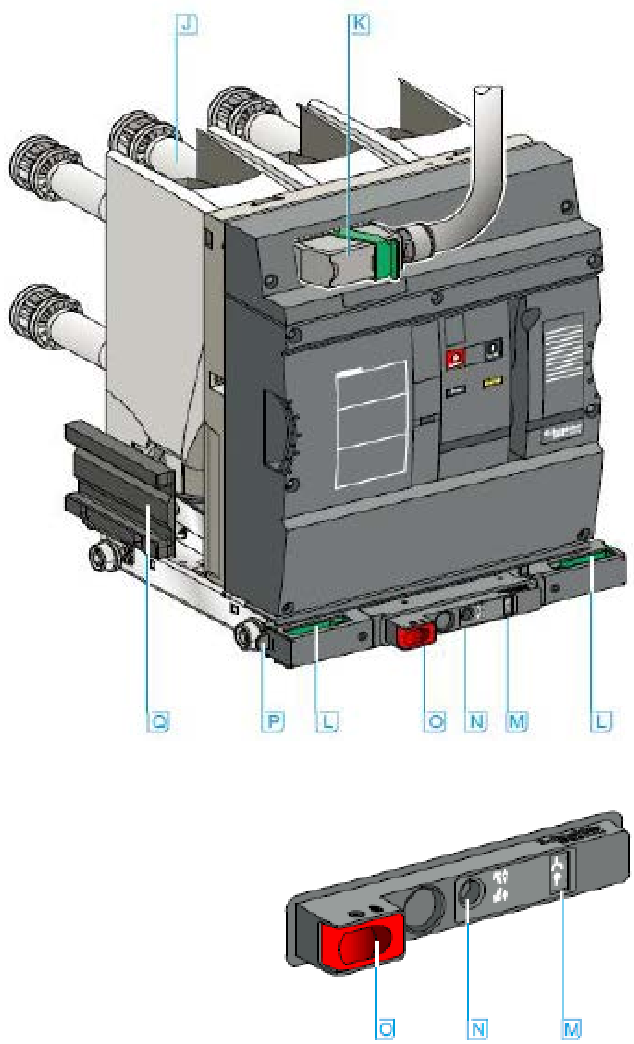


Figure 5

Front view of withdraw-able circuit breaker with all interfaces.



- J Power connections
- K Auxiliary connection plug
- L Locking handles
- M Racking position indicator
- N Hole for crank insertion
- O Opening pushbutton
- P Locking tabs
- Q Shutter ramp

Access to the operating lever for the racking operation is only possible if the earthing switch is in the open position, without need of padlocks or locks.

Removing the truck is only possible after tripping of the circuit breaker.

The racking truck can be easily motorized.

All manual mechanical interlocking functions are electrically doubled.

Adjustable plug-in/unplugged auxiliary contacts installed on the circuit breaker allow for increased accuracy due to a reduced dimensional chain.

The position indicator on the front panel can only move once the final position has been reached.

The simplified interlocking of the low voltage connector installed on the circuit breaker is more robust because there are no components to be added on the cubicle.

The panel builder doesn't have to create inter-locking behind the door of the circuit breaker compartment.

On traditional truck systems, the main screw is fixed without functional gap which can generate a possible risk of hyper-static state.

An additional degree of freedom has been added to allow mechanical opening of the circuit breaker before it leaves its test position or in service.

All functions are thus carried by the circuit breaker reducing the risk of interference.

All the dimension chains are reduced making the whole of the device more secure (figure 6).

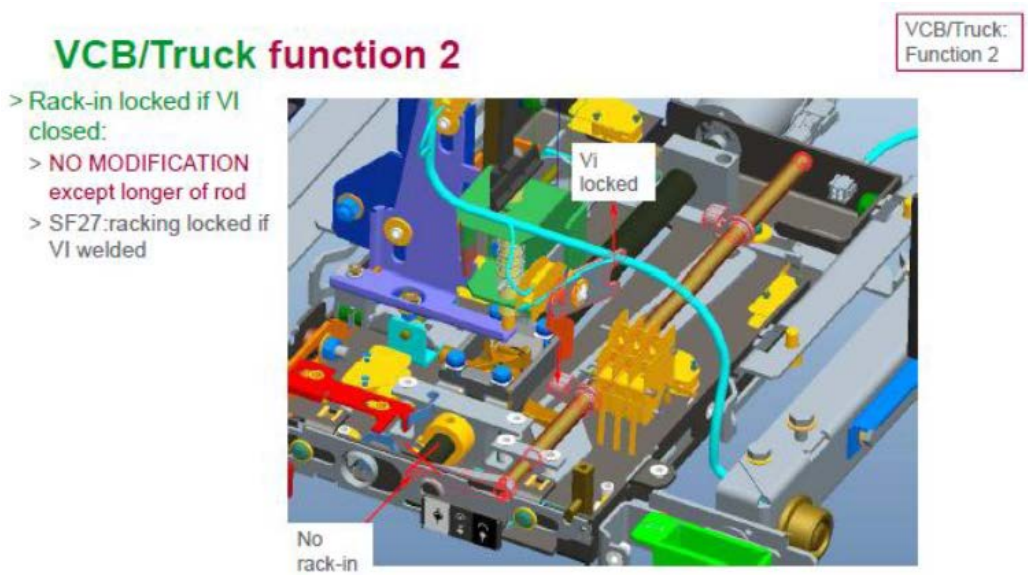


Figure 6

Example of functional analysis of the mechanical drive between the truck and the circuit breaker.

The racking truck guide rails are the only interface elements necessary to guarantee the reliability of the Circuit breaker plug-in function on the plug-in bushings of the MV cubicle.

Earthing switch motorized control unit

The objective of this study was to develop a new system of earthing switch (ES) control in a medium voltage cubicle incorporating a removable circuit breaker.

Particular points of this study are:

- Respect of complex mechanical and electrical interlocks
- Integration into the architecture of the cubicle and the circuit breaker to ensure the integrity of the entire product performance
- Integration of a new motorized function
- Improving the user interface in terms of safety and ergonomics

State of the art at the initial stage

The existing cubicle is equipped with an earthing switch to connect MV cables to earth in order to perform maintenance operations in complete safety.

The earthing switch is operated from the front of the cubicle through a control box allowing only manual operations so far. This control box interacts with the main circuit on the upper side of cubicle, the earthing-switch, the mobile function of the circuit breaker and the bottom cables compartment.

The purpose of the study was to create an earthing switch control box that incorporates the possibility of motorization and can replace the manual box used today in a traditional cubicle (figure 7).

Figure 7

A new HMI has been retained for its simple and clear ergonomics for the operator, allowing manual or motorized operation.

The various technical functions (functional analysis) and interfaces between the control box, withdrawable circuit breaker function, cubicle and operator have been identified. The following uncertainties were due to be lifted:

1. Integrate motor function in this new control box while remaining within the compact dimensions of the cubicle and not degrade performance already established in dielectric and mechanical tests, etc.
2. Maintain and enhance the operational safety aspects through the use of complex mechanical and electrical interlocks
3. Maintain healthy mechanical behavior during the closing and opening of the earthing switch, for example a mechanical margin and ensure operation forces consistent with the standard requirements

4. Improve operating means use ergonomics with selector buttons, while maintaining the operating and locking functions required such as padlocks and locks

The solution with three position rotary and manual mode selectors has been chosen for its clear and simple ergonomics for the operator. These selectors allow traditional operation from the front by the operator, but incorporate into the box by use of cams, each dedicated to the housing functions, and allowing the necessary electrical and mechanical interlocks.

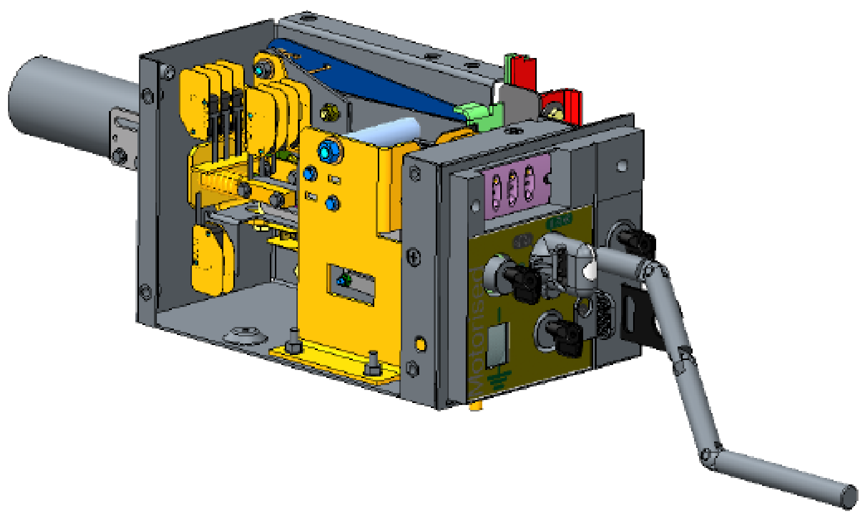


Figure 8

Earthing-switch box with selectors and cams allowing both manual and automatic operations with necessary interlocks.

Verification and validation plans

Every part of each function has been studied and has been the subject of simulations and tests.

All functions' verification and validation tests are carried out with industrial components ensuring dimensional checking and ensuring the robustness of all operating functions required by the terms of functional and technical specifications. Mechanical and electrical tests have validated the reliability and robustness of the entire system.

All validation and qualification tests have been carried out in internationally accredited laboratories and have led to the issuance of certification or test reports.

Embedded sensors

Low power current sensors, due to their small size and large range, can be considered as independent of the application usage. This allows testing the assembly of the sensors inside the cubicle at a very early stage with industrial means and then guaranteeing the repeatability and the quality of this operation.

Protection relay will remain a separate device depending of the application of the cubicle, ensuring protection and control functions related to the load [2].

Maintenance-ready equipment

Sustainable electrical equipment does not request early replacement due to unexpected failures. Sustainability implies that maintenance actions are performed

[2] Philippe Brun, Venanzio Ferraro (2015) "Evolution of control and monitoring functions will lead to embed more electronics in switchboard" MatPost conference

exactly at proper time. The evaluation of the proper time is the critical aspect, and it depends upon several factors including environmental conditions and use of the asset.

With digitization embedded in equipment design, the probability of errors or faults is greatly reduced, decreasing the need for partial or complete replacement. Digitized equipment continuously sends status information and operational data to the AMS (Asset Management Software) through the cloud. The maintenance plan then becomes directly linked to the conditions of usage and environment of the assets[3].

Conclusion

A new approach has been applied in the development project of a new circuit breaker range with a racking truck and earthing-switch system to provide the safest product on the targeted markets.

A new racking truck has been developed to be used for withdrawable circuit breakers. This new truck brings many improvements to existing features and new functions like the motorization of racking operations. Thanks to this racking truck the circuit breaker mobile part moves into the cubicle from the disconnected position to the connected position while performing a series of safety features via mechanical and electrical interlocks.

The approach described above demonstrates all the advantages of the design of the circuit breaker core components and of the interfaces with the MV cubicle controlled by a single manufacturer: this guarantees robustness and life expectancy of the MV cubicles. Electronic and smart features should not be limited to protection relays. By introducing electronic functions inside as part of the architecture of the cubicle, new functions and quality improvement will allow the delivery of electrical energy with more safety and reliability. Sustainability in electrical equipment is the joint result of properly designed switchgear with a service plan flexible enough to cope with diversified customer needs and applications.

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[3] Emiliano Centenaro, Denis Koch (2015) “Flexible Service Plans and Maintenance Ready Equipment increase sustainability in electrical Installations” MatPost conference