

AN ENEL-ABB PARTNERSHIP TO DEVELOP AN ECO-SUSTAINABLE ALTERNATIVE TO SF₆ FOR MV SWITCHGEAR, DIMENSIONALLY COMPATIBLE WITH EXISTENT APPARATUS USING SF₆

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ABSTRACT

In order to satisfy the global requirements to reduce the environmental impact of greenhouse gas emissions, ABB through their Corporate Research Centers and their Technology Centers developed some new technological solutions to substitute SF₆ insulating medium with an alternative gas called AirPlus™, featured by a very high compatibility with the environment.

ENEL, one of the major worldwide distributors of Electrical Energy, present with 13 DSOs in 8 different countries, challenged its organization to introduce new electrical equipment with higher eco-compatibility, considering the physical constraints of existent substations.

Thanks to the partnership between ABB and e-distribuzione (the main Italian DSO, owned by Enel group), a new product has been developed and homologated. This product is fully in line with e-distribuzione technical specification for DY800 (MV compartments for secondary substations with circuit breaker), as the solution has been achieved with already existing and homologated product, by substituting SF₆ with AirPlus™.

The dielectric and thermal challenges associated with AirPlus™ i.e. a mixture of synthetic air with C₅F₁₀O fluoroketone (C5-FK), are fully investigated and engineering solutions are implemented

To ensure a long-term behavior of the equipment on the same level as with SF₆, the materials in contact with AirPlus™ have been tested regarding chemical compatibility and mechanical properties and qualified or replaced by compatible materials.

This paper presents the technical path applied to the development process, constraints and advantages achieved through ENEL-ABB initiative to develop a fully interchangeable product with the existing one but eco-

compatible, finally expectations and targets of pilot installations.

INTRODUCTION

1.MOTIVATIONS

Enel group has among its main targets the climate change fight, with the objective to become carbon neutral within 2050. More in general, the sustainability is a column of Enel strategy, confirmed by its presence in several international sustainability indexes, as the FTSE4Good, the Dow Jones Sustainability Index, the Euronext Vigeo - Eiris, the STOXX Global ESG Leaders indexes, the Carbon Disclosure Leadership Index and several others. The use of SF₆ gas in electrical components is largely adopted due to the reliability of this solution and to the possibility to offer the needed performances and ratings in a reduced footprint. This is especially important in MV/LV indoor substation, usually located in urban area, where the footprint reduction and the reliability increasing are crucial for the network development and quality of service improvement. On the other hand, the SF₆ has a not negligible environmental impact, due to its high GWP (23.500), therefore Enel, considering its sustainability and technical targets, challenged manufacturers to develop products with similar technical characteristics respect to SF₆ insulated products but with low environmental impact, to pursue the climate change fight also in this field.

ABB has clear targets for health, safety, environment, security and sustainability and on climate change and global warming. This leads to the high interest of ABB in the new chemical substances developed by chemical companies, offering high dielectric performance. Even without political pressure at this time, ABB decided for significant investment in deep research if this could be a base for alternative insulation gases to be used in gas insulated switchgear. The good relationship to customer gave ABB the chance to develop prototypes and install pilot projects within 2015, using AirPlus™ insulation gas, a mixture of a C5 fluoroketone and air. As a pioneer ABB

has launched products in medium voltage using this new insulation gas as an alternative to SF₆. The increasing political discussion and the revision of the F-Gas regulation has supported ABB's strategy. An important step for the successful introduction of new technologies is a pull from customer side and confidence in a high quality product development based on basic research.

1.1 Enel DY800 technical specification

In 2007 e-distribuzione developed a new MV switchgear for MV/LV substations to overcome the limits of switch-disconnector until then installed in the field. Basically, there are three main limiting factors: switching time, making-and-breaking rated currents and the electrical and mechanical endurance of the switchgear. The switching time, i.e. the interval between a command and the completion of the correspondent operation (opening or closing), limits the spatial resolution of the fault detection essentially to the ratio between the maximum time available for fault detection and isolation, and the switching time. Considering the limit set by AEEG (Italian electrical authority) for a long duration power shut off supply interruption this time is 180 s, but the worst-case limit can be significantly lower: for example, if the network is run with a Petersen coil earthed neutral, the limit is essentially given by the withstand of the Petersen coil itself (approximately 20 s in Enel networks). The making and breaking ratings are related to the possibility of using procedures where it is required to make or break fault currents. The extended endurance switches currently installed in e-distribuzione MV networks are tested to perform up to 5 short-circuit making operations, but cannot break short-circuit currents, therefore it is necessary to operate the line primary substation circuit-breaker any time it is required to break the short-circuit current. The electrical and mechanical endurance of the MV switchgears obviously determines the lifetime of the device: the higher the operation frequency the shorter the residual lifetime.

With this goal in mind, e-distribuzione specified and adopted a new low cost, high performance MV switchgear for use in automatic MV/LV substations.

The new switchgear is intended for use in MV/LV substations, built according to a standard incoming-outgoing electric scheme, so its basic performance consist of simple ordinary functions such as busbars disconnection and line grounding. In order to overcome the previously listed limitations, the additional obvious requirements that the new switchgear has to meet are fast switching time, short-circuit current making and breaking capability and extended mechanical and electrical endurance.

All these characteristics must be implemented at the reasonably lowest cost possible. Besides, in order to minimize installation costs, this device must be dimensionally interchangeable with currently installed switchgear and fully compatible with the command and

control interface of the remote control smart unit installed in MV/LV substations. Of course, safety and environment protection are a major concern. Automatic operation implies higher usage ratios, thus decreasing the expected lifetime of the device and increasing the frequency of periodic replacement and, as a consequence, maintenance costs. A 16 kA short-circuit breaking current is ensured by a vacuum circuit-breaker. Extended experience and good feedback with line circuit-breakers suggested the use of this, now mature, technology, which also allows compact dimensions and smaller drives. E2 electrical endurance class and M2 mechanical class requirements (IEC62271-100 [1]) guarantee extended duration with limited or even no maintenance. Interchangeability with MV switchgears which are currently installed in MV/LV substations is essential to keep substitution costs low. In fact, to install the new device it is enough to simply remove the old one detaching busbars and cable terminals connections and substitute it, without the need to modify the other substation components.



Figure 1. First homologated devices

Mechanical and electrical interlocks avoid improper using, preventing the operator from performing dangerous operation. Moreover, the device is internal arc classified 16 kA for 0.5 s (DY800/1 and DY800/3 AF and DY800/2 AFL), according to IEC 62271-200 [2]. The result of e-distribuzione specification is a compact modular MV circuit-breaker with disconnector and grounding switch named DY800, a piece of equipment that is faster, more accurate, more reliable and easier to adapt into existing systems than previous generations of equipment for installation in MV/LV substations. From 2007 until today e-distribuzione have already been installed 20.000 panels in the field. Now the solution of DY800 with new gas let to improve also the environmental aspect.

1.2 Selection of alternative insulation gas

In the evaluation process of alternative gas mixtures the GWP has been on the focus. Different alternatives have been discussed with promising dielectric performance. As the fluoroketones were the ones offering a GWP <1 they have a significant advantage over other gases and gas mixtures which might solve the issue regarding SF₆, but might phase problems in the future, because of a too high GWP. In addition, the GWP is not the only environmental impact, but the carbon footprint. If alternative insulation gases require larger dimensions and/or more material, the impact on the carbon footprint will be negative and might even compensate the benefit of the new gas. Using the fluoroketones it was possible to keep the outer dimensions and limit the re-design to inner parts with low impact on material usage. In addition, it allows to keep the proven product platform design in a wide range. In MV applications it is also of importance to keep the pressure below 2 bar absolute, as otherwise issues with transportation of gas filled equipment might rise. It had been achieved to leave the total pressure unchanged and therefore maintain the known standards for SF₆ filled GIS. In total it can be mentioned that the technology using a gas mixture of Fluoroketone and air requires design adaption on manufacturer side, but keeps all the advantages of GIS technology for the end user at a GWP <1.

2.DEVELOPMENT PROJECT

In this context, considering sustainability targets and always increasing level of automatization and digitalization in its grids, Enel challenged ABB to develop a switchgear fully compliant with Enel DY800 technical specification, but using low-impact insulation gas instead of SF₆. This is order to guarantee the perfect interchangeability with existing products, produced by different manufacturers, without need of substation modification.

2.1 Dielectric performance

In terms of dielectric performance, replacing SF₆ with AirPlus™ causes a reduction in the withstand voltage level due to the reduced insulation level of AirPlus™ relative to SF₆. The possible solution to compensate for this is to reduce the maximum electrical field inside the unit to a level below the critical limit for discharge. The strict conditions of maintaining the physical dimensions of the unit typically prevent simply increasing electrode separation distances. Thus, careful optimization through a combination of techniques is required. A common technique is to increase the radius of any sharp feature by adding larger, rounded features such as e.g. field controllers / field diffusers to reduce the net field strength

One example for 3-position disconnecter is show in the figure 2.

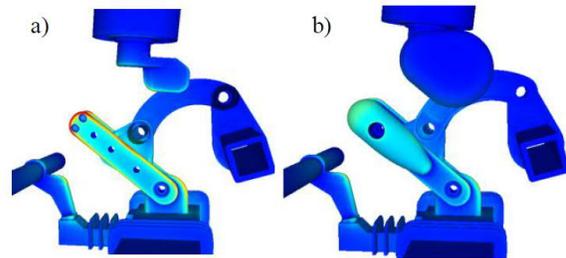


Figure 2 . Simulated electric field distribution of a 3-position disconnecter and earthing switch: a) original SF₆ design; b) adapted design for AirPlus™ [4]

2.2 Thermal performance

The thermal performance of gas is determined by two primary factors which are thermal conductivity and specific heat.

The thermal conductivity of a gas is inversely proportional to the molecular weight and therefore SF₆ has lower thermal conductivity compare to AirPlus™. But on the other hand SF₆ has 1.64 times higher volumetric specific heat compare to AirPlus™ and therefore its overall heat transfer capability, in particular when convection is taken into account is excellent. This lower thermal performance of AirPlus™ needs to be compensated and improvements might be required.

In order to improve the thermal performance of the switchgear, emphasize is put on the choice of materials, optimization of dimensions and reduced number of interfaces in order to reduce the resistance along the current path. Adding heat sinks, increase the heat transfer by radiation, increase the convection in the system by placing the heat source in the lower part of the enclosure or by adding openings around the hot spots inside the switch are examples for possible solution.

2.3 Long-term behaviour

AirPlus™ is not as inert as SF₆ and can chemically react with some substances. Therefore it is important to investigate the long-term behaviour of the insulation gas during 30 years lifetime. Intensive investigations about the material compatibility between AirPlus™ and the materials used in the switchgear are required to decide about a long term behaviour [3]. The impact of materials on the gas and the impact of the gas and its decomposition products on the material needed to be considered in compatibility investigations. For the selection between compatible and non compatible material in combination with AirPlus™, , aging tests are done in a two step approach for material qualification.

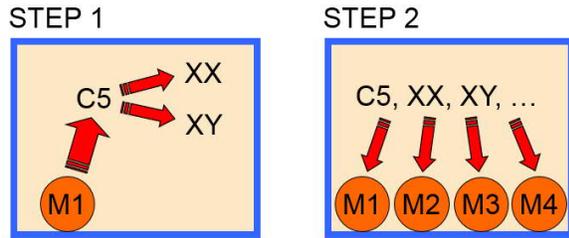


Figure3. Two step approach for investigating material compatibility

In the first step, the materials used in switchgear were subject to an accelerated aging test at 100°C being in contact with the selected AirPlus™ mixture over a defined time. The decomposition rate of C5 FK reflects the compatibility. The materials with zero or with no limited decomposition passed the Step 1 test. In the second step, the materials which passed STEP 1 test as compatible, were combined in a larger gas compartment and have been aged again at 100°C for up to 12 weeks. It is important to investigate whether the materials have been changed in the presence of AirPlus™. Real switchgear components or material probes can be tested in STEP 2 test. The samples were inspected in detail after the test. The real aged components can be included in tests under type test conditions and the results will be compared with tests done with new parts, not aged in AirPlus™. In case of material probes, the test objects are used to perform defined standard tests to verify the material parameter and compare them with datasheets or non-aged samples. Only materials that passed both tests are qualified. Based on the results of material compatibility, some standard materials used in SF₆ design have been replaced by new materials.

3 PILOT AND NEXT STEPS

e-distribuzione bought a first batch of more than one hundred ABB UnisecAirplus DY800 panels with new gas and installed first two panels in different environmental conditions. First one installed near North of Italy close to Milan to test low average temperature by the year and second one in Sardinia for high average temperature by the year. With the initials batch of installed devices e-distribuzione wants to verify the new insulation gas AirPlus™ in the field. ABB will perform periodical check oh those units focused on a evaluation of possible evolution of the AirPlus™ in the panel. The adoption in the field of panels with mix air/alternative SF₆ gas (AirPlus™) insulated solution confirms a high level of performance and reliability and operational safety and last but not least Enel commitment to environmental issue.



Figure4. . First ABB UnisecAirplusDY800 pilot ready for installation

CONCLUSIONS

If the result of the pilot will be satisfactory, Enel will push the adoption of these SF₆ alternatives and will also investigate the possibility to extend the technological solution to other products/applications, in HV and MV field. For example, the next step could be the use of alternative gases also for the current break, for example challenging manufacturers to develop switch-disconnector gas insulated, SF₆-free considering that although the use of circuit breakers is continuously increasing, the majority of existing applications in secondary distribution network are (and still will be for several years) with switch-disconnectors. ABB is working in order to introduce in his own portfolio eco-efficient solution introducing more and more the new gas solution AirPlus™ as industrialised solution in the production processes.

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