HIGH PERFORMANCE SMART MV APPARATUS FOR ARC FURNACE APPLICATIONS

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ABSTRACT

Steel manufacturing represents a critical application for control processes and apparatuses. In particular, switching of the Electric Arc Furnace (EAF) transformer are recognized as challenging for reliability of the switching devices needed for relentless furnace operation. The Medium voltage Circuit Breaker is required to cope up with hundreds of close/open operations per day, limited maintenance and minimum number of downtimes, operations in harsh environment.

In order to support safe and relentless operation and protection a dedicated circuit breaker based on vacuum technology and innovative actuation systems has been developed. The solution allows reliable and efficient service up to 150,000 close-open operations without the need for revamping, contributing to improve the quality of the arc furnace process in the steel industry.

INTRODUCTION

Among the several components implemented in steel manufacturing plant the MV Circuit breaker is considered one of the most critical. This component is not only used for protection but normally in the melting process energize/de-energize the electrodes used to supply the electric arc in the furnace (Figure 1).

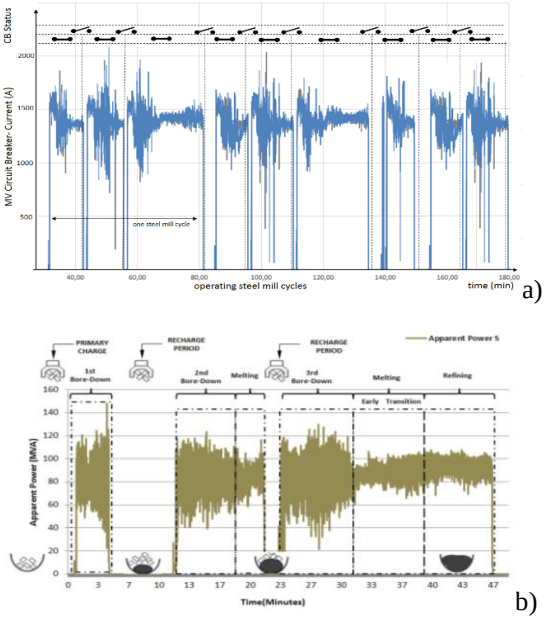


Figure 1: EAF Apparent Power /Load daily profile used in NUCOR Seattle site (a) and the description of the load in the different phase of the process as reported in [1] (b)

The heavy-duty cycle of operation in the harsh environment asks for extensive electrical and mechanical performance of the devices combined with the ability to allow smart containment of current and voltage overvoltage transients.

Severe degradation of the arc furnace transformer insulation is the result of overvoltages arising from voltage circuit breaker opening [2].

The standard proposed solution to damping of the overvoltages and to protection from the effect of virtual current chopping can be sought with the use of a protective RC surge suppressor unit installed near the arc furnace transformer together with surge arresters installed on the main transformer secondary and arc furnace transformer primary terminals [3]. These architectural design recommendations are implemented in combination with the use of series reactors and delta/stars connection of the primary/secondary winding of the AF transformer.

Conventional circuit breakers have a single mechanical or electromechanical operating mechanism. This transmits movement to a shaft, which acts on all three poles at the same time. The circuit breaker is pre-calibrated and factory-tested to ensure that the three poles operate within the values established by the standards (taking into account the mechanical tolerances). After this, the circuit breaker continues to operate until end of life in accordance with the maximum tolerance applicable without, however, allowing modifications or adjustments to be made unless the grid is taken out of service for direct maintenance work. Contact movement is generally designed on the basis of speed in relation to the characteristics of the breaking medium and the maximum current to be interrupted.

A basic concept for the mechanical reliability point of view of a Medium Voltage Circuit Breaker is the accurate design, optimization and control of the energy used in the actuation: travel curve optimization lead to minimized over-travel and back-travel.

The need to provide a new generation of apparatus to perform high number of reliable operations in the case of the most stressful loads, have open the use of innovative switching techniques.

The main drivers for these new developments have been the possibility to control the switching mechanism that affect not only the mechanical and electrical performances of the apparatus but also the quality of the energy supplied causing nuisance tripping of nearby electrical equipment and other sensitive loads.

Accurate control over the movements of the contacts in conjunction with measurement of the voltage waveform enables the optimized use of vacuum interrupter pole as well as the introduction of new medium voltage solid-state electronic components [4].

All the poles can be in general single and independently activated by an equal number of actuators (see Figure 2).

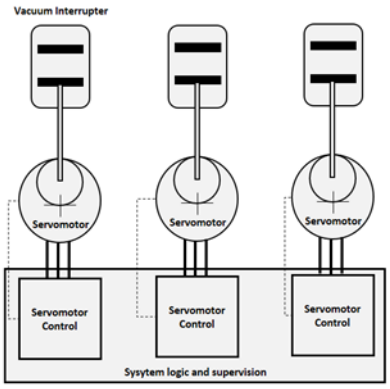


Figure 2: Circuit breaker concept

Three motors directly controlled by the electronic control unit and able to monitor torque, speed and position and provide accurate control over the movements.
In addition to a extend mechanical life of the circuit breaker this allows the operations of each pole (open and close) in the most appropriate point of the voltage waveform of the relative phase.
When, for example, it is used for switching capacitor banks, operation of the contacts must be fully synchronized with voltage crossing through zero in each phase to annul the effects of transients in the grid. [5].

MV VACUUM CIRCUIT BREAKER FOR ARC FURNACE APPLICATIONS

In close cooperation with premium steel manufacturer NUCOR, ABB drives the design of new solutions for MV Circuit Breaker for Arc Furnace Transformer Switchgear.
On January 2015 a beta version of a VD4 ME spring charged version was installed by retrofitting of the existing transform switchgear in NUCOR Seattle site with a breaker enclosure referred to as Power Block. The power block is an enclosure that houses a floor rolling removable arc furnace breaker and allows for reduced down time by immediate replacement of the breaker.
The first beta version of the VD4 ME was implemented to test components of the breaker using standard spring-operated mechanism. This beta lasted two years and provided key data for the design aspects of the new solution. During this period, the retrofit assembly experienced well over 60000 operations and continues in operation service with the VD4 AF.
The VD4-AF vacuum circuit breaker installed in 2017 features a conventional breaking technique with independent control of the poles with accurate monitoring of contact travel in the Vacuum Interrupters servo-assisted with crankshaft coupling and servomotor system. (see Figure 3)
Brushless servomotors represent the state-of-the-art in terms of actuation systems and allow precise control of the movement and position of the contacts [4]. Besides long mechanical life, servomotors also ensure precise control of contact travel thanks to two angular position transducers (encoders).

Figure 3: VD4-AF System Architecture: the operating mechanism consists of a shaft operated by a digital-controlled AC servomotor drive directly coupled with the pole structure

The Apparatus Control Unit is the heart of the apparatus. Inside the ACU, a module with CPU monitors the movement of each individual pole and is able to:

- fully control the movement of the contacts;
- synchronize the phases;
- perform integrated diagnostics on the circuit-breaker: monitor the micro movements of the contacts,
- monitor of the level of stored energy, the capacitance, etc.
- supervise the release circuit, including servomotors and wiring;
- racking-in interlocks and monitoring of truck movement.

An extended system logic allows managing the entire apparatus as one single device with a unique and simple system interface (binary I/Os).
In Figure 4 bounces on closing and oscillations on opening are evident in conventional circuit breakers. They stem from the high impact and release energy caused by the spring operating mechanism. There is a clear improvement in circuit breakers operated by means of brushless servomotors, since torque can be controlled depending on the position of the contacts.
Closed control loop actuation implemented in the ACU fully compensate possible deviations in the mechanical behaviour allowing very stable responses during the life time of the circuit breaker.

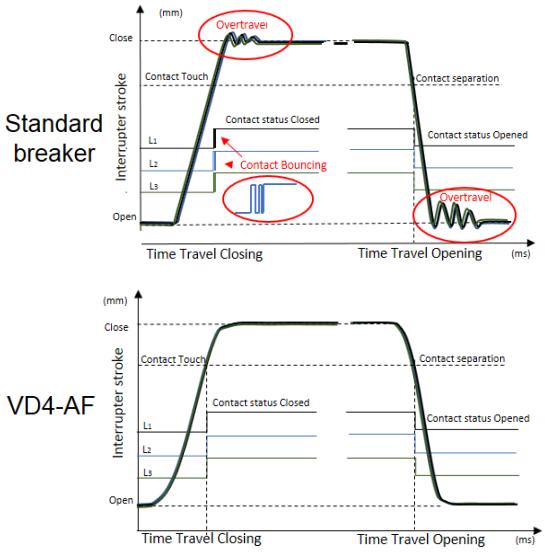


Figure 4: Mechanical travel curves: a) Standard CB spring driven b) VD4-AFservomotor driven

The key feature for the performance extension is the possibility to duly manage two different (and opposite) situations:

- Need of smooth actuation to maximize mechanical performance
- Actuation fast and energetic enough to avoid contact welding

Figure 5 highlight the benefit in the actuator torque control by the Closed Loop approach.

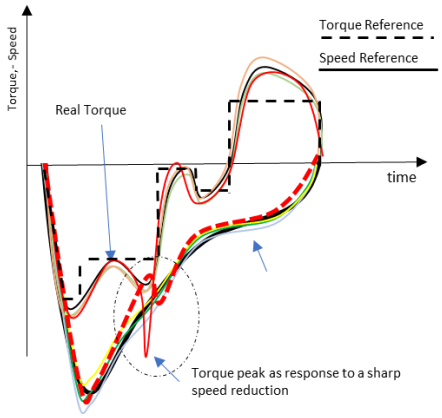


Figure 5: Ability of the torque control in the servomotor to compensate contact speed changes during opening operation.

The industrialization of the apparatus allowed integrating the actuation and controlling system in the standard base frame used in MV circuit breaker.
In order to increase the flexibility of use and minimize the downtime in case of exchange needs the VD4-AF has been realized for both freestanding installation and withdrawable installation (interchangeable with VD4 40.5kV standard type).

Figure 4: VD4-AF free standing and VD4-AF/P withdrawable version

The apparatus has been developed and tested in accordance with IEC 62271- 100 applying the most severe pass-fail criteria where possible (e.g. mechanical endurance) and extending the test collection on order to verify its applicability to special application (IEC62271-103 Shunt Reactors Switching Test). Table 1 reports the main electrical characteristics.

Rating	Value	Remarks
Rated Voltage	36-38kV	
Rated Current	2500A	2000 @ 55°C
Short-time withstand current	31,5kA	3Sec.
Breaking current (rms)	31.5kA	82kA peak
Mechanical endurance	M2 -Extended	150.000
Withstand voltage	95kV (power frequency)	185kV (BIL)
Ambient Temperature	-5°C; +55°C	

Table 1: Main VD4-AF Electrical characteristics

The smooth-controlled operation based on servomotor drive leaded to the possibility to explore the useful life of the CB over the150kCO number of operations.
Several electrical endurance tests have been performed in order to test the long-term reliability of the circuit breaker: Figure 6 shows the VD4-AF useful life diagram.

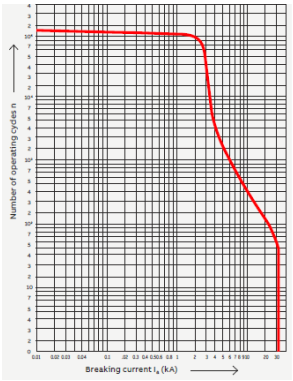


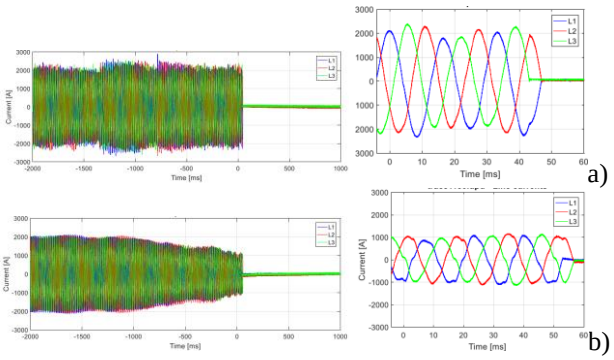
Figure 6 VD4-AF Operating useful life curve

EXPERIMENTAL RESULTS FROM FIELD APPLICATION

As introduced in the previous paragraph the VD4 AF motor drive breaker beta went into operation in the NUCOR Seattle the beginning of 2017 end experienced 50000 since the installation (see Figure 7).
The present total number of operation seen at the NUCOR Seattle site since the retrofit of the Power Bloc has been over 100000 operation on the Power Bloc assembly.

Figure 7: VD4-AF Pilot installation

From the early beginning, the VD4 AF has been appreciated for its great reliability supporting, without unexpected interruptions, the productive furnaces in the NUCOR steel plants.
Several inspection and measurement campaigns have been performed to monitor the status of the Circuit Breaker.
Figure 8 shows the steady state behavior of the current waveforms in the primary side of the MV Switchgear Transformer for EAF during the melting and refining phase of the steal manufacturing process and the subsequent interruption.

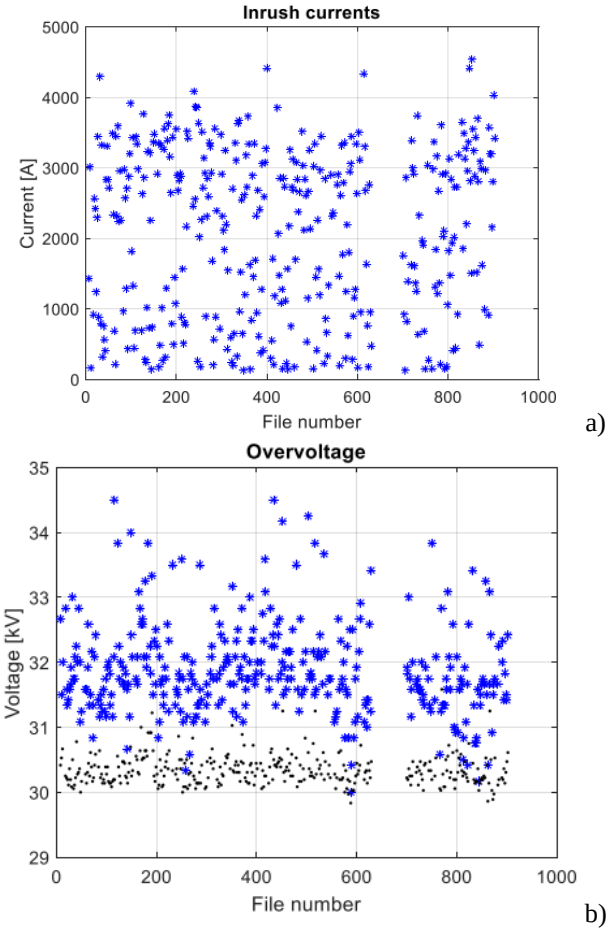


a)

b)

Figure 8: VD4-AF current and upstream voltage waveforms during load current interruption: a) CB opens during full load current (≈ 2000 Apeak); b) CB opens at low current (≈ 1000 Apeak)

During the inspections the measurements sessions allow to duly monitor the current and voltage waveform in the MV transformer switchgear. Figure 9 reports the current and voltage peak values recorded during several cycles of the steal manufacturing process.

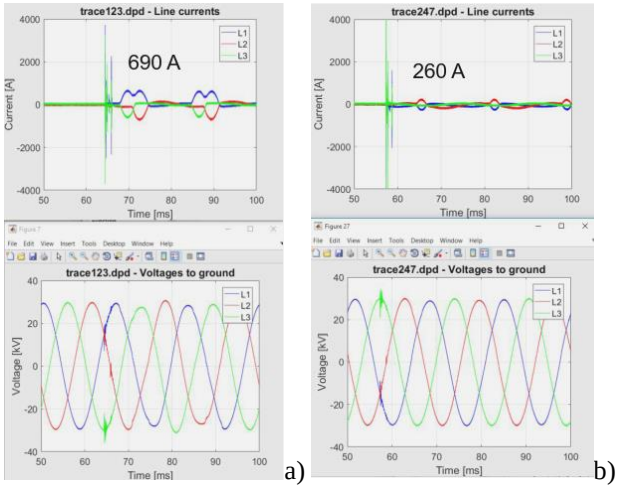


a)

b)

Figure 9: a) Inrush current peak, b) Transient overvoltages at breaking (blue dots represent peak value and black dots peak value of last period)

The advantage of using MV apparatus with advance actuation control opens the possibility for the VD4-AF to mitigate the current and voltage transient during the opening and closing operation of the MV transformer switchgear.
The Figure 10 reports two different scenario when the proper synchronization of the closing operation with the MV voltage and with the condition in the last operation, allow to mitigate the inrush current and the voltage transients.



a) b)

Figure 10: Inrush current and overvoltage transient at breaking in two different condition (blue dots represent peak value and black dots peak value of last period)

Among the new functions enabled by the new generation of MV digital Circuit Breaker, monitoring and diagnostics open the possibility to provide worry free EAF operations with reduced downtime and wise scheduling of the maintenance activities.
Signal processing, sometimes even complex, can provide the user with an overview of the general state of a circuit breaker for the purpose of planning maintenance or informing the assistance service when faults have occurred.
Thanks to the enormous quantity of information available, in addition to the remote monitoring, being able to develop prognostic algorithms for the purpose of predicting imminent faults is the new frontier of diagnostics. The availability of these developments will also lead to a cultural and organizational revolution as to Asset Management, i.e. all those activities aimed at reducing running costs by extending the life cycle of tangible assets and reducing the likelihood of faults or accidents.
On the base of the feedback provided by the first installation, NUCOR supported the installation of two more additional ABB Power Bloc enclosures and one VD4-AF servo drive breaker at NUCOR Duferdofin steel plant in Italy. These two units went into service in February 2018 and have been operating with operational frequency of 1000 operation per week. The preliminary results are very promising for relentless arc furnace operation opening the installation of other units.
In all the steel plants involved VD4-AF is behaving as expected and long-term reliability together with the contact system useful life is in line with all the expectations.
The prospective goal shared with NUCOR is to evaluate the possibility to standardize the VD4 AF solution for all the steal-mills installations leading to a significant decrease of the number of spares to be maintained. In fact this will help to simplify some of the current applications, where an additional set of breakers with pre-insertion resistors had to be implemented due to the constraints of the local utility.
It is worth to underline that in today's high competitive market any improvements that can be achieved on what can be considered the "heart" of any steel mill (the EAFs), with new apparatus able to ensure extended run times, high reliability and life extension, are definitely an "edge" in production.

CONCLUSIONS

The paper introduces the new smart apparatus with advance switching control developed for critical application like MV transformer switchgear for Arc Furnace application.
The feedback from user case application are promised and presents the VD4-AF as a significant step forward towards steel industry 4.0 for all EAF and LMF electrical arc furnace applications.

Acknowledgments

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