# SWITCHING TECHNOLOGY EVOLUTION: THE SOLID STATE CONTRIBUTION TO THE CAPACITIVE SWITCHING CONTROL

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## *ABSTRACT*

*The electrical power consumption is steadily increasing and the possibility to fully exploit the system capacity is becoming a more and more important requirement. In addition to the needs of reactive power compensation to increase distribution capacity and reduce losses, smart grids require also the power system to handle intermittent supply from renewable energy sources such as wind and solar power.*

*Nowadays, the use of capacitor banks and SVCs represents the most common solutions used. Unfortunately, the capacitor bank switching causes high inrush currents and overvoltages that can affect the equipment reliability and the power quality.*

*The paper describes the development and the industrialization of a transient and arc-free medium-voltage (MV) load break switch based on a combination of a solid state device and a mechanical contact system. Only during opening and closing operations the solid state device is active and a mechanical contact system is used for current conduction in closed position and provides isolation in open position. This reduces on state losses to a minimum and the solid state device do not need to be dimensioned for lightning impulse stresses.*

## INTRODUCTION

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 in capacitor bank switching applications have been the possibility to limit the high inrush currents and voltage transients that affect not only the performances of the capacitor banks and switching devices but also the quality of the energy supplied causing nuisance tripping of nearby electrical equipment and other sensitive loads.

The use of solid state technology combined with an advanced control and monitoring strategy allows to obtain outstanding switching performances together with a powerful diagnostic on overall functionalities.

## DS1 CONCEPT

The possibility to use solid state technology in MV circuit breakers has been preliminary investigated in the last few years.

In previous papers [1, 2] a MV capacitor switch has been preliminary introduced.

The proposed concept solved the drawbacks of using "pure" solid state technology by the adoption of a hybrid-solution that combines the good switching properties of solid state technology with the low loss and high voltage withstand of a mechanical contact system.

The target of the industrialization of the DS1 concept was to develop new apparatus specifically dedicated to capacitor bank switching.

The MV three phase solid state based capacitor switch is composed of three synchronized single-phase switches with one diode stack per phase. Each phase consists of two switching contacts and one diode-stack as reported in figure 1.

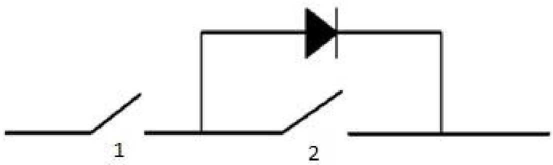


*Figure 1: Basic single-phase schematic of the DS1 apparatus*

The required operation sequence is managed by a smart control system that synchronizes the operation with the voltage on the MV feeder: the mechanical contact movements of the switch is always executed in order to perform electrical commutation into the diode-stack at a current zero crossing.

During operations, the current is commutated from the mechanical contacts (switch 2) to the diode stack (opening) or vice versa (closing). In order to provide an efficient commutation process a synchronizing unit is used to start to the operating mechanism at the correct phase angle of the source voltage.

A closing sequence starts with all switches open. First switch 1 is closed when the diode is in blocking mode. When the voltage difference between the source and load becomes zero the closing diode starts to conduct with a negligible inrush current. After the diode has started to conduct switch 2 closes. At this step, the diode is by-passed preventing conduction losses in the diode stack for the entire duration of the close condition.

The result is an optimal making operation behaviour: the energization occurs naturally when the voltage difference between the incoming feeder and the load is zero and consequently the inrush current is drastically reduced even in back to back configurations.

During the opening sequence the synchronization unit opens the switch 2 in order to commutate current to the diode path. After the current interruption, the diode stack is completely disconnected by switch 1 finalizing the open operation.

## DS1 POWER UNIT

DS1 power unit embodiment in figure 2 is externally based on a standardized MV design. This technical solution, in addition to a guaranteed arc free capacitive switching and suitability up to 17.5 kV applications, provides standard connections to incoming feeders/loads and allows easy integration into switchgears resulting in an optimal industrialization of the previous described switching concept.
The diode stack and fixed contacts are integrated inside an insulating cylinder. A movable contact is actuated in order to perform electrical switching operations.

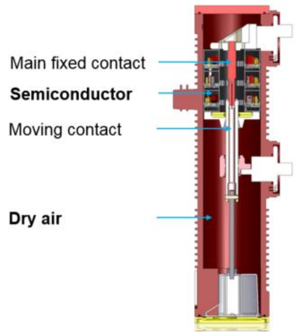


*Figure 2: Power Unit embodiment*

Since the operation is completely arc free, dry air is used as insulating gas resulting in an environmental friendly switch solution. The limited number of components in the power part simplify the assembly and enhance the mechanical performance.

## DS1 APPARATUS CONTROL UNIT

The kinematic operating mechanism consists of a shaft operated by a digital-controlled AC servomotor drive directly coupled with the pole structure of figure 2
The DS1 control unit is based upon an ABB multipurpose platform used for actuator's control in MV circuit breakers and outdoor reclosers.
The control system provide state-of-the-art features including:

- Real-time multi-axis control.
- Real-time AC monitoring and synchronized actuation
- Fully programmable and configurable logic
- Advanced system diagnostic

The control system architecture is based on three embedded actuation systems each one coupled with the corresponding AC servomotor and controlling its single phase switch as the one shown as represented in figure 3. Optimized digital control techniques allow the synchronization of the operation with the AC network.

An extended system logic allows managing the entire apparatus as one single device with a unique and simple system interface (binary I/Os). In addition, a powerful background diagnostic, verify the integrity of peripherals, motor connections, pole pressure etc.

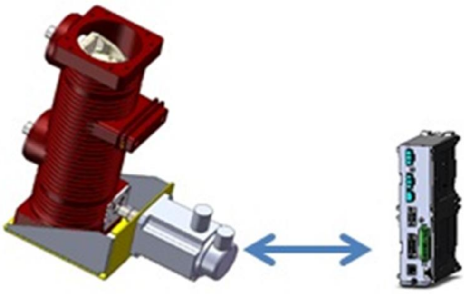

*Figure 3: DS1 single pole operation mechanism*

Closed control loop actuation fully compensate possible deviations in the mechanical behavior allowing very stable responses during the life time of the switch.
The monitoring of key parameter at the end of every operation also allow to detect anomalous behaviors.

## DS1 ELECTRICAL CHARACTERISTICS

The apparatus has been industrialized as shown in figure 4. The frame is based on a standard MV main assembly with the control system integrated inside the switch encapsulation.

*Figure 4: DS1 main assembly*

Its main electrical characteristics are reported in table 1.

| | |
|---|---|
| Rated Voltage | 17.5 kV at 50 Hz 15 kV at 60 Hz |
| Rated Current | 630 A at 50 Hz 600 A at 60 Hz |
| Mechanical Life | 50.000 CO |
| Electrical Life | 10.000 CO (capacitive load) |
| STC | 20kA 0.5 sec |
| Working Temperature | -15°C. +55°C |

*Table 1: Main DS1 Electrical characteristics*

The apparatus was tested in accordance with IEC 62271-103 (special purpose switch) applying the most severe pass fail criteria where possible (eg mechanical endurance and capacitive switching).
For example the capacitive switching has been performed according the IEC62271-100 since is more demanding compared to the IEC62271-103.

A typical DS1 behaviour during the Closing operation is represented in the waveforms reported in the figure 5. The making behaviour is characterized by a negligible inrush current and no transient events can be observed on the upstream and downstream voltages.

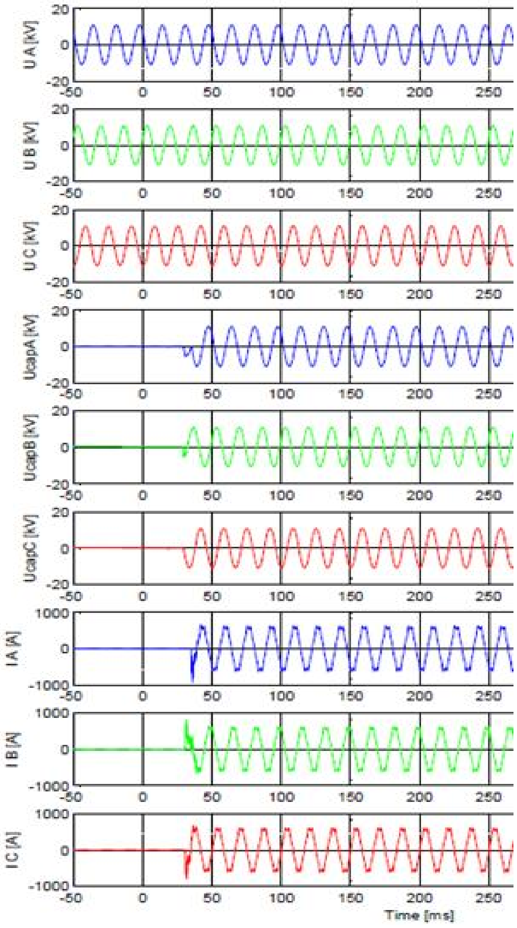


*Figure 5: DS1 Close Operation*

In figure 6 the oscillograms are reported related to an Open operation. The current is interrupted at the zero crossing by the diode without any current chopping behaviour and no transient can be observed in the voltages.

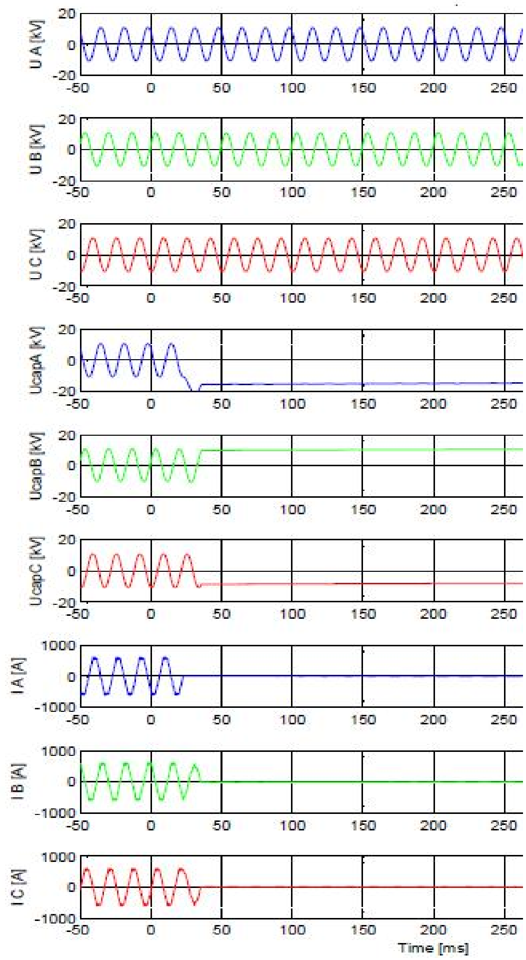


*Figure 6: DS1 Open Operation*

Additional test integrate the standard validation procedure in order to check the performances and verify the strength of the apparatus.
A pilot installation has been made in order to prove the effectiveness of the DS1 directly in the field.
The collection of a full set of data representing the status and the electrical behaviour of the apparatus has shown consistent results and the benefit of the transient free switching operations enables more frequent capacitor bank switching optimizing the reactive power compensation in the power system.

## CONCLUSIONS

The paper presents the DS1 apparatus: a load break switch for capacitive switching.
It provides a new technical solution, based upon hybrid solid state switching technology for an effective definitive

response to the need of managing capacitive loads.
It is possible to use one DS1 in single bank configuration or several DS1 in back to back configuration with an upstream protection (mandatory requirement) based on the total compensation target required.

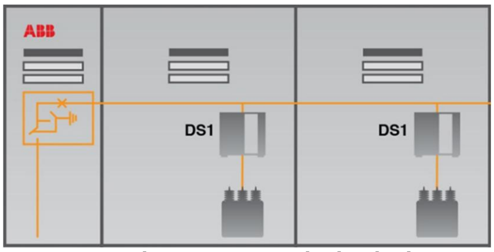


*Figure 7: DS1 solution to integrate back to back capacitor banks*

## REFERENCES

[1] Backman et. al, 2007, "A diode based transient free capacitor switch", *Proceedings CIRED conference*

[2] Backman et. al, 2011, "A diode based capacitor switch – A novel solution for power quality management", *Proceedings CIRED conference*