A DIODE BASED TRANSIENT FREE CAPACITOR SWITCH

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ABSTRACT

A novel medium voltage switch concept is presented utilizing diodes for interruption and making. The switch concept features closing at voltage zero, is restrike free and has a long electrical and mechanical lifetime making it especially suited for frequent capacitive switching.

INTRODUCTION

In previous papers [1-2] a similar medium voltage switch or circuit breaker has been presented. That circuit breaker was designed to be able to switch all types of loads and faults. That resulted in a design with independent pole operating mechanisms and diodes with short circuit current interruption capability. Since one of the major benefits with the previous concept was capacitive switching performance, a dedicated capacitor switch is now being proposed.

This paper will describe the dedicated capacitor switch. The main difference is based on the fact that the load is known and a fixed time delay between the phases can be accomplished with a mechanical offset. This makes it possible to use a three pole operating mechanism. Furthermore a de-rating of the diodes is feasible since the switch will only interrupt load currents. These changes reduce the cost for the switch and also make it possible to operate capacitor banks more frequent and with less transients compared to today's breaker switched capacitor banks.

CAPACITOR SWITCH CONCEPT

The patented concept consists of a mechanical contact system for current conduction in closed position and electric isolation in open position and two diode stacks, one for interruption and one for making, in each phase. The mechanical switch assembly consists of three gaps in series with the diode stacks in anti-parallel on the outer gaps, see figure 1. The diodes can be de-rated significantly compared to the circuit breaker application. In the circuit breaker application the max peak diode surge current is in the range of 50kA and for the capacitor switch the diode can be designed for about 1kA current depending on the nominal current capability. This gives a large diode cost reduction for this concept compared to the circuit breaker concept.

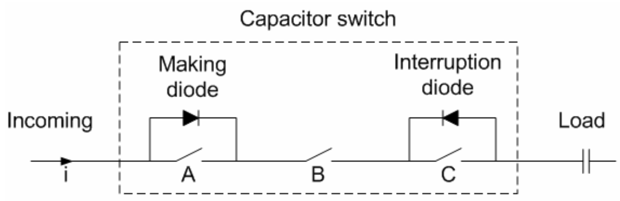

Figure 1. Lay-out of diode based capacitor switch.

During an interruption, the current in the mechanical contacts have to be commutated to the interruption diode stack. To have a fast commutation from the mechanical contacts to the diode stack a synchronizing unit is used. The synchronizing unit calculates when to start the operation of the contacts to have contact separation close to a current zero to enable a fast commutation of the current from the mechanical contacts to the diodes stack. At the initial state all contacts are closed and at a current zero when the current becomes negative, contact C is opened and commutates the current to the interruption diode. At the next current zero the diode interrupts the current and the recovery voltage starts to build up across the diode and contact C. Contact B is then opened before the peak recovery voltage that appears 10ms after current zero. The recovery voltage is then distributed across both gap B and C and the interruption is finalized.

To do a making operation, contact A is opened and C is closed. Then contact B is closed when the making diode is in blocking mode. When the diode becomes forward biased it starts to conduct and before the next current zero crossing the diode is short circuited by contact A. This gives an optimum making operation when the voltage difference between the incoming feeder and the load is zero and the inrush current is minimized. Even if the capacitor has a remaining charge the diode will start to conduct automatically at the optimum instant. This is not possible with a conventional synchronized switch.

The mechanical design to achieve the required sequence is realized with one rotating banana shaped contact and four fixed contacts connected to the diodes, incoming feeder and load. The banana shaped contact is attached to a shaft that is operated by a digitally controlled servomotor operating mechanism, MotorDrive™ [3]. Figure 2 shows the principal mechanical lay-out and the sequence during an interruption showing from left to right; closed position, commutation position and finally open position. A making operation will take place if the counter clock wise rotation is continued until the closed position is reached once again.

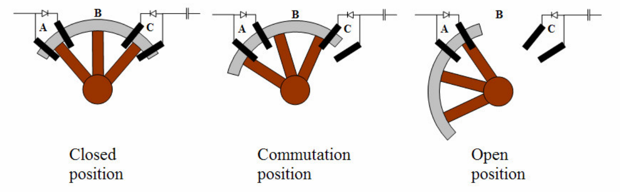

Figure 2. Mechanical lay-out and opening sequence.

For a complete three phase unit, three sets of fixed and rotating contacts are placed on the same shaft to be able to use only one MotorDrive™ operating mechanism. With a known load, the phase shift between the phases can be adjusted mechanically by different lengths of the rotating contacts and positioning of the fixed contacts.
For an ungrounded capacitor bank, contact C should be opened with a time shift of 60 electrical degrees between the phases and then contact B of phase two and three should open 90 el degrees after phase one.
At making contact B is closed in phase two and three at the same time and contact B in phase one is closed 270 el degrees later. It would be possible to do it after 90 el degrees but by using 270 el degrees it is possible to do a make operation with the capacitor bank fully or partly charged and still have an optimum making with low inrush currents. Figure 3 shows a prototype design of the capacitor switch concept.

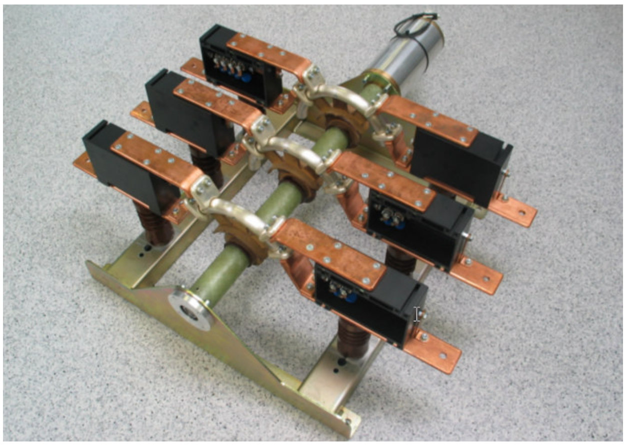

Figure 3. Prototype of capacitor switch concept.

EXPERIMENTAL RESULTS

A mechanical endurance test has been made on a similar test object with a rotating contact system [1-2] where 100 000 close-open operations were made with successful and stable results. From an electrical point of view a high endurance can be expected since practically no arc erosion takes place, only a small commutation spark. Figure 4 shows a fixed contact after 10 000 operations at 630Arms where only a small area shows signs on arc erosion.

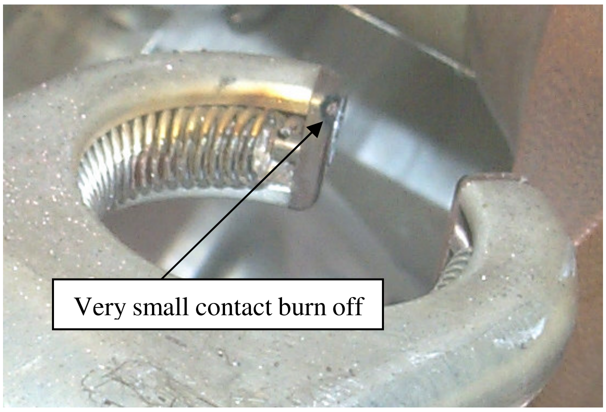

Figure 4. Fixed contact subjected to 10 000 op at 630Arms.

It can therefore be concluded that this switch will have a very high mechanical and electrical endurance.
Interruption and making tests have also been made with the switch operating a 2.9Mvar capacitor bank at 11kV giving a capacitive current of 150A. In figures 5-6 a making operation is shown when an ungrounded capacitor bank was fully discharged before the operation. U_{gap} is the voltage across the switch and I is the current through the switch. It is clearly seen that the inrush current is very small.

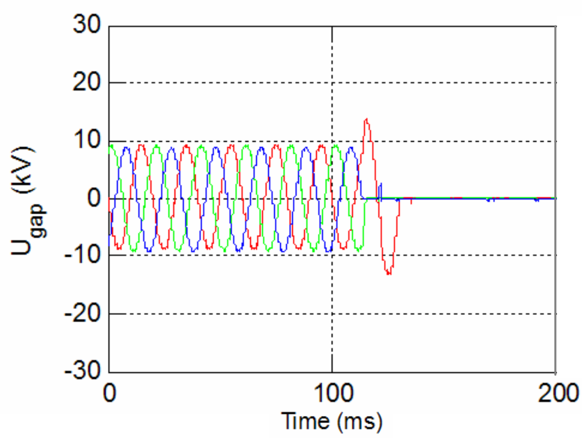

Figure 5. Voltage across the switch during making, discharged capacitor.

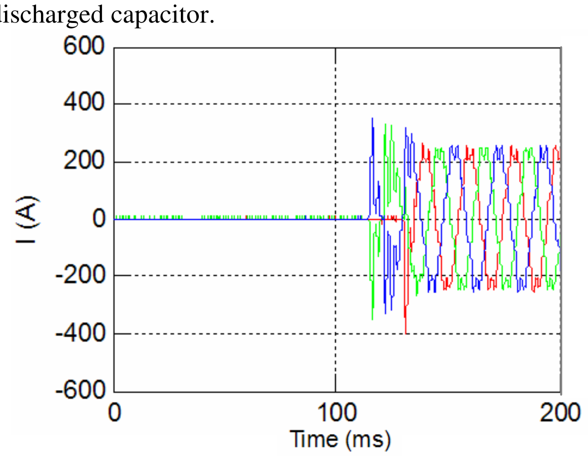

Figure 6. Current during making operation, discharged capacitor.

When a making operation is made on a pre-charged capacitor the inrush current is reduced even more. Figures 7-8 shows the voltage across the switch and the very small, almost non-existent, inrush current.

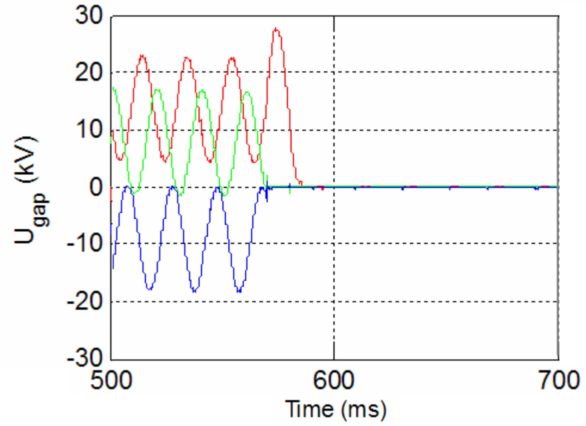

Figure 7. Voltage across the switch during making, pre-charged capacitor.

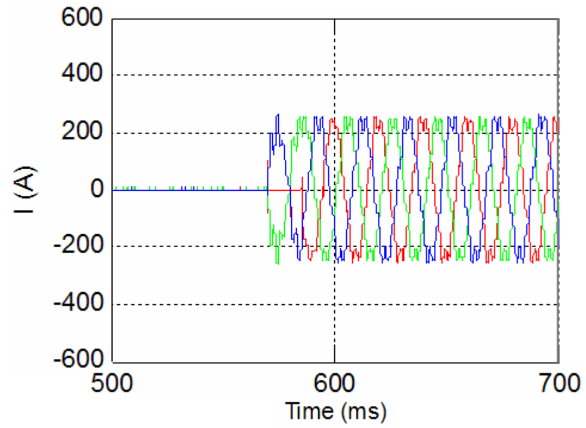

Figure 8. Current during making operation, discharged capacitor.

Field tests have also shown that when operating capacitor banks back-to-back this concept gives very low inrush currents [1]. With such low inrush currents it is therefore possible to eliminate inrush limiting reactors in these applications.
An example of interruption test is shown in figures 9-10 where the recovery voltage and current is presented. Interruption performance looks similar to a conventional switch but there are some differences. Firstly the diodes interrupt the current at its natural current zero without any current chopping and secondly the operation is perfectly synchronized. That means when the current is commutated to the diode there is sufficient time to open the parallel contact gap (C) before the recovery voltage starts to increase across the diode and the gap. Then an additional series contact gap (B) is opened to furthermore increase the voltage withstand. The probability of restrikes is therefore very low since both gaps are cold and will have sufficient gap distances at peak voltage.

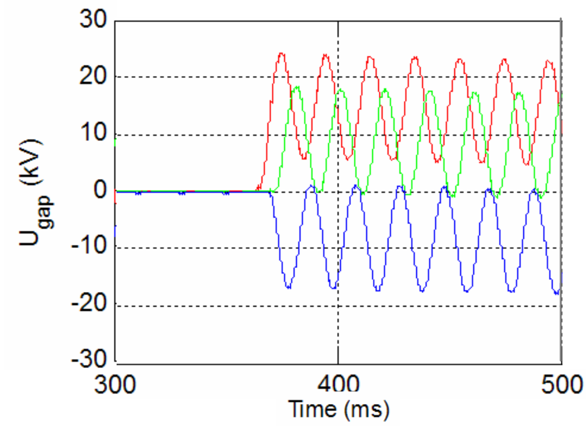

Figure 9. Voltage across the switch during interruption.

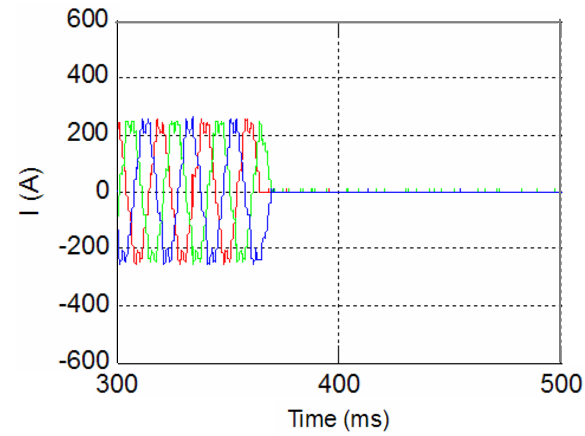

Figure 10. Current during interruption.

CAPACITOR SWITCH APPLICATIONS

Capacitor banks are commonly used for reactive power compensation in medium voltage distribution systems. The capacitor banks are mostly fixed, breaker or contactor switched without synchronization operating on low frequent basis. On the sub- transmission level capacitor banks are often equipped with synchronized switching to reduce switching transients and they are also switched more frequently e.g. on a daily or hourly basis.
A more optimum solution would be to follow the load variations and allow a much more frequent switching on the distribution level close to the loads to switch the capacitor banks in or out on an hourly basis to minimize power losses and increase maximum power flow in the system. The diode based synchronized capacitor switch is able to reduce all possible limitations like switching transients, significant inrush currents or restrikes to practically zero.
With the proposed switch concept these limitations are overcome. This enables to divide large capacitor banks to smaller units and operate each unit with a capacitor switch. In this way a stepwise controllable capacitor bank can be achieved. Figure 11 shows a single-line diagram of such a lay-out. An upstream circuit breaker is used for fault clearance in case of a short circuit and the capacitor

switches are used for load switching. In this example a 15Mvar unit is divided in four separate capacitor banks, 1, 2, 4 and 8Mvar making it possible to adjust the reactive power from zero to 15Mvar in steps of 1 Mvar.

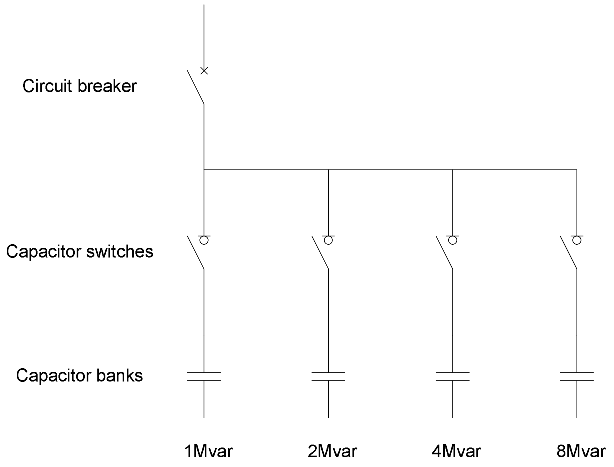

Figure 11. Single-line diagram of a four step capacitor bank.

It is also possible to use the switch to operate a single capacitor bank and have an upstream fuse for fault clearance. In many installations today, fuses can not be used due to the high inrush currents that can blow the fuses. In this application the inrush current is so low that the fuse does not trip.

Operating the capacitor banks more frequent, for instance hourly switching, makes it possible to reduce power losses and increase power flow in the distribution system.

CONCLUSIONS

A novel capacitor switch has been presented showing very good performance in terms of low switching transients and high mechanical and electrical endurance. The switch eliminates need of inrush current limiting reactors and is restrike free. It also opens up new possibilities to operate capacitor banks more frequent and in smaller steps to minimize power losses in the system and mitigate overloaded circuits.

REFERENCES

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