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Advanced LCC HVDC control with MACH3

Improved commutation failure prediction, and additional functionality for 800 kV UHVDC

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***Abstract*—LCC (Line Commutated Converter) HVDC has always been and will always be susceptible to commutation failures, due to the physical properties of the thyristor. Typically, the key input for predicting when a commutation failure is likely to happen at the inverter are the AC voltages [1]. In this paper, new features of the MACH3™ HVDC control system are used to improve the performance of the commutation failure prediction functionality. By synchronous sampling and rapid execution, it is possible to avoid commutation failures in some typical cases. Also some of the commutation failure improvements made in [2] are implemented in the MACH3™ system, and verified in real time simulation.**

Recently 800 kV has been used in many UHVDC projects in China. A pole typically consists of two series connected 12-pulse groups, which operate together. An advanced control functionality called "converter swapping" is introduced. It allows for online swapping of the operating converter, with a minimal disturbance to the HVDC transmission. Typical usage of this functionality would be when the two 12-pulse groups are connected to two different AC networks, like the common 500/1000 kV AC systems recently constructed in China [3].

Keywords— HVDC transmission, Real-time systems, High performance computing, Power system simulation

I. INTRODUCTION

As discussed in [4], the calculation capacity of the latest generation ABB MACH3™ HVDC control and protection system has increased drastically, compared to the previous generation. The power efficiency has also increased in a similar way, which enables the whole system to run without cooling fans, which in turn increases the overall reliability and lifetime. With such a powerful computing platform as a basis, the performance of a HVDC system can increase in different ways. One such area is LCC commutation failure prediction, which primarily looks at rapid changes in the inverter AC voltage. By synchronous sampling and rapid execution, it is possible to avoid commutation failures in some typical cases.

Although most commutation failures originate from the AC side, there are also situations where they can originate from the DC side. Very long DC lines like applied in ±800 and ±1100 kV UHVDC transmissions will form a relatively large mutual inductance. The effects that this mutual inductance has on the HVDC system is mostly going to appear during a DC line fault in one of the poles, since at that moment the current flow in the two poles are very different. In particular, the healthy pole can easily get a commutation failure at the moment when the faulty pole restarts again. This can be avoided by increasing the extinction angle in the healthy pole at the right moment.

A typical LCC UHVDC system consists of two series connected 12-pulse group converters in each pole. It is possible to take individual converters in and out of operation, while still transmitting power on the pole. A typical scenario would be that both converters are operating in a station, and then a protective action takes one converter out of operation. The remaining converter will then continue to operate the pole at half the rated DC voltage.

In the other station, one converter must also be taken out of operation in order to match the DC voltage. In principle either of the two converters can be taken out of operation, since both are healthy in this station. If both converters are connected to the same AC network, it does not matter which one is operating. But if the two converters in the same pole are connected to two different AC networks, then depending on circumstances it can be highly beneficial to use one specific converter. Naturally, the most beneficial HVDC converter to use can change dynamically, due to external AC network circumstances such as under/over frequency due to generator/load trip. In order to get maximum benefit from the HVDC system, a novel control functionality is hence implemented, called “converter swapping”. Using this new control, it is possible to change the operating converter dynamically, with an almost unnoticeable disturbance to the pole. This is because the total pole voltage is kept virtually unchanged during the whole sequence, regardless of rectifier or inverter operation.

This paper has the following layout: In section II, the commutation failure prediction improvement attained with MACH3™ is discussed. In section III, the results of improved of DC line fault handling is shown, done using real time simulation. In section IV, converter swapping is introduced and also here the results of real time simulation are shown. Finally, conclusions are drawn in section V.

II. IMPROVEMENTS OF COMMUTATION FAILURE PREDICTION WITH MACH3™

In this section, the MACH3™ system is firstly introduced. Then state of the art for commutation failure prediction is shown. Finally, the improvements made possible with MACH3™ is discussed.

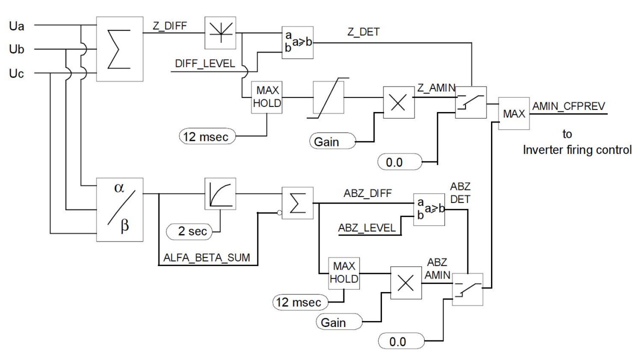
A. Brief introduction to MACH3™

Due to the natural need for very fast and accurate control and protection actions, ABBs HVDC control systems have always been on the forefront on related electronic technologies. The MACH3™ system is no exception to this. It has plenty of raw calculation power due to multicore CPUs and DSPs, but is nonetheless highly energy efficient. Due to the unprecedented high energy efficiency, every single circuit board and main computer is passively cooled. This ensures long life and stable operation, since for instance there are no cooling fans or air filters that needs replacement. In Fig 1, the main DSP circuit board PS935 is shown.

1. The passively cooled PS935 DSP board

B. State of the art for commutation failure prediction

To avoid commutation failures, today's solution has AC voltage measurements as the key input. The most common cause for a commutation failure is indeed a temporary AC voltage dip at the inverter. The detection principles consist of two main parts. The first part adds the three AC voltage measurements together, thus it can detect a sudden zero sequence component, i.e. a symmetrical three phase fault. The other part does an αβ-transformation of the three phases, and creates a steady state reference value by applying a low-pass filter. If the instantaneous input is much lower than the steady state reference value, AC faults without a zero sequence can also be detected, i.e. any asymmetrical fault. Once a detection has been made by either part, a rapid contribution is made to the gamma reference. This causes an earlier firing of the inverter, and depending on circumstances, a commutation failure might be avoided.



2. Commutation failure prediction, from [1]

C. Improvements made possible with MACH3™

The algorithm in [1] was firstly introduced with MACH2™ and later used in the updated MACH2.1/DCC800 platform. Firstly, the AC voltage measurement was executed with one sampling interrupt, and then the commutation failure prediction was executed with another slower time interrupt. The new MACH3™ system offers exceptional performance. It is possible to run all measuring and DSP boards synchronized on the same interrupt at 10 µs execution time, or 100 kHz sampling frequency. This feature is hence used to rapidly sample the AC voltages and execute the commutation failure prediction algorithm. The commutation failure prediction performance of the three different ABB HVDC control platforms are shown in TABLE I.

TABLE I. COMMUTATION FAILURE PREDICTION PERFORMANCE

	MACH2	*MACH2.1*	*MACH3*
Sampling interrupt (µs)	24	24	10 (both run on the same interrupt)
Execution interrupt (µs)	80	50	
Total delay in µs (min/average/max)	80/92/104	50/62/74	10
In electrical degrees for a 50 Hz system	~1.4/1.7/1.9	~0.9/1.1/1.3	~0.2

The MACH3™ system hence offers significantly improved commutation failure prediction performance compared to previous generations, since it acts faster when an AC voltage disturbance happens. The improvements are typically ~1.5 and ~0.9 electrical degrees faster in a 50 Hz system.

III. IMPROVED DC LINE FAULT HANDLING

In this section, real time simulations of DC faults are performed. The mutual inductance between the two pole lines is the root cause of commutation failures. It is shown that commutation failures in the healthy pole can be avoided, by increasing the extinction angle at the right moment.

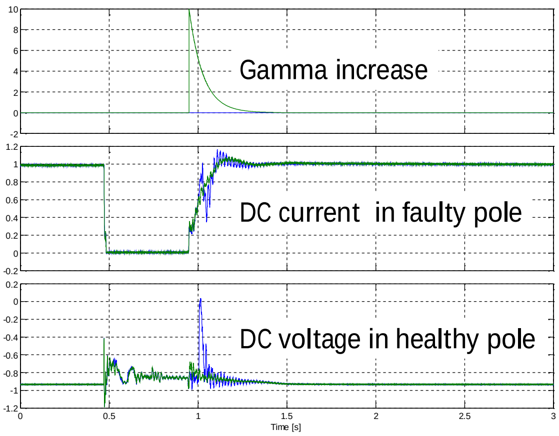
A. Influence of mutual inductance during DC line faults

Two DC conductors placed side-by-side with each other for thousands of kilometers are naturally going to form a mutual inductance. The effects that this mutual inductance has on the HVDC system is mostly going to appear during a DC line fault, since at that moment the current flow in the two poles are very different. It was observed that the healthy pole can quite easily suffer from a commutation failure shortly after the faulty pole restarts. This is due to the mutual inductance between the DC lines, in combination with the rapid recovery of the faulty pole. One option could be to recover the faulty pole much slower, but since this is undesirable a novel commutation failure prediction was designed in [2].

B. Key principle of the novel commutation failure prediction

To make a fast and reliable detection mechanism that is not dependent on interstation telecommunication, the key principle is based on local measurements: The healthy pole monitors the DC current in the faulty pole. As soon as there is DC current flowing again, the healthy pole rapidly increases its gamma.

A real-time replica of the actual Xiangjiaba – Shanghai ± 800 kV UHVDC system [5] was used for all testing in this paper. The results without (in blue) and with the novel commutation failure prediction (in green) is shown in Fig 3.



3. Recovery after a DC fault

IV. Converter Swapping

A normal UHVDC pole consists of two series connected 12-pulse group converters, each rated at half the DC voltage. In this section a new control function is introduced, called converter swapping. When operating at half the nominal DC voltage, converter swapping enables the system to change the operating converter, with a minimal disturbance to the whole DC system.

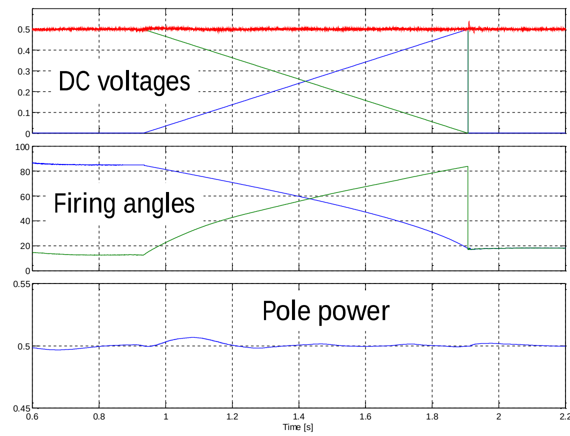
A. Description of converter swapping

The way converter swapping works is:

1. Initially only one converter is in operation, hence the pole is operating with half the nominal DC voltage
2. The non-operating converter is taken into operation, but still operating with virtually zero DC voltage output, i.e. with a firing angle close to 90 degrees
3. Based on the measured pole DC voltage, two DC voltage references are calculated and ramped simultaneously. The voltage reference for the initially operating converter is ramped down, while the voltage reference for the other converter is ramped up. This way the total pole voltage is virtually constant
4. The DC voltage references are then passed through calculations, which produces two firing angle orders. The orders are then sent to the corresponding converter
5. Once the DC voltage reference ramping has finished, the initially operating converter is taken out of operation, and bypassed on the DC side
6. The pole continues to operate at half of the nominal DC voltage

B. Converter swapping in rectifier operation

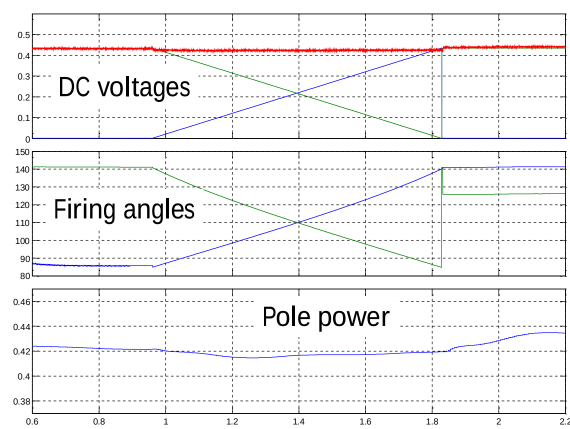
In Fig 4, converter swapping in the rectifier is shown. Top graph: Converter DC voltage references in blue and green, and measured pole DC voltage in red. Middle graph: Firing angle orders. Bottom Graph: Total DC pole power. Since the total DC voltage is kept virtually constant throughout the whole converter swapping sequence, there is very little variation in the total DC power. The sudden jump in the green curves at the end of the sequence is because the converter is fully bypassed on the DC side. Thus, there is no disturbance which the DC voltage and DC power also reflects.



4, Converter swapping in rectifier operation

C. Converter swapping in inverter operation

Inverter operation was also tested, and as expected there is no notable disturbance to the system. The legend in Fig 5 is the same as in Fig 4.



5, Converter swapping in inverter operation

V. Conclusions

The new MACH3™ system offers exceptional performance. It is possible to run all measuring and DSP boards synchronized on the same interrupt at 10 µs execution time, or 100 kHz sampling frequency. This feature is hence used to rapidly sample the AC voltages and execute the commutation failure prediction algorithm. Compared to previous generations, the improvements are typically ~1.5 and ~0.9 electrical degrees faster in a 50 Hz system.

When restarting after a temporary DC fault, the mutual inductance in the DC line can cause a commutation failure in the healthy pole. By increasing the extinction angle at the right moment, a commutation failure can be avoided.

Using converter swapping, it is possible to change the operating converter dynamically in a UHVDC system, with an almost unnoticeable disturbance to the pole. This is because the total pole voltage is kept virtually constant during the whole sequence, regardless of rectifier or inverter operation.

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