Safety in speed

ABB's Fast Protective Device scheme for series capacitors is in a league of its own

Rolf Grünbaum, Joacim Redlund, Louis P. Rollin

Many over-voltage protection schemes for series capacitors are limited in terms of size and performance, and are easily affected by environmental conditions. While the need for more compact and environmentally robust equipment is recognized, so too is the necessity for a new type of general series capacitor protection scheme that would improve performance, reduce total costs and increase flexibility, as well as enhance the series capacitor concept.

Thanks to modern technology and recent developments, ABB has developed such a scheme and called it Fast Protective Device. It is intended to operate in combination with a primary metal oxide varistor in high voltage and extra high voltage series capacitor applications. The scheme has already been tested in high voltage and high power laboratories, and in a pilot installation in the Hydro-Québec 315 kV network in Canada.

Reactive power compensation by means of series capacitors is an efficient way of improving power transfer in high voltage systems with long transmission lines [1]. Series capacitors basically consist of capacitor banks connected in series with the transmission lines, thereby effectively reducing the inductive impedance of the lines. They also increase power transfer and dynamic system stability. Due to the nature of this connection, a series capacitor installation must be able to provide full system insulation to ground. This is achieved by locating the main circuit hardware on single-phase platforms which are then insulated to line voltage level. Unfortunately, equipment at this location is exposed to environmental conditions such as snow, ice and air pollution.

As well as full system insulation to ground, the capacitor bank must also withstand all line currents. However for practical and economical reasons this may not always be possible. The solution then is to bypass harmful currents (thereby limiting the voltage across the capacitor bank). The equipment to do this has to handle very high power and must be stable with respect to protection performance regarding both speed of control and capacitor protection level. It also has to provide qualified dynamic performance for quick capacitor reinstatement after a line fault clearance. Control and protective equipment is normally located at ground potential and signal communication is required from ground to line voltage level.

With so many conditions, it is no wonder the industry has long felt the need for a new type of general series capacitor protection scheme. And this need has been satisfied by ABB with its *Fast Protective Device (FPD)* scheme.

Fast protective device scheme

Many utilities use the *Metal oxide varistor (MOV)* scheme which was introduced around 1980. Although its basic performance is excellent, the number of MOV elements required in many practical applications makes it quite costly. When high fault currents occur, MOV has to absorb large amounts of energy during the fault duty cycle. To reduce the amount of MOV elements needed, the scheme can be combined with a *forced triggered spark gap*. Unfortunately environmental conditions limit the performance and reliability of the spark gap and therefore that of the complete scheme. Furthermore, a protective scheme combining MOV and forced triggered spark gap requires a lot of platform space.

The FPD scheme is a new approach to the protection of high voltage equipment. It has been especially adapted to series capacitor applications but may also be used for the protection of other types of equipment located at high voltage levels. Its design gives it the potential to enhance the series capacitor concept by adding new features. A single line diagram of an FPD scheme is shown in 1 and a schematic overview is illustrated in 2. Included in the scheme are two newly developed key components: the hermetically sealed and very fast high power switch that replaces conventional spark gaps, *CapThor*, and the *Operation and Supervision Unit (OSU)* for control, supervision and power supply from ground to any line voltage. Both are described in greater detail in this article.

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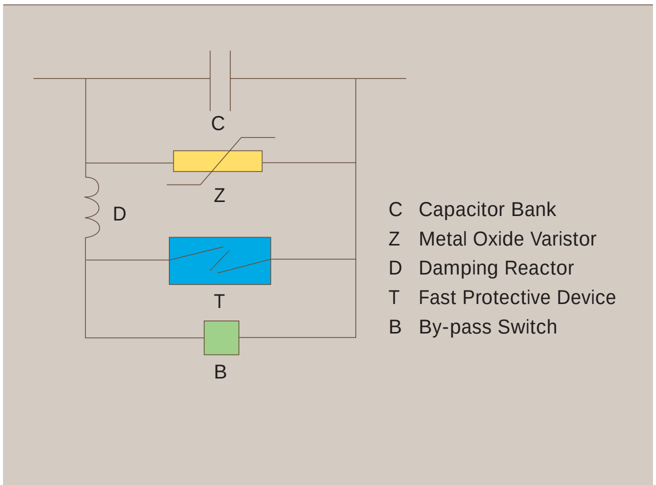
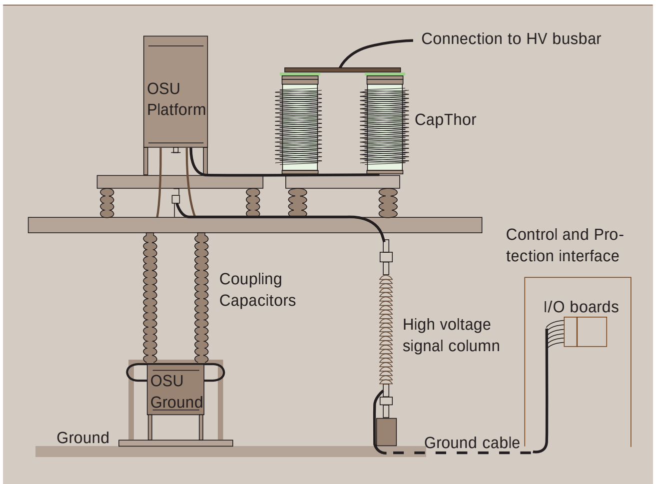
The FPD scheme works in combination with an MOV, and allows bypassing in a very controlled way in order to reduce energy dissipation in the MOV. CapThor can be operated a number of times during a fault cycle so that the series capacitor can be bypassed and reinstated without problems.

The OSU consists of a power supply unit at ground potential; a power supply transmission link to platform

1 Single line diagram of the Fast Protective Device (FPD) scheme



2 Schematic overview of one phase of the Fast Protective Device (FPD)



potential; a cabinet on the platform with energy storage capacitors; and control for activating and supervising the switch.

The FPD operates in combination with a damping reactor that limits the capacitor discharge current, and a fast bypass switch which is used for general switching as well as series capacitor bypassing. In accordance with common practice, FPD control signals are transmitted via a high-voltage optical link. Retrofitting most existing series capacitor installations with the FPD scheme (using standard components) is possible as the hardware is generally independent of the line current and the particular characteristics of the capacitor banks. In addition, the equipment is compact thus simplifying transportation and installation tasks. It is pre-tested before delivery, and with the exception of pressurization during installation, no on-site adjustment or maintenance is needed. Other advantages of ABB's FPD scheme over those that use spark gaps include:

- Capacitor by-passing is possible at low voltages
- It is not affected by environmental conditions
- FPD is flexible for future series capacitor upgrading
- It is self supervising

CapThor

An external and internal view of CapThor is shown in 3. It consists of a very fast-acting high power plasma switch connected in parallel with a fast mechanical switch 3b. The two switches are housed in two composite high-pressure insulator chambers which are filled with gas at an elevated pressure and placed side-by-side on the platform. These chambers, or tubes, are similar to those used for the breaker head housings of modern live tank circuit breakers.

Plasma switch

The plasma switch consists of a high power electrode arrangement into which a conducting electric arc or plasma can be injected, bridging the insulating distance between the main electrodes. In contrast to triggered spark gaps, the function of the plasma switch is essentially independent of the voltage between the electrodes. The time needed before the plasma switch is fully conducting after receipt of an external "close" signal is in the range 0.3 – 1 msec. The injected electric arc is powered by an external energy source, ie, a capacitor rated at 820 µF and charged to 2.4 kV. A trigger unit with very low ignition voltage initiates the arc. The injected electric arc current increases at a rate of about 100 A/µs, an amplitude of 10 kA and a duration of about one millisecond. It is directed into the main electrode gap by magnetic forces created by the current loop in the trigger unit.

The high power arc injection trigger method has been used for 10 years in medium voltage series capacitor applications. The plasma switch has a very high current making capability, and is static with no moving parts.

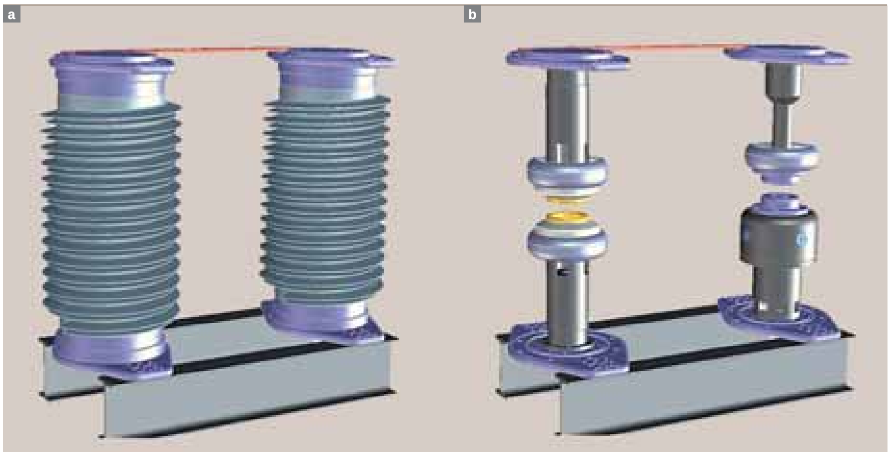
Fast mechanical switch

The mechanical switch consists of a contact which can be moved very quickly between the open and close positions, and is actuated by means of the Thompson magnetic mirror effect of repulsive forces. Like the plasma switch arc injection, it is powered by a similar external energy source but in this case the capacitors are rated at 4,785 µF and charged to 1.2 kV. The basic switch principle is the same as that applied to the high speed closing switches[1)] used in indoor medium voltage switchgear for paralleling ground fault currents to prevent severe damage and personnel danger. The fast mechanical switch has a very high current making capability at low voltages corresponding to the voltage drop in the plasma switch arc and in the local circuit impedances. Closing and opening times are both less than five milliseconds. The switch has only a small breaking capability, and in FPD series capacitor applications it can only be opened when the high voltage bypass switch is closed.

Operation and Supervision Unit

The OSU comprises one control module located at ground potential, a high voltage transfer link and a control module located at line voltage on the platform. In the grounded module, a DC voltage – from an uninterruptible DC supply – is converted to a high frequency AC voltage by an oscillator. The oscillator is connected to two high voltage coupling capacitors bridging the potential difference between ground and line potential. The capaci-

3 External a and internal b view of CapThor. The plasma switch to the left in b and the mechanical switch to the right



Factbox The Kamouraska installation

The Kamouraska installation consists of four series capacitors; each rated at 192 Mvar, and supporting transmission of power in four parallel 315 kV lines. The series capacitors, which compensate the line reactances by 60 percent, also increase the transient stability of the system. The transmission corridor is an important link for the export of power to New Brunswick, Canada. The capacitors were installed in 1987 and are equipped with protection schemes consisting of MOV in combination with triggered spark gaps.

tors are of the same type as those used for Capacitive Voltage Transformers and Power Line Carriers. The capacitance of the transfer links are matched with two connected compensating inductors to give zero circuit impedance for the actual frequency.

In the platform control module, the AC voltage is converted to 1.2 kV and 2.4 kV local DC supply voltages which are then used to continuously charge the energy capacitor bank needed by the CapThor plasma and mechanical switches. The required number of consecutive CapThor operations determines the number of energy capacitor units.

Customer collaboration

In October 2003, as part of the verification process, an FPD field demonstrator was added to the existing Kamouraska series capacitor Factbox located in the Hydro-Québec 315 kV grid in Canada 4. For the first eight months in service the FPD had no protective duty. Instead it was merely energized and exposed to real environmental conditions while various FPD functions were repeatedly tested and controlled by ABB and Hydro-Québec together. At a later stage, the FPD electrically replaced the original spark gap scheme and since then a combination of FPD and the original MOV have functioned as bank protection.

To communicate with the OSU platform module, a fiber communication system was installed between the platform and the control room[2]. In the control room, a control and protection interface (CPI) was fitted and this is coupled to the existing protection system and the existing sequence of event recordings with the OSU platform module. During a protective action, the protection system issues a "close" order to the CPI which then transmits it to the OSU platform module where, upon receipt, CapThor goes into action.

FPD testing is expected to end during 2007.

4 Close-up view of the FPD pilot installation: the power supply transfer link in the foreground, the optical transmission link to the right, and CapThor and the OSU cabinet on the platform

Potential for the FPD scheme

The development of a new protection scheme, characterized by its fast and controllable performance, has opened the way for engineers to focus on new protection strategies. For example, t he FPD has the potential to bypass a series capacitor as soon as an internal line fault is detected and before the protection level of the capacitor is reached. This in turn would reduce discharge current amplitude, MOV energy dissipation, and general stress on capacitors and other equipment. Given this important breakthrough it is now possible to relax the overall design criteria of the series capacitor concept which in turn reduces costs.

Another strategy is as a result of the fast closing and opening feature of the FPD. Because of this, it has the potential to bypass and reinsert the series capacitor for all types of line faults without affecting the system conditions. In other words, the FPD becomes the primary protection and the MOV acts as back-up. In such a set-up, the MOV design requirements can then be relaxed.

The foundation for the third strategy comes from the high closing speed of the FPD, and its ability to be triggered at low series capacitor voltages. A series capacitor in a transmission line can have an increasing effect on the amplitude of the transient voltage, which appears when a line circuit breaker opens to clear a fault. The voltage, which affects the breaking performance of the line circuit breaker, is referred to as the Transient Recovery Voltage (TRV). With the FPD's high closing speed and ability to be triggered at low series capacitor voltages, it is possible to bypass the series capacitor well in advance of the line circuit breaker opening. Given the speed of FPD operation, the line conditions and the TRV voltage across the breaker will be similar to switching the line without any series capacitor.

Everyone's a winner

For Hydro-Québec, the opportunity to work with ABB on a project involving a new product gives the company the chance to evaluate innovative equipment out of the normal supplier-buyer relation path. Both parties gain from the knowledge exchanged during the project in that the designer is made aware of the user's needs while the user becomes familiar with the new equipment.

In a world of growing demand for electric power, ABB's FPD scheme adds to grids' ability to increase power transmission in both a time and cost effective way. It can be expected that the scheme will find increased use in series capacitors all over of the world.

Rolf Grünbaum
Joacim Redlund
ABB AB, FACTS
Västerås , Sweden
rolf.grunbaum@se.abb.com
joacim.redlund@se.abb.com

Louis P. Rollin
Hydro-Québec

References
[1] Grünbaum, R., Pinero, J. L., Series compensation goes the distance, Modern Power Systems, June 2001.

Footnotes
1) These switches are only capable of closing and must be manually opened.
2) The control room is located approximately 240 meters from the platform.