Alternative Solutions for Thyristor Control and Gating for HVDC-valves

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Abstract: The next generation of thyristor valves for HVDC developed by ABB will be provided with an on-line diagnosis system. This is realised by further development of the thyristor control unit, TCU, using state of the art electronic circuits. Detailed information such as the status of the snubber circuit, thyristor temperature, etc., will be continuously available for each thyristor position. Each thyristor position has its own individual control, protection and monitoring, thus giving true redundancy for every component. With the diagnosis system the intervals between scheduled maintenance measures can be increased. The diagnosis system will also give accurate information on the overload capability of the converter in real conditions.

Keywords: Thyristor Valve, Thyristor Gating, Thyristor Monitoring, Thyristor Valve Diagnosis

I. INTRODUCTION

A thyristor valve for HVDC is built up from several thyristors connected in series, all of them on different voltage level. Since all the thyristors are controlled by a common control system, Valve Base Electronics, VBE, on ground potential, the communication between the control system and the thyristors must be electrically insulated. Different systems for this have been developed, e.g. magnetic coupled circuits, optical systems using lenses, and what has become the dominating design principle today, signal transmission using fibre optics.

For the firing of the thyristors the optical control signal FP (Firing Pulse), transmitted in the fibre must in some way turn the thyristor from blocking condition into conducting state. This can be done directly in the thyristor if the light pulse has sufficient energy by using Light Triggered Thyristors, LTTs, or the light pulse can be converted into an electrical pulse in a Thyristor Control Unit, TCU, that gives an electrical gate pulse to an Electrically Triggered Thyristor, ETT. Usually the TCU also includes protective facilities, such as protective firing at overvoltage and recovery protection, as well as monitoring of the thyristor position. It is important that the control and protection of each thyristor operate independently from the other thyristor positions in order to achieve full redundancy of the positions in the valve and to avoid unnecessary commutation failures. The information on the status of the thyristor is sent back to the VBE in a separate optical fibre. This Indication Pulse, IP, is binary, and contains only a message stating whether the thyristor position is working or not, and thus the resolution in this information is limited. Also, if the thyristor is fired by the protective firing system, an IP is given via this optical fibre. When the number of failing thyristor positions equals the number of redundant thyristors in a valve, the converter is tripped. Otherwise all the thyristors in the valve might be damaged.

Drawing on their separate experiences, the two HVDC manufacturers ASEA and BBC were able to derive synergetic benefits when the two companies merged, forming ABB. Thus, for HVDC thyristor valves ABB has experience from four different designs, the BBC-design, the ASEA ETT design, the ASEA LTT design and the ABB design. These different systems have been evaluated in order to find the basis for the next generation of thyristor valves and to establish the possibilities of utilising state of the art technology to meet requirements from clients.

II. THE BBC DESIGN OF THE TCU

The basic functions are as described above. The TCU at each thyristor position is powered by the voltage across the corresponding thyristor. The circuit diagram on the power supply circuit is shown in Fig. 1. In brief, the TCU includes the following features:

- Protective firing of the thyristor at high voltages
- Protective firing of the thyristor at high dU/dt during the recovery interval
- Indication on protective firing from the TCU
- Indication of failing (= short-circuited) thyristor.

The TCU is a single Printed Circuit Board, p.c.b., 200 x 300 mm. All components on the thyristor level, except the snubber capacitor and the water-cooled snubber resistor, are located on this p.c.b. The logic circuits are located inside a screened enclosure so as to separate low voltage electronics from the high power components. The circuits necessary for the power supply of the TCU and the components for the protective firing are located on the p.c.b. outside the screened enclosure.

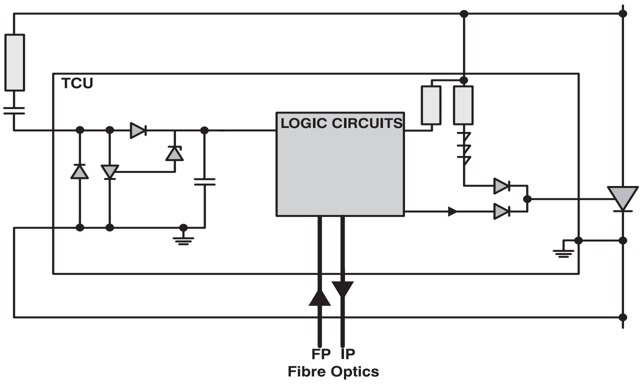

Fig. 1. Basic circuit diagram of BBC thyristor control unit.

Since the trigger pulse for the protective firing is derived directly from the voltage across the thyristor via a set of BOD (Break Over Diode) elements connected in series, the protective firing operates almost independently from the rest of the TCU and will work even if there is no power supply to the TCU.

The auxiliary power to the TCU is taken directly from the main snubber current.

III. THE ASEA DESIGN OF THE TCU

Basically the ASEA design is similar to the BBC design. There is one TCU for each thyristor, and the power supply for the TCU is derived from the voltage across the thyristor. The basic elements of the snubber circuit and power supply are given in Fig. 2.

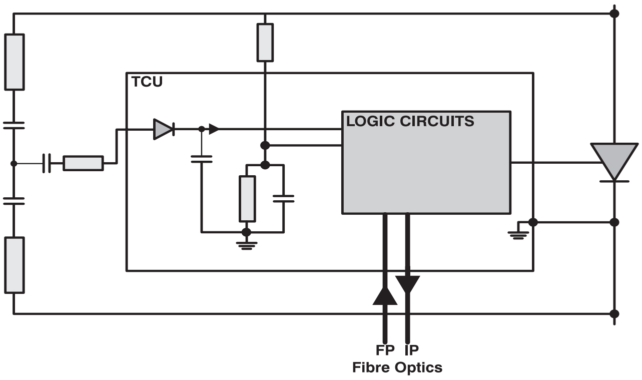

Fig. 2. Basic circuit diagram of ASEA thyristor control unit.

The complete TCU is encapsulated in one shielded box. This is made possible since all the high power components in the snubber circuit and in the power supply to the TCU are separated from the TCU. Also, the auxiliary power to the TCU is taken from a tap on the capacitors forming the snubber capacitor. This means that the main snubber current does not pass through any active components or through the TCU circuits, and the maximum transient current in the TCU board is limited by a factor of ten to about 10 A.

The charging of the TCU starts on the positive slope of the thyristor voltage and in normal operation the TCU is fully charged before the zero crossing of the voltage. Further, steep front impulses will charge the TCU fast enough to ensure safe firing of the thyristors before an excessive voltage level across the thyristor has been reached.

The level of the protective firing is determined by a compensated high voltage divider, with high impedance, and the protective firing will operate only if the power supply of the TCU is working. A high-ohm resistor outside the TCU limits the fault current in case there is a total short circuit of the voltage divider.

The complete TCU is thus enclosed in a shielded box, 40 x 70 x 190 mm.

IV. THE ASEA LIGHT TRIGGERED DESIGN

In order to investigate the LTT concept in detail, several different LTT concepts were investigated and tested in accordance with IEC Standard Publication 700 and IEEE Std. 857-1990. A test valve with LTT was installed by ASEA in the Konti-Skan link in 1988 as a replacement for a mercury arc valve [1].

If triggering of the thyristors is the only desired feature it is possible to eliminate all electronics at the thyristor level. In practice, the use of LTTs instead of ETTs does not mean that all the electronics on a thyristor basis can be eliminated. A minimum requirement imposed on thyristor valves for HVDC is that a defective thyristor position must be detected in order to trip the converter if all the redundant thyristor positions fail. In the test valve this was solved by using a separate monitoring unit and one return optical fibre for each position. The protective firing was solved by designing the thyristors as self-protecting units. In this test installation no recovery protection was necessary due to special conditions at this station.

The main concern in this installation was the lifetime of light sources. Since the LTT requires a fairly high amount of light for safe triggering, even though a multistage amplifying gate was used, the light sources must operate at very high power. Both LEDs and laser diodes are used. In order to reduce the number of the costly laser diodes, and to obtain the necessary redundancy, the optical fibres from three laser diodes are mixed together in an optical mixer and serve six thyristors. (However, there is no redundancy for the optical mixers). For the thyristors fired by LEDs, there is one LED for each thyristor, see Figs. 3a and 3b. The degradation of the light sources has been closely followed over the years.

With the LTT HVDC valves the drawback is the reduced voltage capability of the self-protecting thyristors, and the cost and maintenance of the light sources. Moreover, not all the electronics on each thyristor position can be eliminated unless the monitoring and protection are sacrificed. The arrangement for the recovery protection is complicated if the redundancy of the thyristor positions is to be secured. Recovery protection operating on groups of thyristors, or even on a complete valve, have proven less reliable in earlier tests. Thus, when using LTTs, the electronics and the associated arrangements for power supply on each thyristor position cannot easily be eliminated and, in a practical HVDC thyristor valve, use of LTTs instead of ETTs will end up in a compromise without the full advantage of either concept.

At ABB today, LTTs are only used for special applications, where ETTs cannot be used for technical reasons.

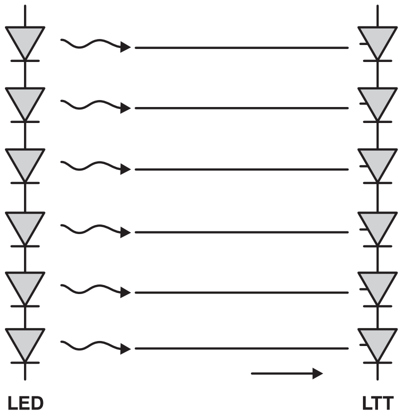

Fig. 3a. Optical firing systems for self-protecting LTTs, based on Light Emitting Diodes (LEDs).

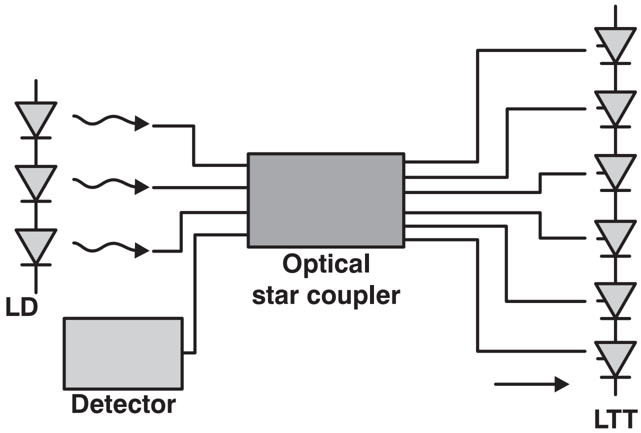

Fig. 3b. Optical firing systems for self-protecting LTTs, based on Laser Diodes (LDs).

V. PRESENT ABB DESIGN

The present ABB TCU is a further development of the ASEA design. No major changes have been made for many years. The most important modification is the conversion from discrete components into thick film circuits that was carried out in 1987. The electronics consist of three hybrid circuits. The only discrete components are those associated with the power supply and the final gate drive transistor. 12,000 TCU units have been produced, and operational experience is excellent. It is considered an advantage that the high power components are separated from the circuit board, and that there are no active components in series with the main snubber components. Another basic design idea is to avoid high currents on the p.c.b. Therefore, as in the ASEA design, the power supply of the TCU is taken from a tap in the snubber circuit, and all the connections between the TCU and the thyristor and snubber circuits are made via high impedances. Thus the risk of an open circuit occurring in the snubber circuit is reduced, as well as the risk of overheating of the TCU.

To make the protective firing dependent on the operation of the TCU means that, in the event of a failure in the snubber circuit or in the TCU, the result will be a short circuit of the thyristor, and no further energy will be fed into the defective position.

VI. FUTURE ABB VALVE ELECTRONICS

In recent years there has been a demand for increased use of on-line diagnosis of most sophisticated equipment, such as cars, circuit-breakers, power transformers, etc. Another general trend in society is towards the increased exchange of information, and a great deal of this information exchange is done via fibre optical communication. In the thyristor valves the optical fibres are at present used solely to transmit the most basic information, like thyristor position operating and protective firing operation, IP (down channel), and firing order, FP (up channel). This means that the capability of these communication links is far from fully utilised, and much more information can be transmitted by these links, such as detailed information on the conditions in the thyristor valve. However, this requires even more intelligence on each thyristor position, and this can be obtained only by further development of the TCU. This contradicts the ideas behind the LTT concept and the elimination of the TCU. The development of microcomputers and microelectronics has been awesome in the last few years. The reliability of electronic circuits mainly depends on the number of components involved and not on the complexity of the circuits. Thus, by implementing the latest in electronics into the TCU, it is possible to increase reliability and at the same time obtain better resolution in the monitoring of the valve.

A diagnosis system for the thyristor valves gives the following advantages:

- reduced overall cost
- unscheduled repair can be planned in advance
- simplification and reduction of scheduled maintenance
- increased availability
- information on the overload capability of the valve at every instant.

Most of the measurements carried out on each thyristor position during the annual maintenance period can be made continuously on line while the valve is in operation and can be transmitted to the VBE for evaluation. Thus, the maintenance work traditionally done on HVDC valves can be reduced as regards both time and frequency. Of course, the diagnosis system must, as far as possible, be independent of the basic TCU functions in order to avoid the firing and protection circuits to depend on the operation of the diagnostic system.

A microcomputer-based thyristor diagnosis system for HVDC valves is now being tested at ABB, before installation in a test valve. The features of this system are:

- monitoring of the snubber circuit
- monitoring of the heat sink temperature
- monitoring of the optical transmission links
- water leakage detection.

The monitoring of the snubber circuit is realised by measuring the RC time upon firing of the thyristor. Since the capacitors are of dry-type, “self-healing” design, a fault in the capacitor will show up as a decrease in RC time, and a degradation of the capacitor will be detected well ahead of a complete failure. The resistive part of the snubber is built up using parallel resistors and thus a resistor failure will be detected as an increase in RC time.

The temperature of the heat sink of each thyristor is measured continuously. The highest thyristor temperatures will determine the status of the valve and provide exact information on the overload capability at actual ambient conditions.

The fire barrier under each thyristor module is designed to collect water in case of a leak. The collected water is detected by a sensor and a signal is sent to the VBE. The position of a leak can thus be located with precision on six thyristors.

Since parts of the monitoring sequence are performed at reduced light levels in the optical systems the margins for safe operation of the firing system are monitored for each optical link.

This monitoring system can easily be extended to other measurements as well, such as local smoke detection, etc.

VII. SUMMARY

Different solutions for thyristor triggering and monitoring have been analysed: The BBC design, the ASEA design for electrically triggered thyristors, the ASEA design for light-triggered thyristors and the ABB design. Experience from the different types of thyristor control forms the basis for future ABB design.

The electrically triggered design used by ABB has proved to have very high reliability. The main principles in the valve design are:

- Full redundancy for each single component in the valve
- All the monitoring and protections in the valve act independently on each thyristor position
- Fail-safe design, that is no component failure will cause a major consequential failure.

To meet requirements from clients for modern power equipment, a diagnosis system for thyristor valves has been developed. This system includes the following features:

- Advance information on changes in snubber circuit components
- On-line information on changes in the margins in the optical transmission links
- Immediate detection and exact localisation of small water leaks
- Exact information on the overload capability of the converter in actual conditions.

The diagnosis system has been based on the existing well proven design of thyristor valves using ETTs and TCUs and by add-on state-of-the-art monitoring circuits.

Light-triggered thyristors are at present used by ABB only in applications where electrically triggered thyristors cannot be used for technical reasons.

VIII. REFERENCES

[1] Bo E. Danielsson, “HVDC valves with light-triggered thyristors”, Power Semiconductor Devices and Circuits, Plenum Press, New York 1992, pp239-269.

IV. BIOGRAPHIES

Urban Åström was born in Njurunda, Sweden in 1946. He received his M.Sc. degree in physical engineering and B.Sc. degree in astronomy from the University of Uppsala, Sweden in 1973. In 1974 he joined ASEA AB’s HVDC department and worked with design and development of control equipment, thyristor valves and valve cooling. In 1978 he joined the transformer department and worked with design of converter transformers for HVDC. In 1986 he joined the HQ/NEH HVDC project team, being responsible for converter equipment. From 1989 to 1995 he was manager of the HVDC Project Engineering Development department, and since 1995 he has managed the Converter Valve Development department.

Bo E. Danielsson was born in Örebro, Sweden, on June 21, 1941. He received his B.Sc. in physics from the University of Lund, Sweden, in 1969, and his Ph. D. in solid state electronics from Chalmers University of Technology, Sweden, in 1982.

From 1971 to 1986, he worked with high power thyristors at ASEA Power Semiconductor Department in Västerås, Sweden. His experience covers basic development, electrical and mechanical design and production technique, and he has worked as a manager in all these areas. In 1986, he joined the HVDC division at ABB Power Systems in Ludvika, Sweden. There he worked as the manager of thyristor valve development, and since 1991 has operated as Senior Specialist in power semiconductor applications.

Dr. Danielsson has given several courses in power semiconductor physics at Chalmers University of Technology and the Royal Institute of Technology in Sweden. He is a member of NIST WG on Model Validation.

Krister Nyberg was born in Borlänge in 1948. He received his B.Sc. degree in electrical engineering from Mälardalens Institute of Technology in Sweden in 1987. In 1973 he joined ASEA AB’s HVDC department and worked with the design and development of control equipment. Since 1991 he has been manager of the HVDC Control System Development department.