HVDC

TOSHIBA

TOSHIBA HVDC

Toshiba provides the best and most economical HVDC system.

In 1955, Toshiba started a development of HVDC technology, and is the leading developer in Japan. Toshiba has the experience to provide the best HVDC system engineering.

Toshiba is the world pioneer of light triggered thyristor (LTT) valves.

In 1983, field operation of the LTT valve was performed for the first time in the world.
In 1992, Toshiba installed DC125kV-300MW LTT valves in the Shin-Shinano frequency converter station, as the world's first commercial application.
Since 1983, a great number of LTTs have been installed in many systems around the world. Toshiba is the world's leader in LTT valve technology.

High reliability, high flexibility, excellent performance and easy maintenance are realized by intelligent controllers based on microcomputer technology.

Since 1987, Toshiba has applied microcomputer based controllers widely in various HVDC and SVC systems.

Toshiba provides high quality HVDC systems.

Toshiba's LTT valves and microcomputer based controllers offer highly reliable HVDC systems.
Toshiba holds certificates in quality assurance control system in accordance with the standards ISO9001/EN29001/BS5750/JISZ9901.

NOW DEVELOPING FOR YOUR HVDC PROJECT

DC17.9Kv
50MW Fig.6

DC 125kV
300 MW
Fig.5

URUGUAIANA FREQUENCY CONVERTRE COMISSIONED 1995

250Kvdc QUADRUPLE VALVES COMISSIONED
IN HOKKAIDO-HONSHU HVDC LINK 1993

1992 WORLD'S FIRST COMMERCIAL OPERATION OF
LTT VALVES IN SHIN-SHINANO S/S

DC125Kv
300MW Fig.3

LTT VALVES DEVELOPED UP TO 500kV 1986

DC500Kv
1800A
Fig.4

1983 WORLD'S FIRST
OPERATION OF LTT
VALVE

DC125kV
300MW
Fig. 1

1979 HVDC TRANSMISSION
SYSTEM COMMISSIONED
IN HOKKAIDO-HONSHU
HVDC LINK

1977 BTB SYSTEM COMMISSIONED IN SHIN-SHINANO S/S

THYRISTOR VALVE FIELD TESTED 1970

DC250Kv
300MW
Fif.2

TOSHIBA STATED DEVELOPMENT WORKS
FOR HVDC 1995

TOSHIBA HVDC

SYSTEM ENGINEERING

The System Engineering Department is in the centre of the whole engineering project to establish the optimum HVDC system. Work's Laboratories as well as its Production Departments are active in developing reliable HVDC systems.

Engineering meeting and discussion.

Power system simulator as well as digital analysis using super computers are conducted to evaluate the complex phenomena of the AC and DC systems.

System engineers are familiar with today's power transmission systems and equipment as well as tomorrow's technology.

Advanced control strategy and tactics are realized by production designer for each HVDC system.

RESEARCH AND DEVELOPMENT

System engineering and equipment manufacturing are supported by many researchers from various fields. Toshiba incorporates three research and development organizations: the R&D centre for basic and future science and technology, the works laboratory, and the production department development group.

Works' laboratory is active in development of new operation and control technology.

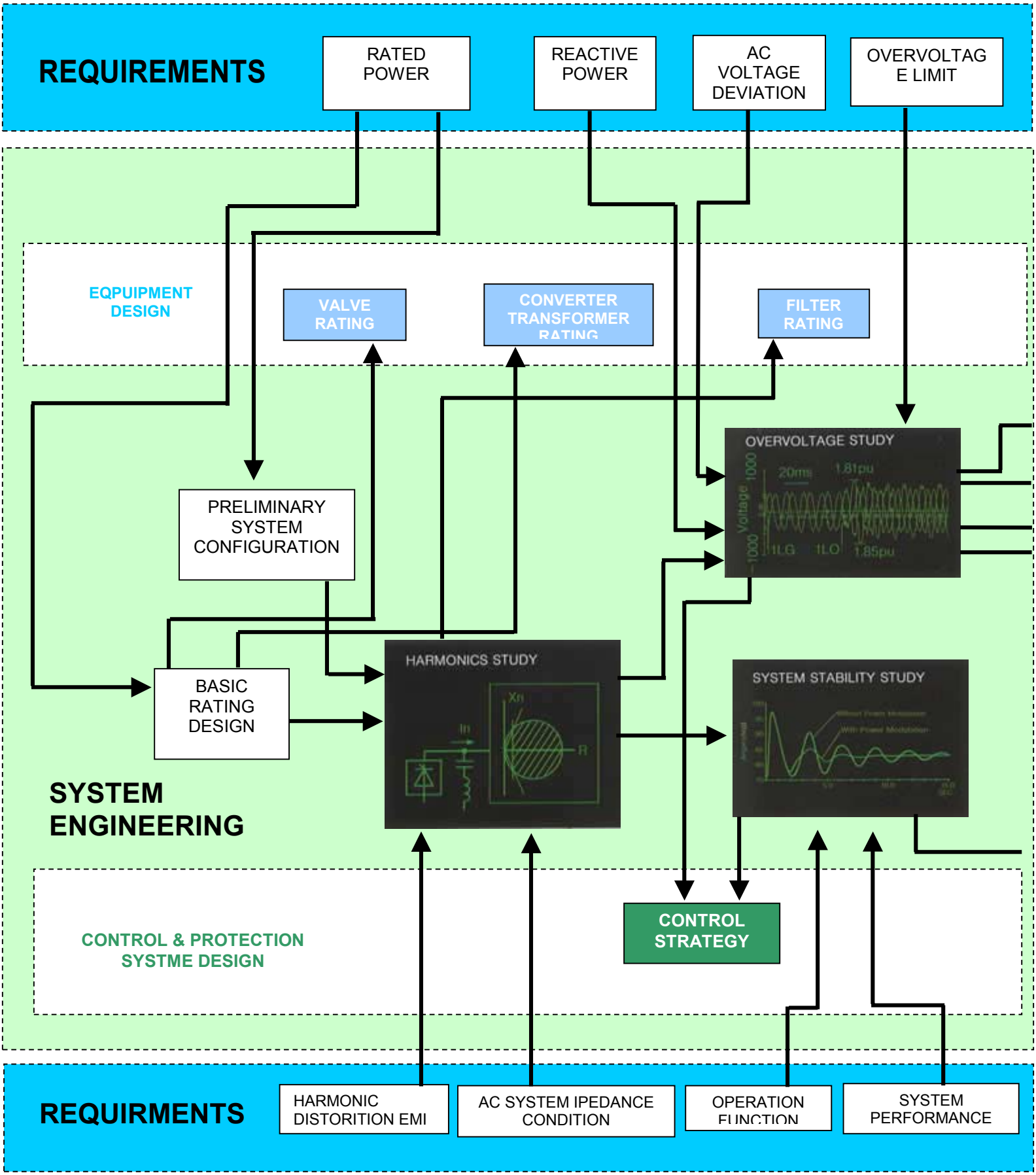
This picture shows the thyristor stack development to study the application technologies of power electronics devices.

+/- 2000kVDC generation testing facility in the Ultra High Voltage Laboratory is used for the DC high voltage test and the voltage reversal test.

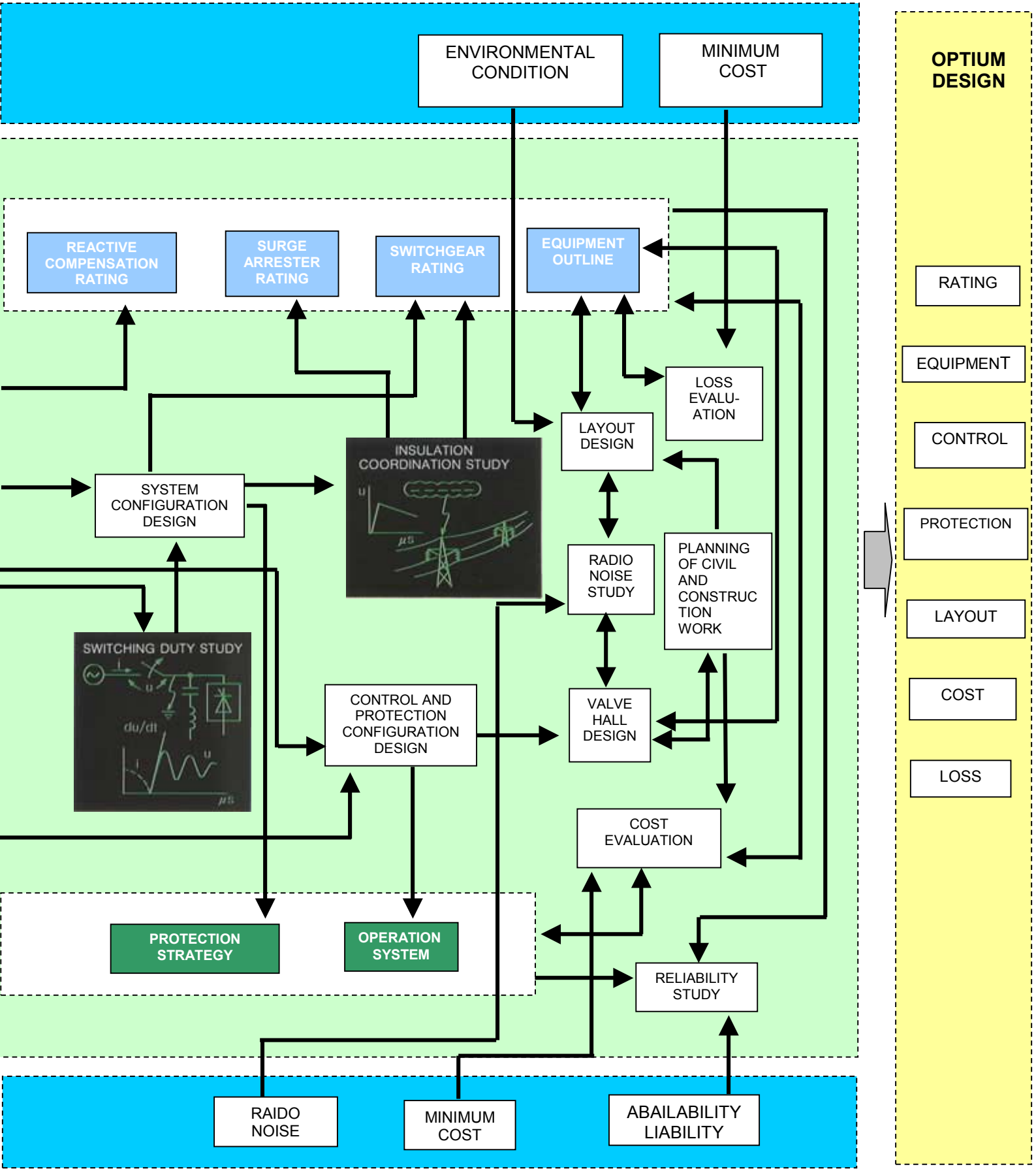
6000kV, 600kJ impulse generator in the Ultra High Voltage Laboratory.

TOSHIBA HVDC

HVDC SYSTEM ENGINEERING FLOW DIAGRAM



Toshiba complies with customer's specifications and forwards economic alternatives by cultivated HVDC system engineering art.
The following diagram shows the typical system engineering flow.



TOSHIBA HVDC

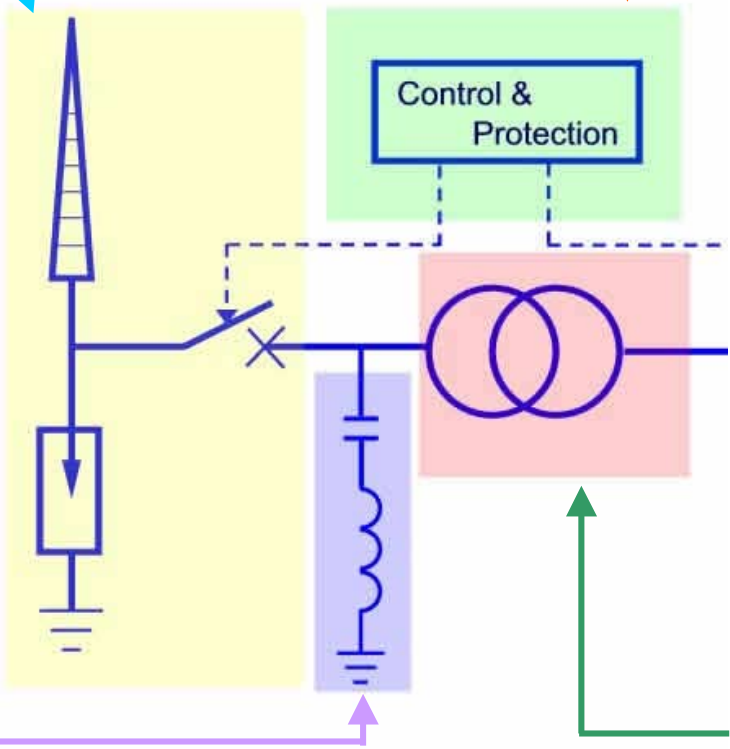
PRODUCTION ACTIVITIES

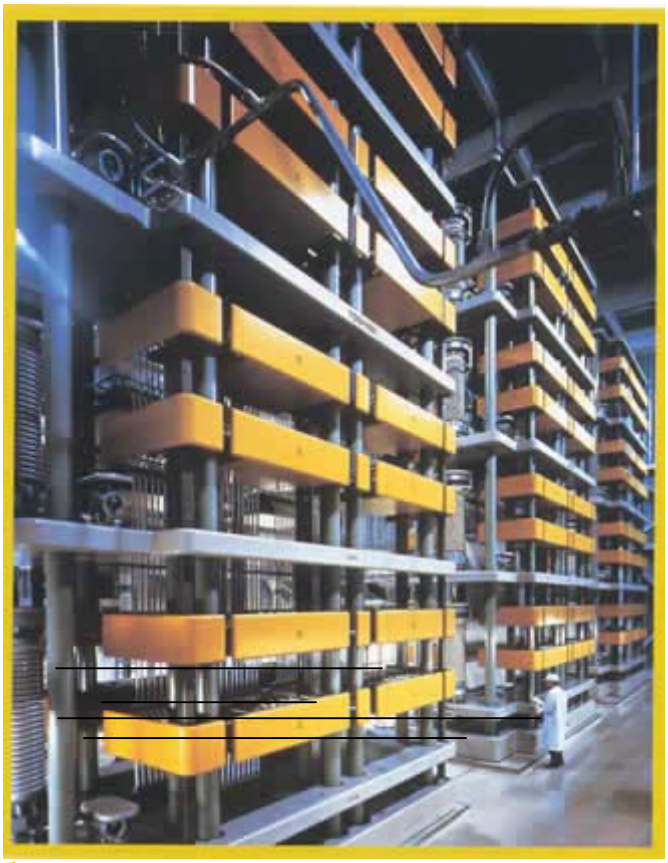
Toshiba has developed and supplied various equipments for AC and DC power systems.

Toshiba has supplied a lot of switchgear covering voltages from 72kV to 1100kVAC.
The picture shows 550kV Gas insulated switchgear with three phase encapsulated main busbar.

Toshiba produce telecontrol devices, man-machine devices, programmable controllers, power system controllers, converter controllers, and protection relays.
The picture shows a supervisory control and data acquisition (SCADA) system.

The picture shows an AC harmonic filter for an HVDC project.

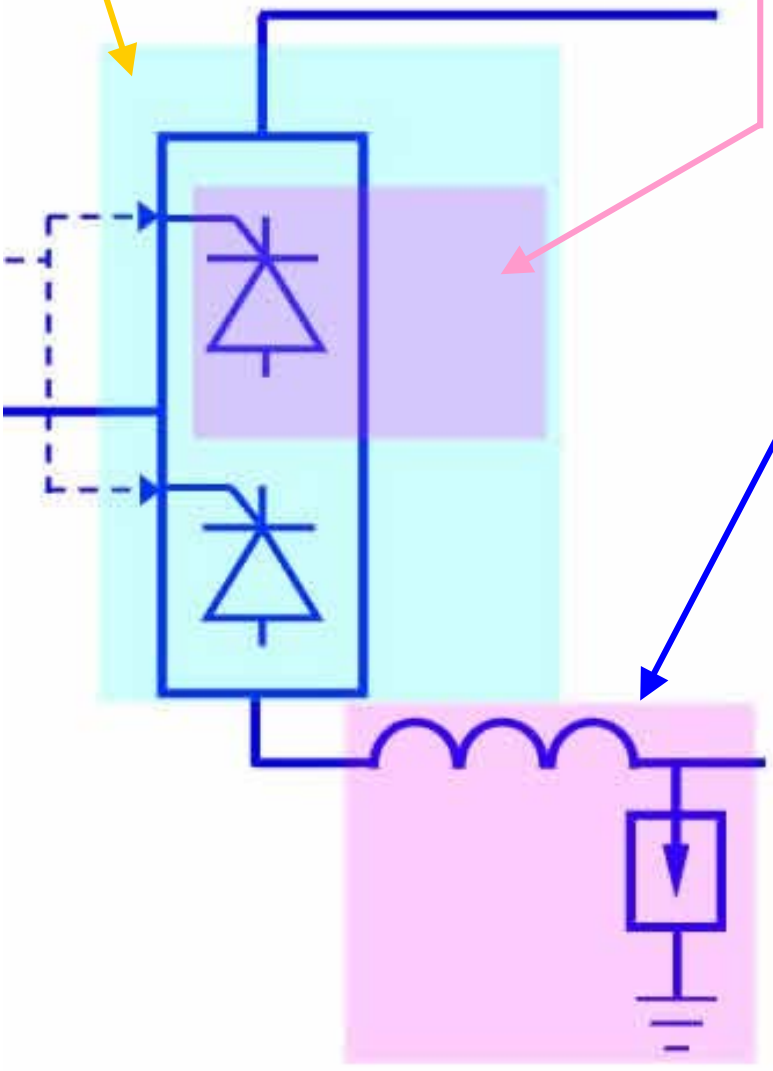




The LTT valve the most advanced thyristor valve. The picture shows 250kV DC LTT valves for HVDC link.

Toshiba is manufactures various semiconductor products (Memory IC's, Gate alley, Micro-processor, High power thyristor, GTO's GTR's.)

The picture shows a DC smoothing reactor and a DC surge arrester for an HVDC link.



Toshiba has supplied many transformers up to 800kV since 1894. The picture shows converter transformers for an HVDC link.

TOSHIBA HVDC

CONTROL & PROTETION TECHONOLOGY

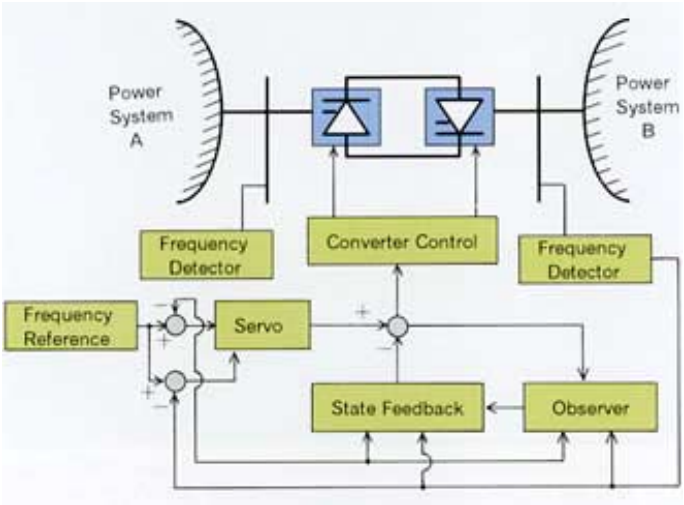
Toshiba provides a wide variety of control and protection technology, and utilizes optimum strategies for each HVDC project. The optimum control and protection systems are designed with careful attention to the interaction between DC and AC systems to which converters are to be connected. Toshiba's intelligent controllers flexible operation is guaranteed to meet your requirements.
Typical technologies are as follows:

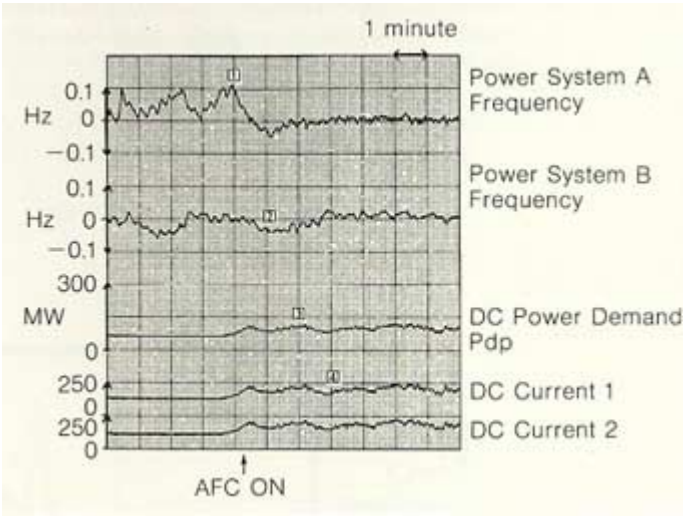
Basic control functions

Constant power control
Constant DC voltage control
Constant current control
Extinction angle control
Voltage dependent current order control

Automatic Frequency Control

When you require to improve frequency deviation in normal operation and after large disturbances, application of Automatic Frequency Control (AFC) function is recommended.
Basic AFC executes proportional control by taking into account frequency differences between two-systems, which are connected via an HVDC link.
The multi-variable AFC, based on modern control theories has many advantages. It produces better control response because it contains the observer. Furthermore, it is sufficiently robust to allow stable control even when there are large changes in the AC power systems.

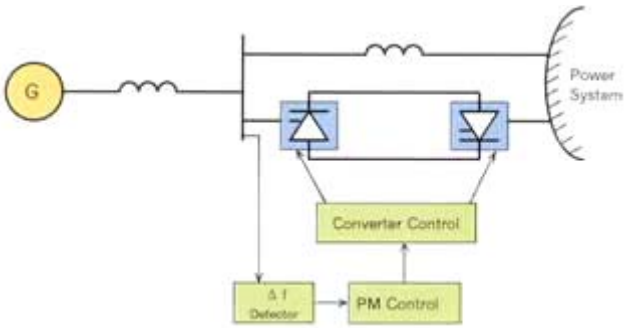


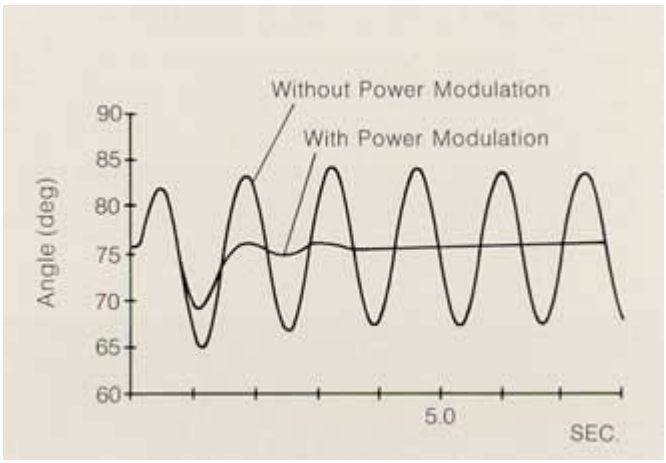


Frequency control performance of the multivariable AFC when there are load variations of normal magnitudes.

Power Swing Damping Control

The modulation control of the DC power improves power swing stability and effectively dampes power oscillations.

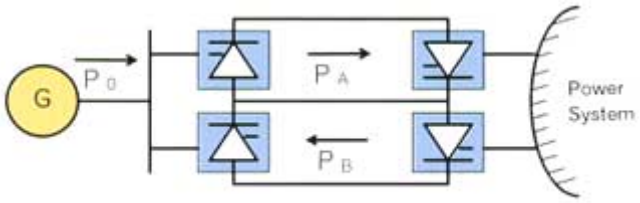


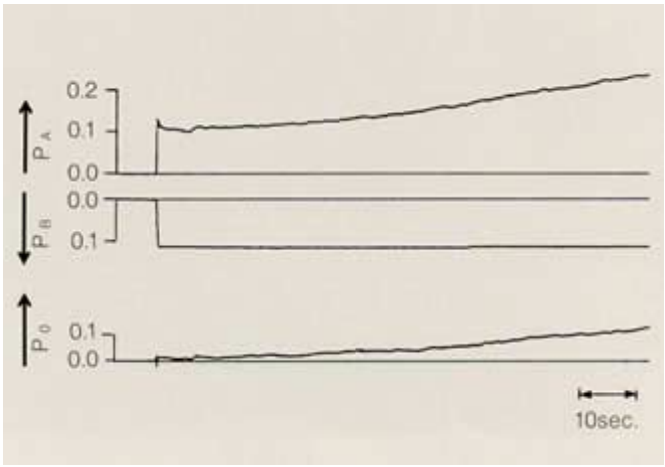


Stating Up the Generator

When an HVDC system is connected to the isolated generator at the sending end, the system has to be started up in coordination with the governor action of the generator.

When bipolar operation is available, overall transmitted power can be built up smoothly from zero to the rated value by having two poles transmit power in opposite directions.

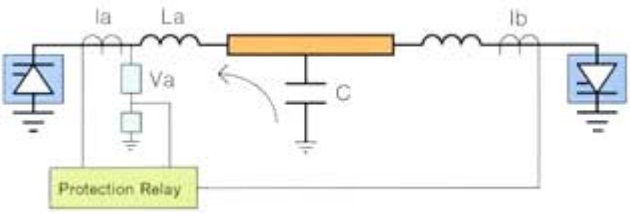




High Speed Protection of DC Line fault

During transient phenomena, a very large charge or discharge current flows on the stray capacitance of the transmission line, especially in a cable transmission system.

Toshiba's high-speed differential protective relay is provided with a special compensation function to avoid maloperation. The relay eliminates the difficulty of distinguishing between internal and external fault that existed on traditional system.



Charge current compensation Algorithm

$$Ida = \left| Ia + Ib - c \times \frac{d}{dt}\left(Va - La \frac{d}{dt} Ia\right) \right|$$

Charge Voltage of cable terminal

Charge current compensation

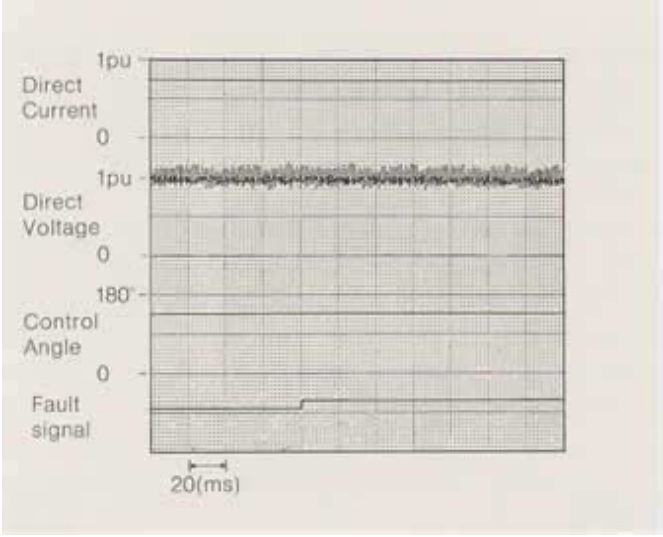
High Reliability and Easy Maintenance

Control and protection system

Toshiba's control and protection equipment for HVDC consists of fully digitalized components, based on microcomputer technology using a full graphics code generating tool or high level programming language. Control parameters can be easily modified on the setting panel.

Duplicated or triplicated control and protection systems

You can choose the optimum system from many technical and economical alternatives, e.g., duplicated, dual and triplicated.
For example, with the dual system, if the power supply of the operating fails, the back-up system instantaneously takes over, without causing disturbance to either AC or DC system. Repair work of the faulty system can be easily done without interrupting the operation.



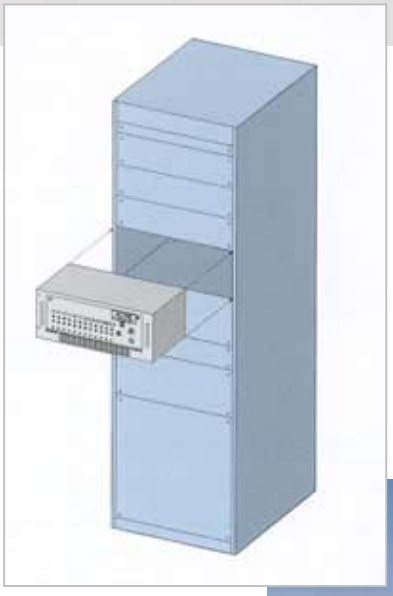
Test waveform showing automatic change over to the back-up system from the operating system when power failure occurs.

Power system simulator

Toshiba has a large sophisticated power system simulator, which enables real-time, high-accuracy analysis of dynamic phenomena in power systems.
We can fully check the performance and robustness of your HVDC controller by means of this simulator before shipping.

Simplified simulator

Maintenance and trouble shooting are greatly simplified by the microcomputer-based self-diagnostic functions and by the optional simplified simulator attached, to the HVDC terminal controller.
The simplified simulator consists of an HVDC terminal model that includes converter transformers, thyristor bridges, a smoothing reactor, transducers, monitors, etc.



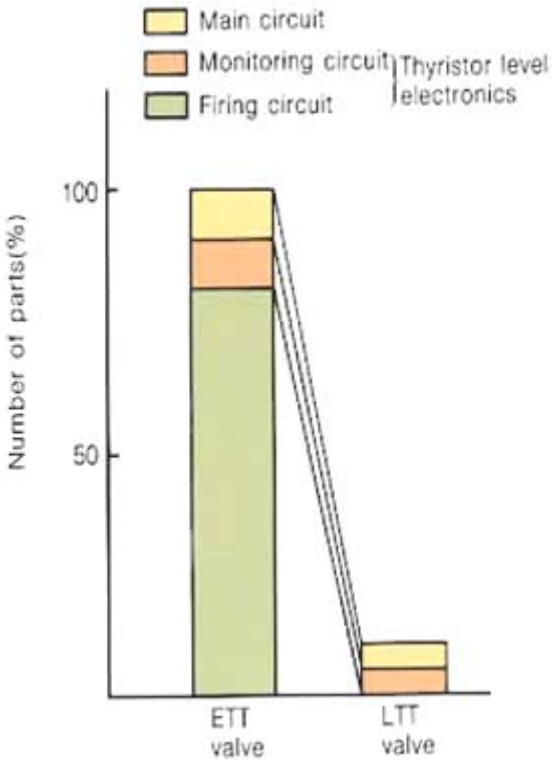
Out line of simplified simulator

Directly Light-triggered Thyristor valve

Improved reliability

Electrically Triggered Thyristor (ETT) valves require many thyristor level electronic parts. LTT valves eliminate 90% of these parts, resulting in higher reliability.

The world largest LTT
8kV 3,500A



Improved operational flexibility

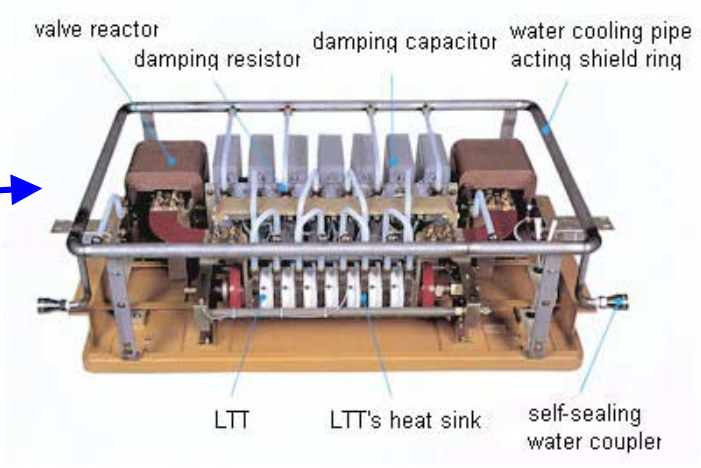
The LTT valve can start to operate immediately after it is energized, since it does not have any thyristor level electronics to be changed. The LTT valve also can be fired when the AC system voltage drops.

Improved electromagnetic noise immunity

A triggering signal is sent to the LTT in the form of light energy. This gives the LTT valve much better noise immunity than a conventional ETT valve.

Simplest Thyristor Valve in the World

Toshiba eliminated electrical parts in the thyristor-level auxiliary circuits by employing the direct-light-triggered thyristor (LTT) to the valve. The elimination of thyristor level electronics leads to many superior features.



Easier maintenance

The thyristor valves and modules are designed for quicker and easier maintenance.

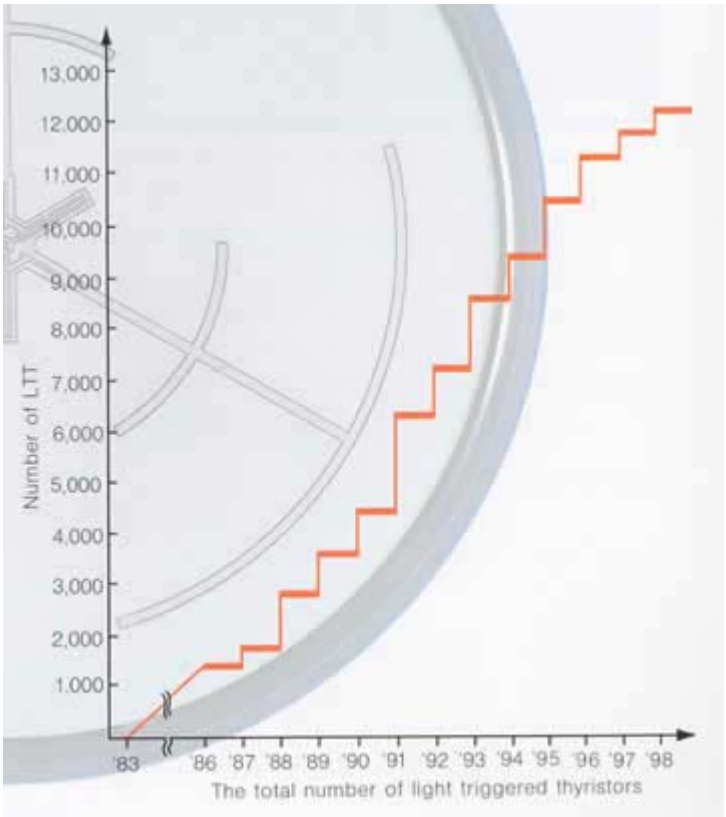
1) Since there are no complicates electronic circuits at the thyristor level, inspection of only a few parts at the thyristor level is required. Because the electrical connections are located at the top of the valve module, they are very easy to visually check.
2) The thyristor can be replaced without opening the cooling circuits and without removing the thyristor modules.
3) The thyristor module can be easily removed and replaced by using the module replacement lifter.

The self-sealing water coupler, used to connect the cooling water piping to the thyristor module enable easy disconnection and reconnection between the module and the piping without spilling cooling water.

Abundant experience of TOSHIBA LTT

Since Toshiba employed LTTs in the power system for the first time in the world at Sakuma frequency converter station in 1983, LTTs has been mainly applied in the power system and also in some industrial fields such as motor drive system.

Max, rating	LTT				V_{BO} free LTT
	SL1500 GX23	SL3000 GX23	SL2500 JX21	SL3500 LX21	SLV2500 JX21
V_{DRM}/V_{RRM} (V)	4000	4,000	6,000	8,000	6,000
I_T (AV) (A)	1,500	3,000	2,500	3,500	2,500
di/dt (A/μs)	300	300	400	300	400
dv/ dt (V/μs)	3,500	3,500	4,000	4,500	4,000
tq (μs)	300	300	300	300	300
I_{TSM} (A)	30,000	60,000	42,000	60,000	42,000

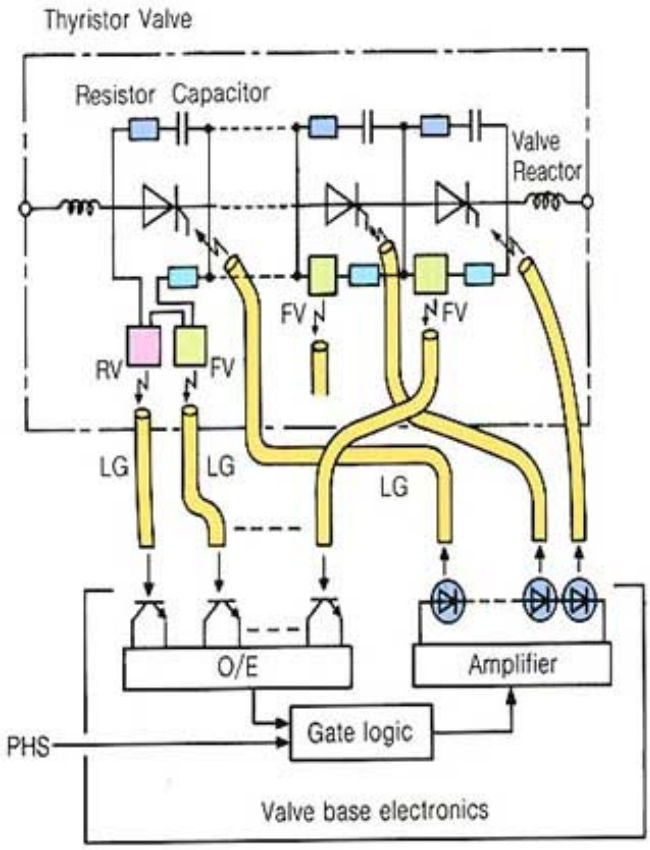


TOSHIBA thyristor valve technology

Overvoltage protection strategy

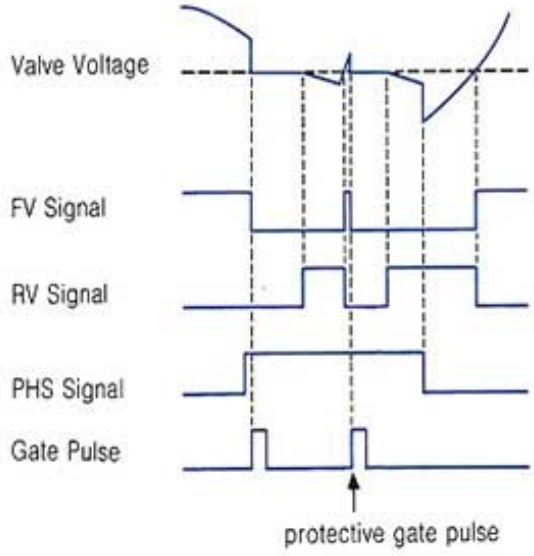
There are two causes of over-voltages
(1) From outside the valve
--- Switching or lightening surges from AC or side
(2) From inside the series string of thyristors
--- Dynamic voltage unbalance among series connected thyristors caused by partial turn-off, etc.
The valve protection means are shown in the table below.

Over-voltage	Protection means
From outside	Valve arrester directly connected across each valve
From inside	Protection firing provided to all thyristors connected in series simultaneously when forward voltage (FV) appears during thysistors should be turned on.



V_{BO} free LTT

Although performance of our protective firing mentioned above is good, Toshiba has already developed a Voltage Break Over (V_{BO}) free thyristor, which implements an over-voltage self-protection function. This system has been applied to several commercial systems.



FV : Forward Voltage RV : Reverse Voltage
LG : Light Guide PHS : Phase Signal
O/E : Optical signal to Electrical signal converter

Timing chart of protective gate pulse

Seismic design

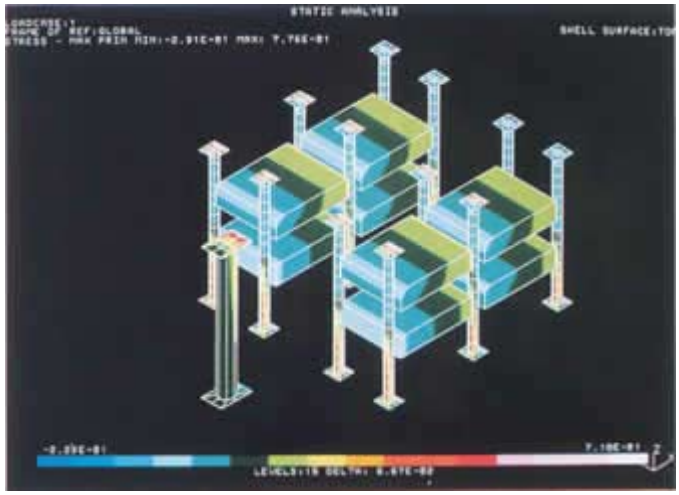
Toshiba's thyristor valve is a floor-mounted, stand alone type.

Superior features of the stand-alone type are:

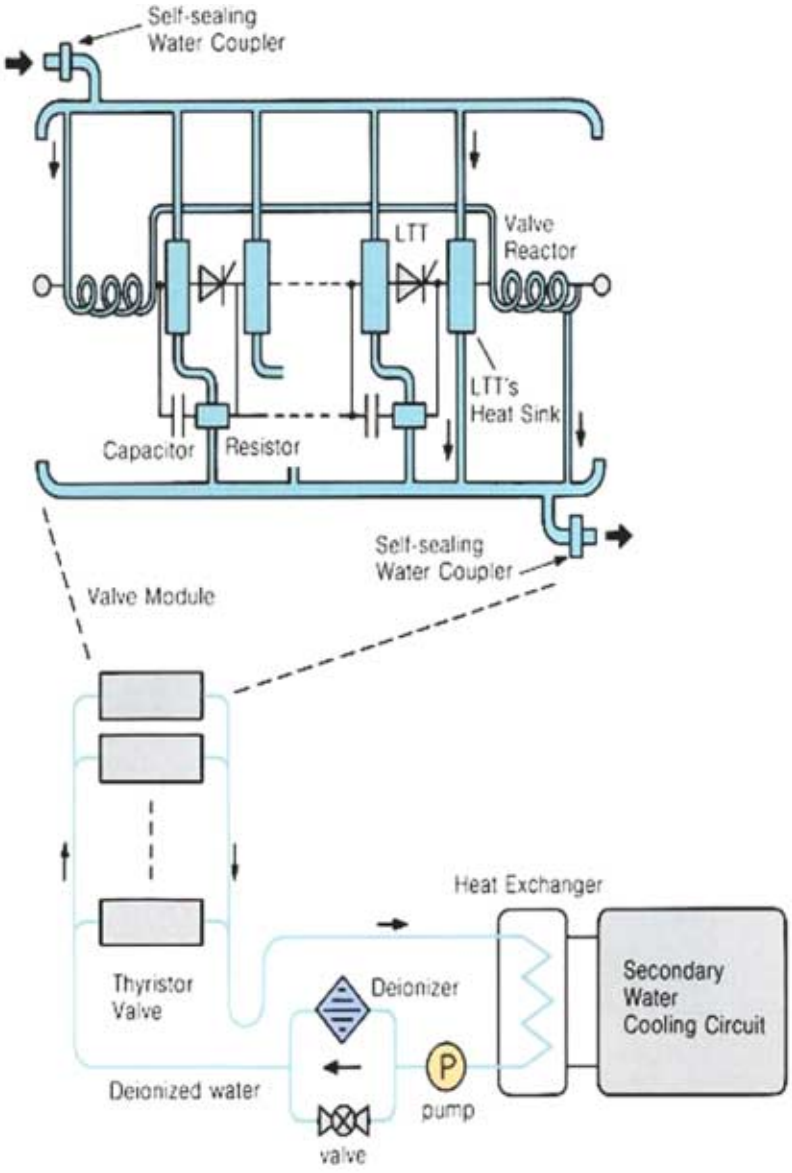
- ●Reinforcement of valve hall structure is not necessary.
- ●High quality verified in the factory is transferred to the site, because disassembly for transportation is minimized.
- ●The installation period is short.
- ●Displacement of valve in case of earthquake is small and wiring around the valves is simple.

Toshiba's thyristor valve is designed using highly accurate computer analysis and vibration test of a full-scaled thyristor valve model.

Seismic vibration test of full-scaled quadruple valve



Stress analysis of thyristor value



Valve cooling system

Toshiba has experience in manufacturing oil cooled, air-cooled and water cooled valves. Toshiba proposes water-cooled vales because water has the most efficient cooling properties, which provides the following advantages.

- ●Compact design
- ●High current conduction of the thyristors
- ●Low auxiliary losses

Quality assurance of TOSHIBA HVDC

Toshiba has established a hierarchical quality assurance system, and carries out a rigorous quality control program at each manufacturing step.

Control and protection equipment
Control and protection equipment is tested individually.

Site
A performance test is carried out,
- ●Combining all control and protection
- ●Equipment with all AC and DC equipment

Power system simulator
Performance of control and protection equipment is fully verified using the power system simulator.

Certificate and registration from outside organization

Toshiba Corporation, Fuchu Works
Power Electronics Equipment Department
Fuchu-Shi, Tokyo, Japan

Design, development and manufacture of static power converters.

ISO9001
Certificate of approval of manufacturer applied standard ISO9001

Parts

To ensure high performance and high reliability of the thyristor valve, Toshiba is also making every effort to develop highly reliable parts. Each part is subjected to rigorous verification. Each parts of the valve module is also subjected to inspection and testing in accordance with quality assurance program.

Valve module

All valve modules are tested according to IEC-700 in module testing line.

Valve

All thyristor valves are assembled factory. Insulation and operation testes are carried out to confirm production quality.

Site

Thyristor valves are transported as a whole unit without disassembling any buses or cooling pipes, enabling us to ensure the same quality at site as in the factory.

TYPICAL PROJECTS

HVDC LINK

Hokkaido-Honshu HVDC Link

The HVDC Link between Hokkaido Island and Honshu Island of Japan was up-graded in 1993 from 300MW to 600MW.
This facility has performed the following functions:

- ●Efficient power interchange in Japan
- ●A rational reduction in power supply reserves
- ●Improved frequency deviation of two AC systems during normal conditions and in the event of a fault in the AC systems

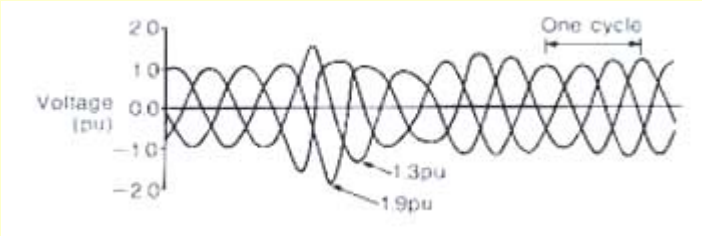
Prototype Valve for Kill Channel HVDC Link

An HVDC project for a ±500kVDC & 2800MW bipolar system is planned to interconnect the 500kVAc networks of western Japan.
Toshiba is manufacturing the proto-valve for this project. The current rating is 2800A and 3500A at overload. To achieve this rating a 8kV-3500A LTT made of a 150mm-diameter silicon water is developed.

SVC FOR HVDC

Durnrohr SVC

This SVC is provided to absorb over-voltages, which occur when the HVDC converter is suddenly shut down.
When an over-voltage occurs, it consumes 580MVar instantaneously, and the over-voltage is suppressed to less than 1.3pu.



BACK TO BACK STATION

Shin-Shinano Frequency Converter

The power system in Japan operates with two frequencies: 50Hz in the eastern area and 60Hz in the western area. These two frequency areas are inter-connected by a Shin-shinano frequency converter.
The converter started operation with a capacity of 300MW in December 1977, and was up-graded to 600MW by the world's first LTT valves in 1992.

Sakuma Frequency Converter

Sakuma was commissioned as the world's first frequency converter station in 1965, and its mercury arc valves were replaced with LTT valves in 1993.

Uruguaiana Frequency Converter

The Uruguaiana frequency converter station interconnects Brazil and Argentina.
This system has a very weak AC power system and is equipped with unique control functions, such as Black Start, Automatic Frequency Control, and Automatic Speed Control of synchronous compensator, Automatic Voltage control and Voltage Dependent Active power Control.

Advanced Technologies
- facts application -

Toshiba's power electronics technologies extend to FACTS (Flexible AC Transmission Systems) applications. In addition to line-commutated converter technology using a light triggered thyristors, Toshiba is a leader in development of advanced self-commutated converters using GTO (Gate Turn-Off) thyristors. Application of the self-commutated converter to an HVDC, an SVC or any other FACTS system has the following advantages over the conventional commutated type converter.

HVDC

- ●Easier application to weak AC systems, because commutation does not rely on system voltage.
- ●Higher power transfer capability during AC system faults
- ●Reactive power control capability independent of active power from lag to lead without capacitors and reactors
- ●Less filter capacity requirement due to less harmonic generation

SVC (STATCOM: Static Compensator)

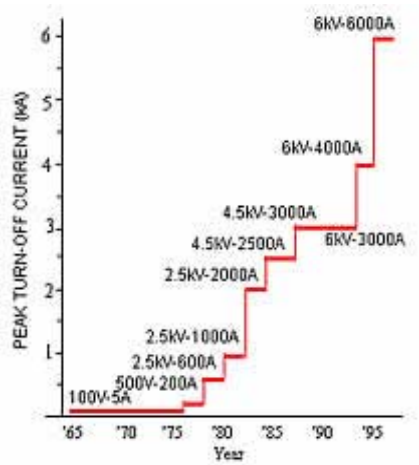
- ●Superior voltage support capability compared to a conventional SVC (TCR/TSC)
- ●Less space requirement

UPFC (Unified Power Flow Controller)

- ●Fast and continuous control of power flow and voltage without capacitors and reactors

Toshiba has developed new technologies for these advanced systems. A basic coordination control method for a self-commutated converter HVDC system has been developed and verified by simulator tests. A high voltage STATCOM of 50 MVA has been operated successfully since October 1992 at Shin-Shinano Substation in Japan. A basic UPFC control strategy has been established.

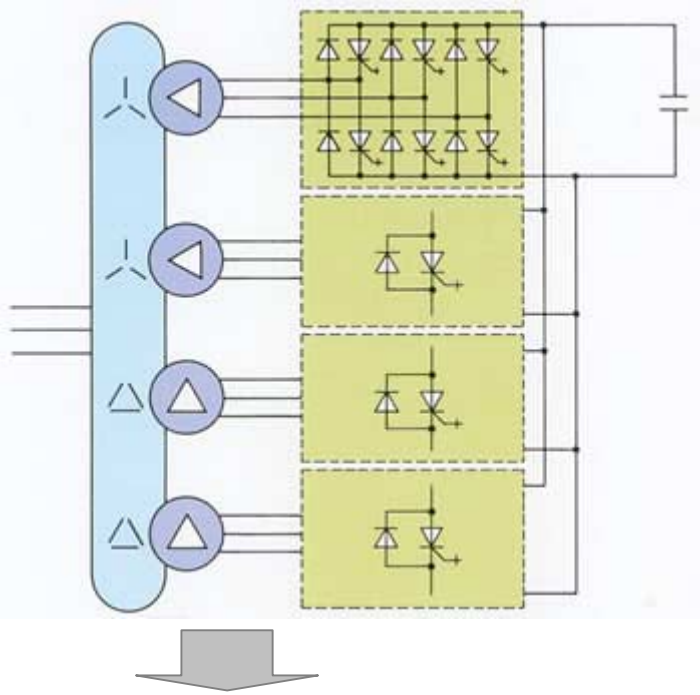
World Largest GTO



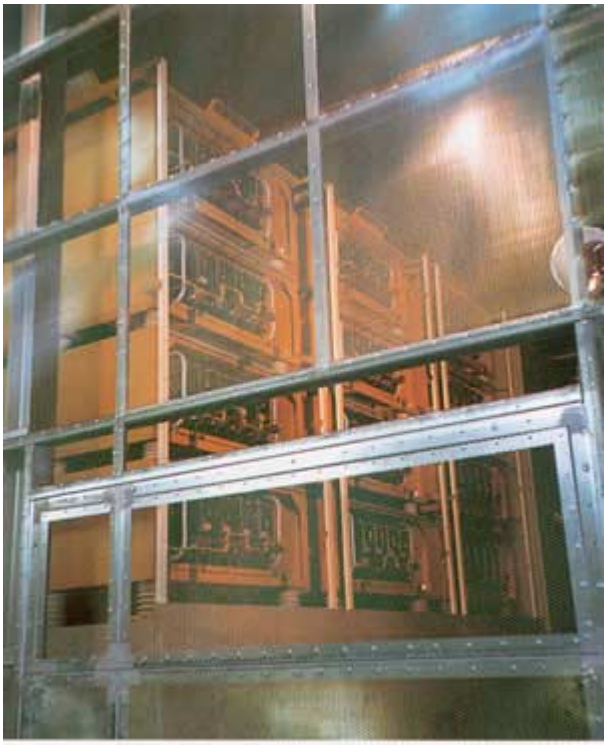
Toshiba's semi-conductor technology facilitates improvement of self-commutated converters. Since development of the 600V-200A GTO in 1976, voltage and current ratings have increased rapidly. Toshiba has manufactured the world's largest GTO in the following two decades. Their excellent characteristics in addition to their large ratings have pushed Toshiba's world market share of GTOs to the top. The latest rating has reached 6kV-6kA with the largest wafer of 150mm in diameter.

50 MVA STATCOM operated in Shin-Shinano S/S

Configuration



GTO valves



Converter Transformer

Ratings of STATCOM

Capacity	: 50MVA (4 units of 12.5MVA)
DC Voltage	: 16.8kV
Converter type	: 3-phase 3-pulse PWM
GTO	: 6kV-2.5kA
Insulation	: Air
Cooling	: Water

- New Generation Switching Device -

Research on a new generation self-turning-off device IEGT (Injection Enhanced Gate Transistor) invented by Toshiba is also in progress. The following advantages are expected.

- ●Lower loss
- ●Lower gate power by voltage drive with MOS (Metal oxide Semiconductor) gate
- ●Higher switching capability

TOSHIBA

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