
Energy from Waves
Energy from Wind
Tidal Energy
RENEWABLE OCEAN ENERGY
HIGH-POWER SEMICONDUCTOR DEVICES
Sal
Salinity Gradient Power
Thermal Energy

HIGH-POWER SEMICONDUCTOR DEVICES

- Los avances en el campo de las energías renovables han sido posible gracias a los impresionantes y continuos avances en el campo de la Electrónica de Potencia y muy en particular en los dispositivos de potencia durante estos últimos 50 años.

- Tenemos dos tipos principales de semiconductores de muy alta potencia (High-Power semiconductor devices):

1.- Basados en los tiristores (thyristor-based).
debemos incluir al SCR, GTO y el IGCT (o bien GCT)

2.- Basados en el transistor (transistor-based).
debemos destacar el MOSFET, IGBT y el IEGT

HIGH-POWER SEMICONDUCTOR DEVICES

"Cuando comenzó la historia de los semiconductores de potencia nadie, ni en sus sueños más disparatados, habría imaginado que alguna vez se alcanzaría semejante grado de complejidad, sofisticación y sintonía funcional.

Tampoco podría haber pronosticado nadie que en el camino entre la central eléctrica y el consumidor final la corriente eléctrica circularía alguna vez a través de uniones de silicio"

Hansruedi Zeller
Antiguo ingeniero de ABB Semiconductors
Lenzburg, Suiza

HIGH-POWER SEMICONDUCTOR DEVICES

EN ELECTRONICA DE POTENCIA
SEMICONDUCTOR = INTERRUPTOR

SEMICONDUCTORES BASICOS

- DIODO
- SCR (Silicon Controlled Rectifier) (thyristor)
- GTO (Gate Turn Off thyristor)
- IGCT (Integrated Gate Commutated Thyristors)
- BJT.s (Bipolar Junction Transistor),
- MOSFET.s (Metal Oxide Semiconductor Field Effect Transistor)
- IGBT (Insulated Gate Bipolar Transistor)
- IEGT (Injection Enhanced Gate Transistor)

HIGH-POWER SEMICONDUCTOR DEVICES

Switch type	GTO	IGCT	BJT	MOSFET	IGBT
Voltage (V)	6000	4500	1200	1000	3300
Current (A)	4000	2000	800	28	2000
Switched-off time (µs)	10-25	2-5	15-25	0.3-0.5	1-4
Pulse bandwidth (kHz)	0.2-1	1-3	0.5-5	5-100	2-20
Drive requirements	High	Low	Medium	Low	Low

HIGH-POWER SEMICONDUCTOR DEVICES

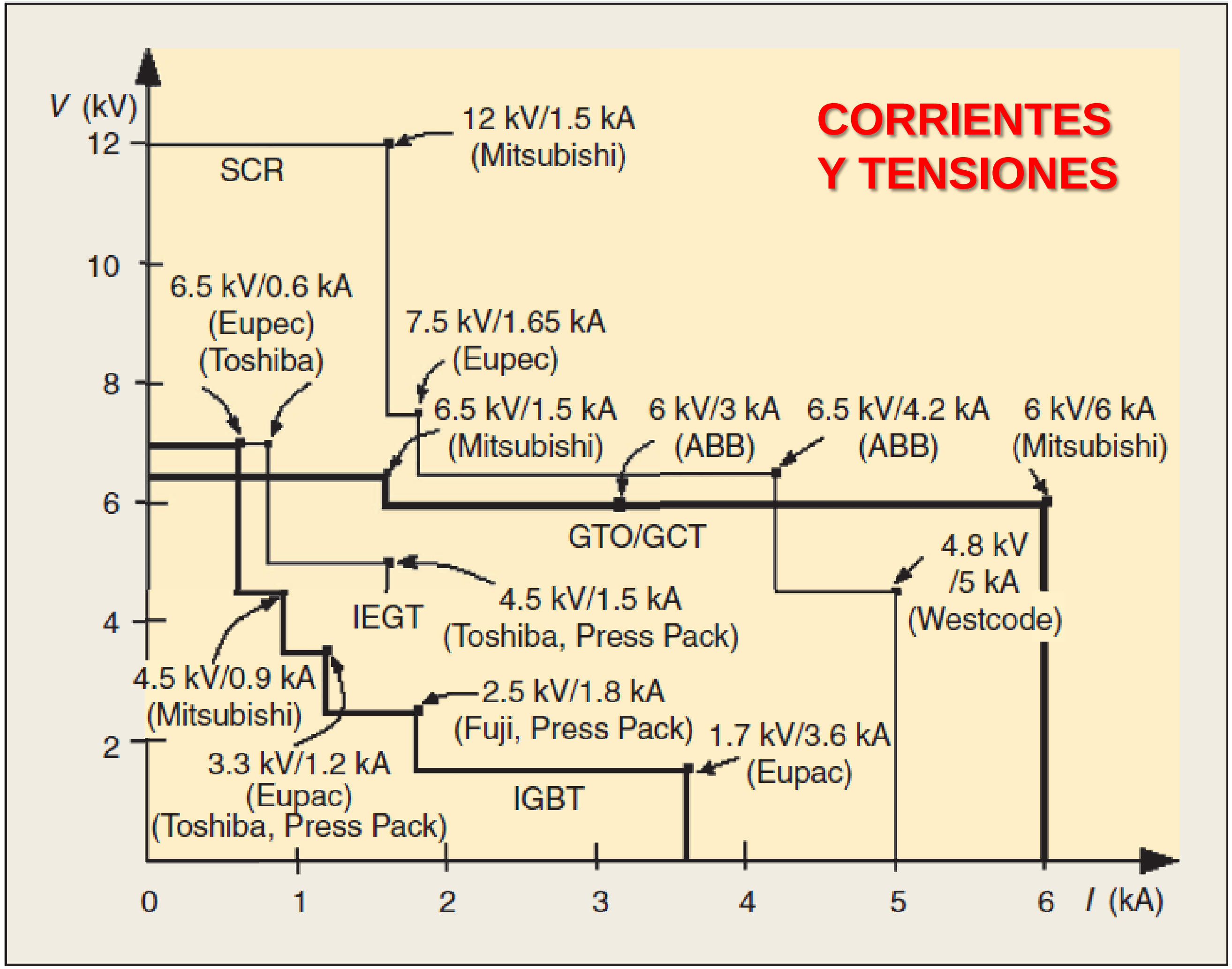
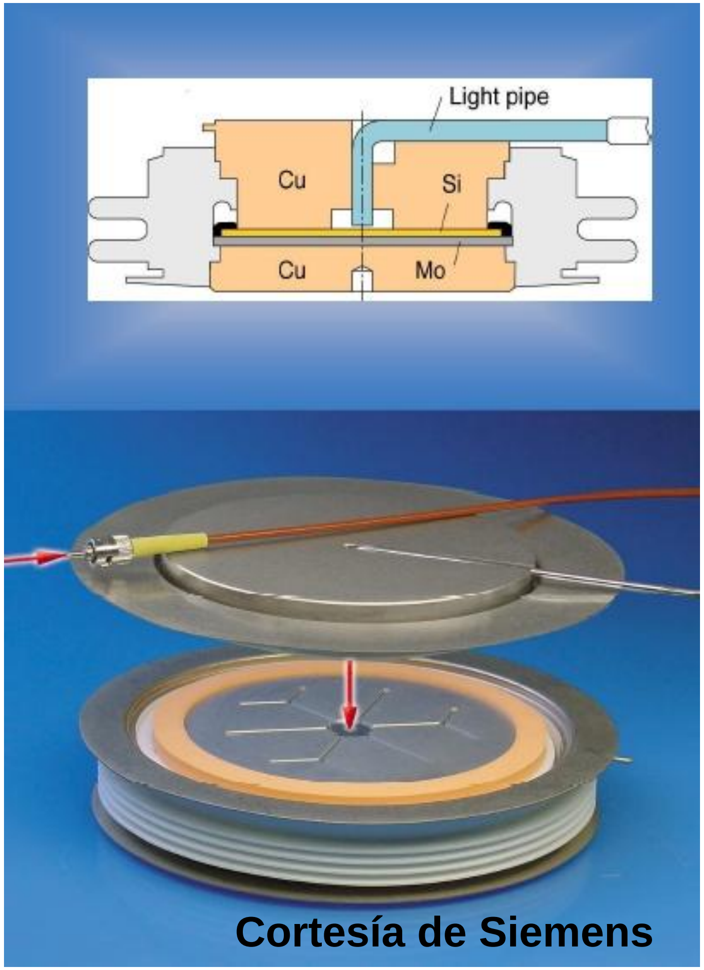


FIGURE 5 – Voltage and current ratings of high-power semiconductor devices. Figure reprinted with permission from IEEE and John Wiley and Sons [7].

HIGH-POWER SILICON CONTROLLED RECTIFIER



Cortesía de Siemens

EL SCR ES EL COMPONENTE ELECTRÓNICO MAS ROBUSTO

High Reliability

- 80 % less Electronic Components
- Direct Laser Light-triggered Thyristor
- Wafer-integrated Overvoltage Protection
- Thyristor Blocking Voltage: 8 kV
- Thyristor Wafers:
  - 4" for currents up to 2,200 A
  - 5" for currents up to 3,700 A

SCR originally developed and marketed in 1958 by GE (General Electric) in the United States

HIGH-POWER SILICON CONTROLLED RECTIFIER

Puede verse en la gráfica anterior que el SCR mas potente en la actualidad (2011):

Mitsibishi: 12 KV y 1.5 kA

Turn-on time de 14 µs
Turn-off time de 1200 µS
On-state drop is about 4 V

it is the highest rated power device:
(especially with the light-triggered loads)

- Cycloconverter
- LCI-fed motor drives
- High-voltage dc systems
- Static volt–amperes reactive(VAR) compensators (SVCs)

HIGH-POWER SILICON CONTROLLED RECTIFIER

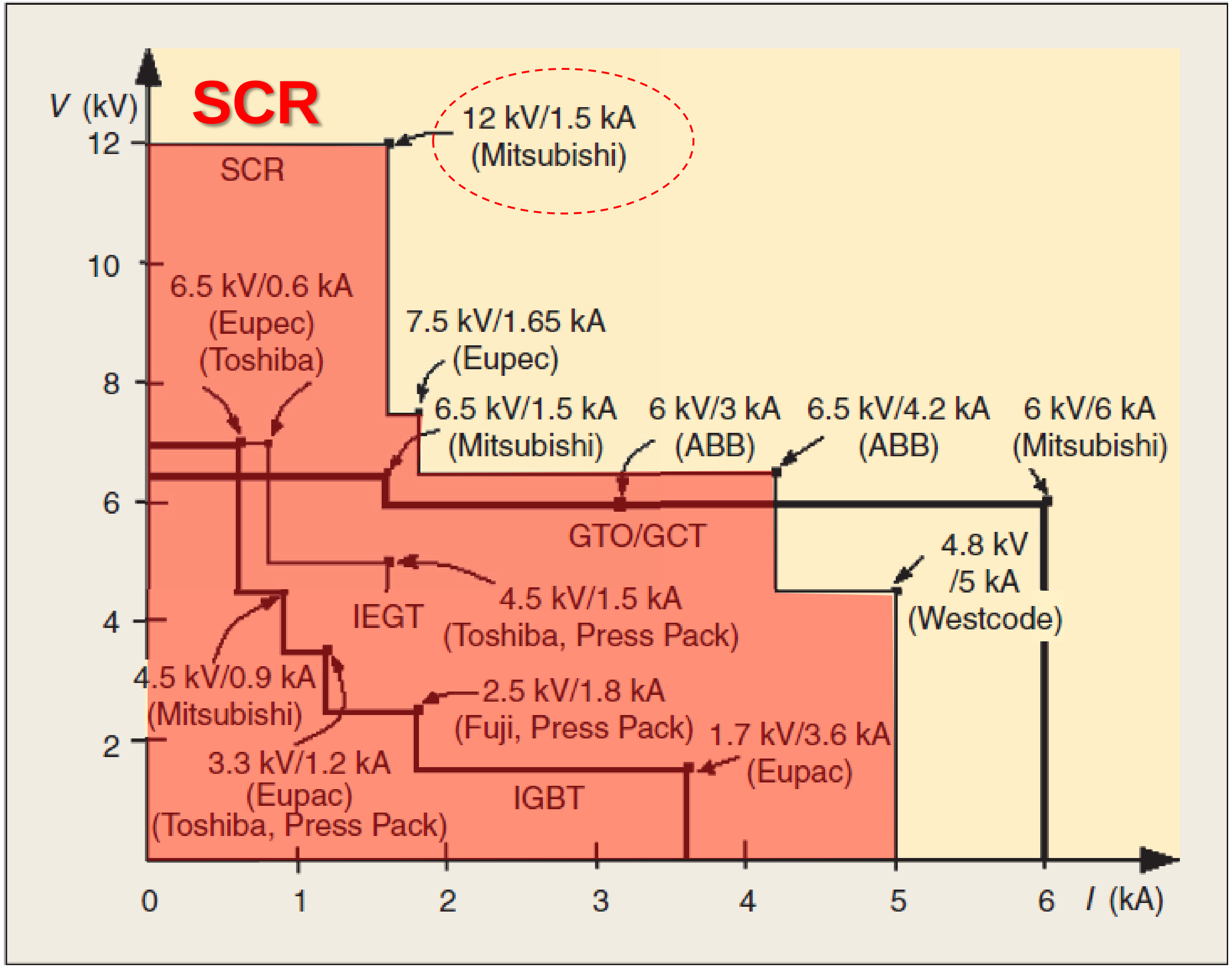


FIGURE 5 – Voltage and current ratings of high-power semiconductor devices. Figure reprinted with permission from IEEE and John Wiley and Sons [7].

HIGH-POWER GATE TURN-OFF THYRISTOR

The **GTO** is a self-commutated thyristor-based device that can be turned off by a negative gate current.

High-power GTOs that have been developed by the Japanese since the 1980s

Is turned on by a pulse of positive gate current and turned off by a negative gate current pulse.

The turn-off current gain is typically four to five:

¡¡ A GTO with a 6 KA anode current rating may require 1.5 KA gate current pulse to turn off !!

GTOs need bulky and expensive turn-off snubbers and complex gate driver

HIGH-POWER GATE TURN-OFF THYRISTOR

The typical turn-on time is 2.5 µS, and turn-off time is 25 µS.

The on-state voltage drop is typically 4.4 V.

GTO has low switching frequency capability

GTO converters operating in PWM (high-frequency) mode use energy recovery snubbers.

Energy recovery snubbers
Consisting of a capacitor, a diode, and a resistor
across each device in addition to a turn-on snubber

turn-on snubber
consisting of an anode
inductor in series with each device to reduce di/dt of the anode current.

HIGH-POWER GATE TURN-OFF THYRISTOR

TYPES OF GTO

Voltage Source Inverters (VSI) asymmetrical structures

Current Source Inverters (CSI) symmetrical structures

El GTO mas potente a día de hoy:

Mitsubishi 6 kV y 6 kA

HIGH-POWER GATE TURN-OFF THYRISTOR

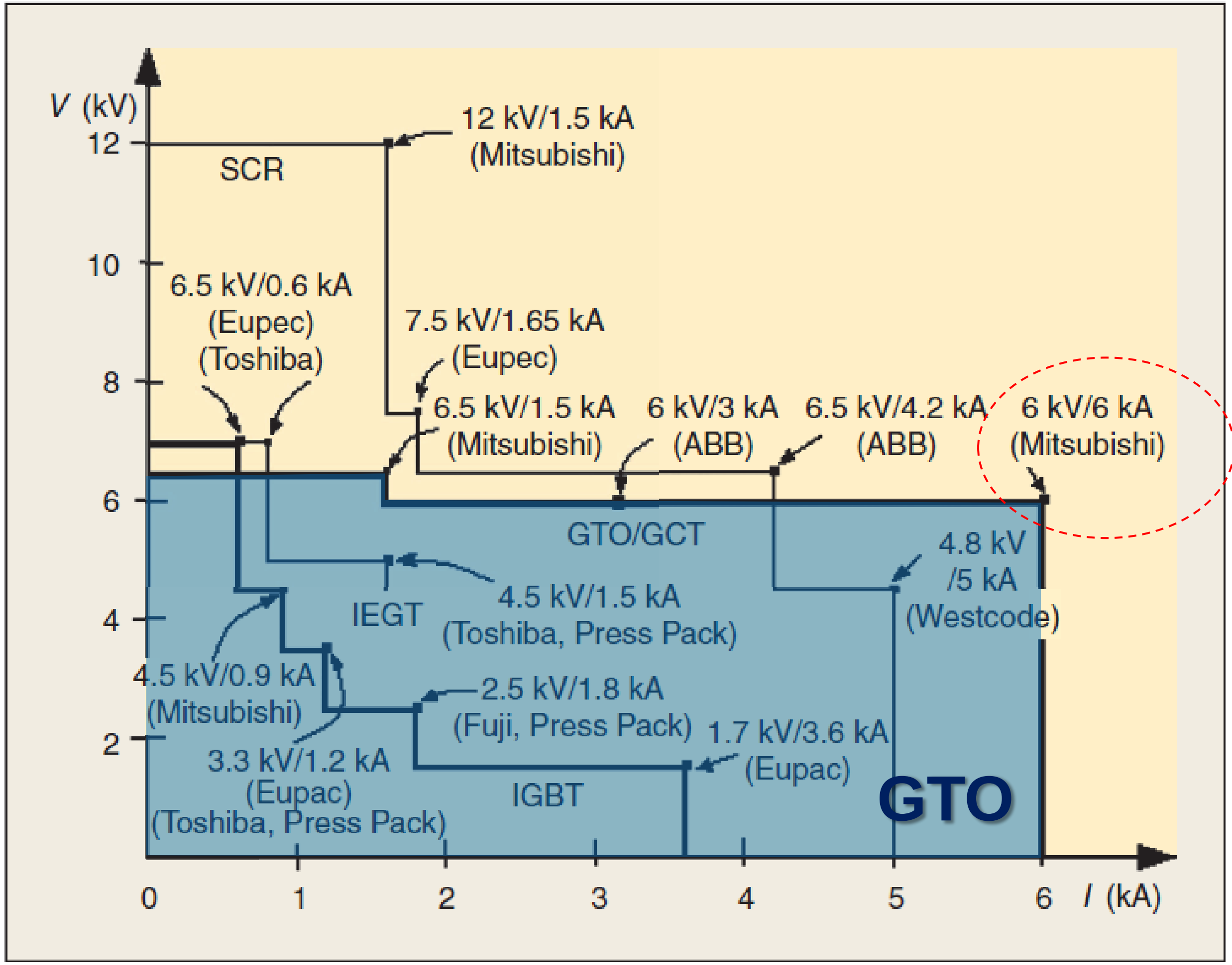


FIGURE 5 – Voltage and current ratings of high-power semiconductor devices. Figure reprinted with permission from IEEE and John Wiley and Sons [7].

INTEGRATED GATE-COMMUTATED THYRISTOR

IGCT

Cortesía de ABB

also known as **GCT**

It is a hard-driven GTO

(developed by ABB in 1996)

¡¡¡ A 6 KA (anode current) device is turned off by a 6 KA gate current !!!

<u>IMPORTANT ADVANTAGE:</u>

The current pulse should be very narrow with low energy for fast turn off.

INTEGRATED GATE-COMMUTATED THYRISTOR

ABB press-pack type
6.5-kV, 6-kA IGCT

Built-in integrated gate drive
circuit

GATE DRIVER:
Several MOSFETs in parallel
on the same module.

The IGCTs have replaced the GTOs for the medium voltage drives:

- snubberless operation
- Low switching loss

INTEGRATED GATE-COMMUTATED THYRISTOR

Snubberless operation:

It is possible because of the extremely low gate inductance

(typically <3 nH compared with <30 nH for GTOs)

Low switching Losses:

The rate of the gate current change at turn off is normally greater than 3 KA/μs compared with around 40 A/μs for GTO.

INTEGRATED GATE-COMMUTATED THYRISTOR

<u>Low switching Losses:</u>

The turn-on and turn-off times are much faster than those of the GTO.

IGCT does not require a **<u>turn-off snubber</u>**.

Requires a simple **<u>turn-on snubber</u>** or a clamping circuit, since the di/dt capability of the device at turn between on is around 1 KA/µs only.

INTEGRATED GATE-COMMUTATED THYRISTOR

On-state voltage: IGCT versus GTO

IGCT at 6 KA is 4 V

GTO at 6 KA is 4.4 V

IGCT is best

Switching Frequency:

Storage time of IGCT is reduced to one tenth compared with GTO

IGCTs have a higher switching frequency capability (typically 1.0 kHz) than GTOs (typically 0.5 kHz).

INTEGRATED GATE-COMMUTATED THYRISTOR

ABB

asymmetrical IGCT

Suitable for VSI

Mitsubishi

SGCT = symmetrical IGCT

Suitable for CSI

Smaller ratings

INTEGRATED GATE-COMMUTATED THYRISTOR

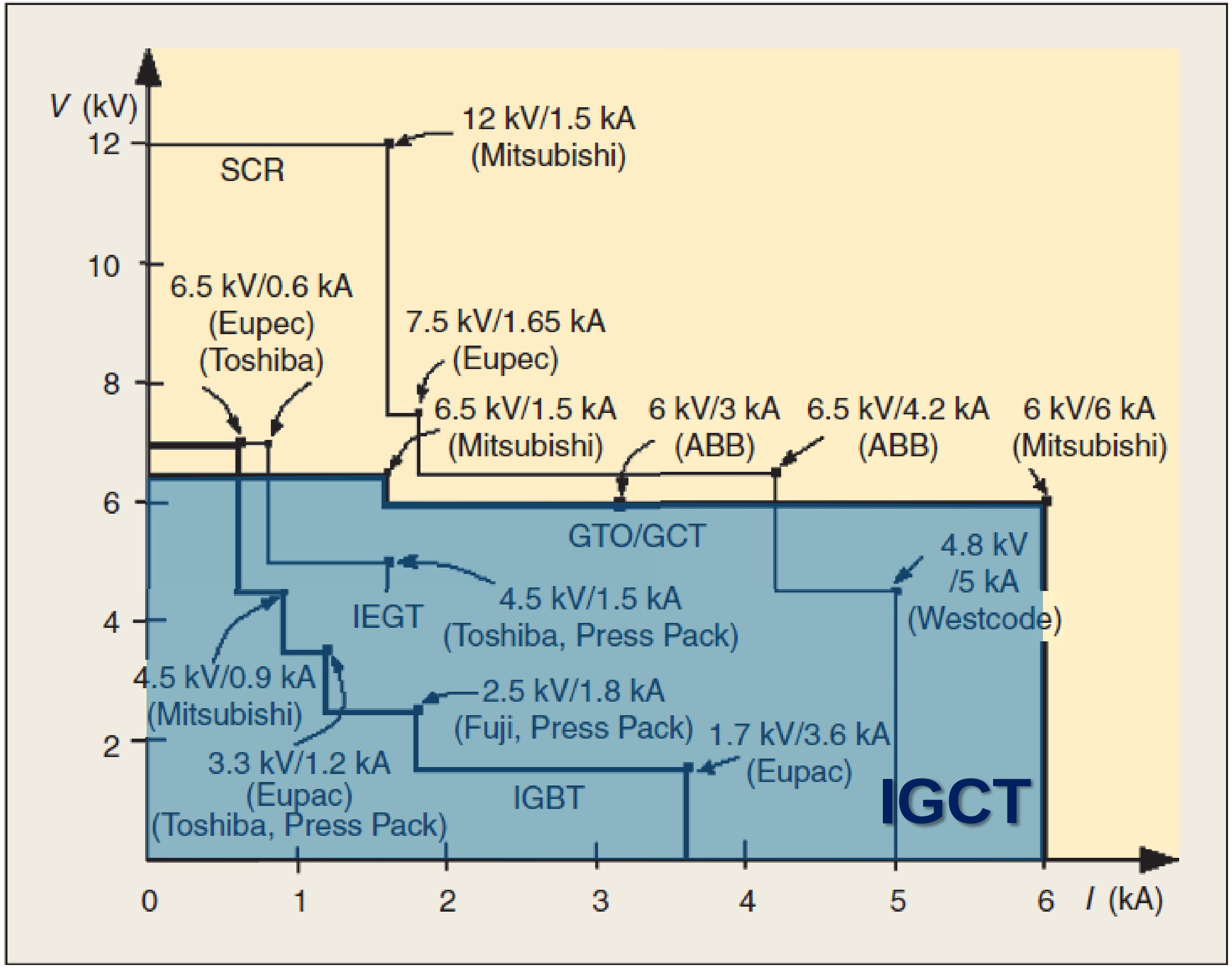
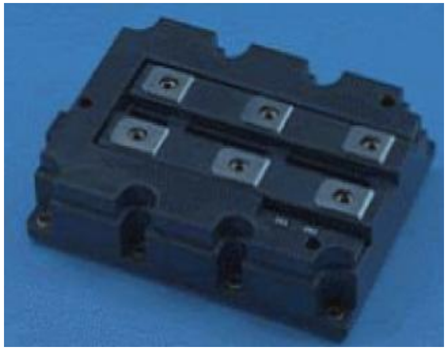


FIGURE 5 – Voltage and current ratings of high-power semiconductor devices. Figure reprinted with permission from IEEE and John Wiley and Sons [7].

INSULATED-GATE BIPOLAR TRANSISTOR



IGBT has been developed by General Electric in 1983

IGBTs are increasingly used for medium-voltage converters.

Combine the advantages:
MOSFET's high-gate circuit resistance

BJT (bipolar junction transistors) small collector–emitter drop at saturated condition.

Ratings:
6.5 kV with 0.6 kA
3.3 kV/4.5 kV with 1.2 kA.

The majority of high-power IGBTs are of modular design

INSULATED-GATE BIPOLAR TRANSISTOR

Advantages:

FAST: It can be turned on within 1 µS and turned off within 2 µS (high switching speed)

Simple gate driver

Snubberless

Modular design

Controllability of switching behavior providing reliable short-circuit protection.

INSULATED-GATE BIPOLAR TRANSISTOR

The device has only forward blocking capability

For VSI a feedback diode is needed.

Reverse-blocking IGBTs have recently become available.

High-voltage IGBTs (HVIGBTs)

High voltage drop = 4.3 V for a 3.3-kV, 1.2-kA

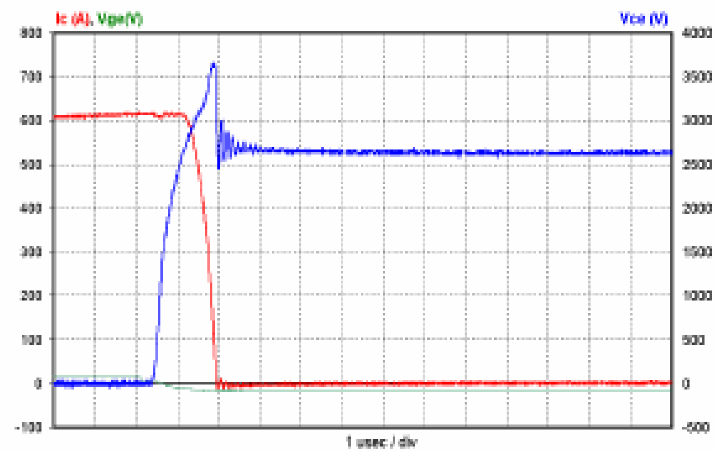
INSULATED-GATE BIPOLAR TRANSISTOR

Intelligent Power Modules
IPM and HVIPM devices

IGBT devices plus gate drivers and built-in protection features to provide lower size and cost, improved reliability, and fewer electromagnetic interference problems.

Medium voltage IGBT module

- IHV / HiPak Module (E1/E2)

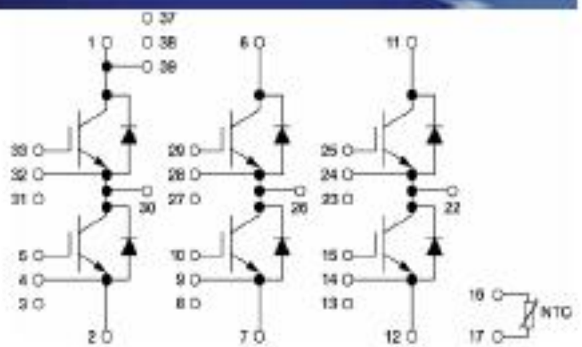


Turn off 3x rating current (3300V IGBT)

- 2500 V, 3300 V and 6500 V
  Maximum blocking voltage
- 1500 A, 1200 A, 600 A
  Maximum phase current
- Switching frequency (f_{PWM})
  - 3300 V: Typical 1..2 kHz
- Integration
  - Electrical insulation
  - Up to 2 devices (dual pack)
- Loss-optimized
  - Soft Punch Through or
  - Trench
- AlSiC base plate
  - Traction

Low voltage IGBT module

- Econopack /SKiiP/LoPak Module

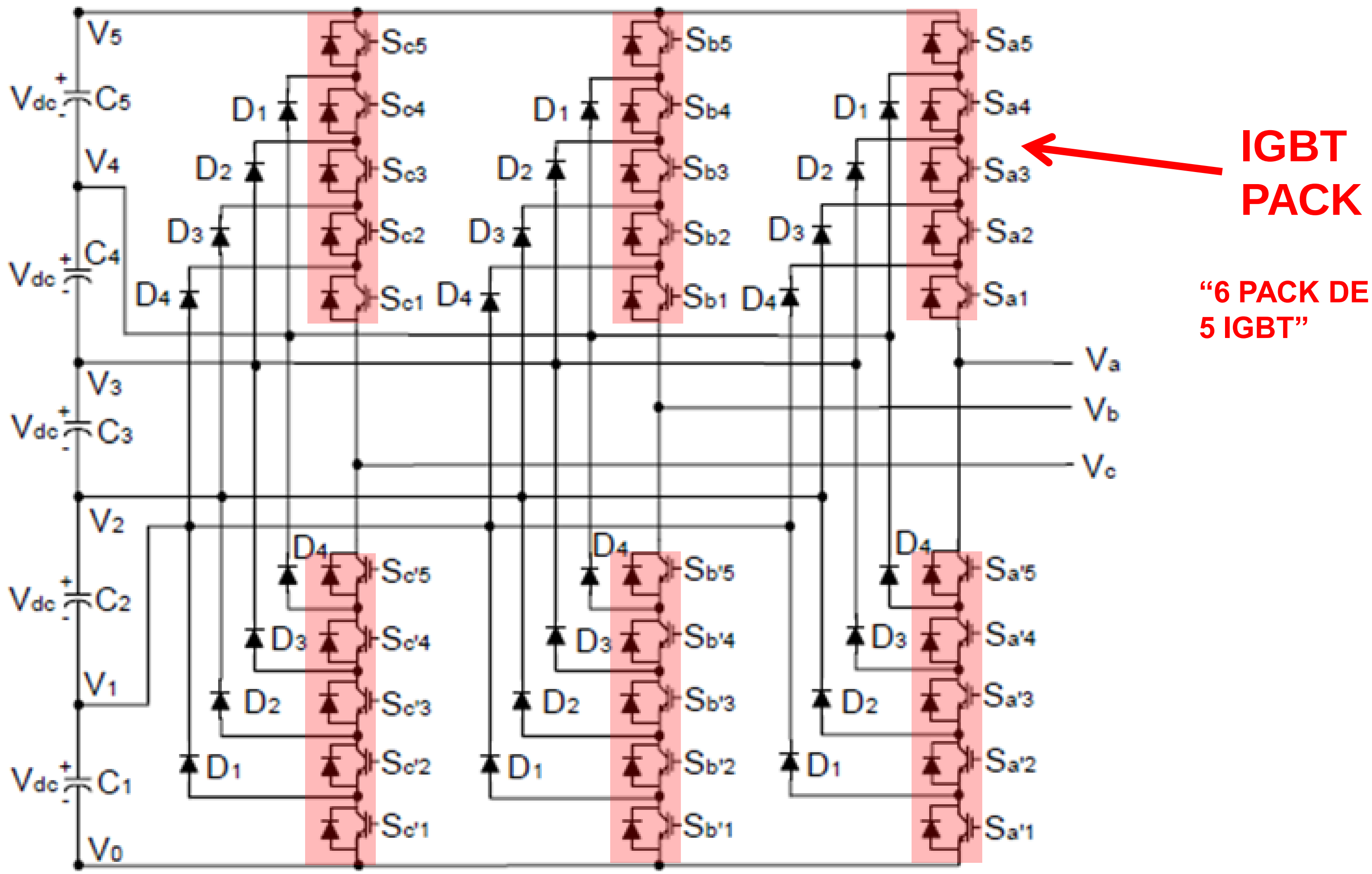


- 1200 V und 1700 V
  Maximum blocking voltage
- 75 – 450 A
  Maximum phase current
- Switching frequency (f_{PWM})
  - 1200 V: Typical 3..5 kHz
- Integration
  - Electrical insulation
  - Up to six switching devices
- Loss-optimized
  - Soft Punch Through or
  - Trench
- Copper base plate (EconoPack)
  - Limited in thermal cycles

ABB

INSULATED-GATE BIPOLAR TRANSISTOR

ELECTRÓNICA DE POTENCIA EN EL TRANSPORTE DE LA ENERGIA A TIERRA



INVERSOR MULTINIVELTRIFÁSICO DE SEIS NIVELES (BASADO EN IGBT)

INSULATED-GATE BIPOLAR TRANSISTOR

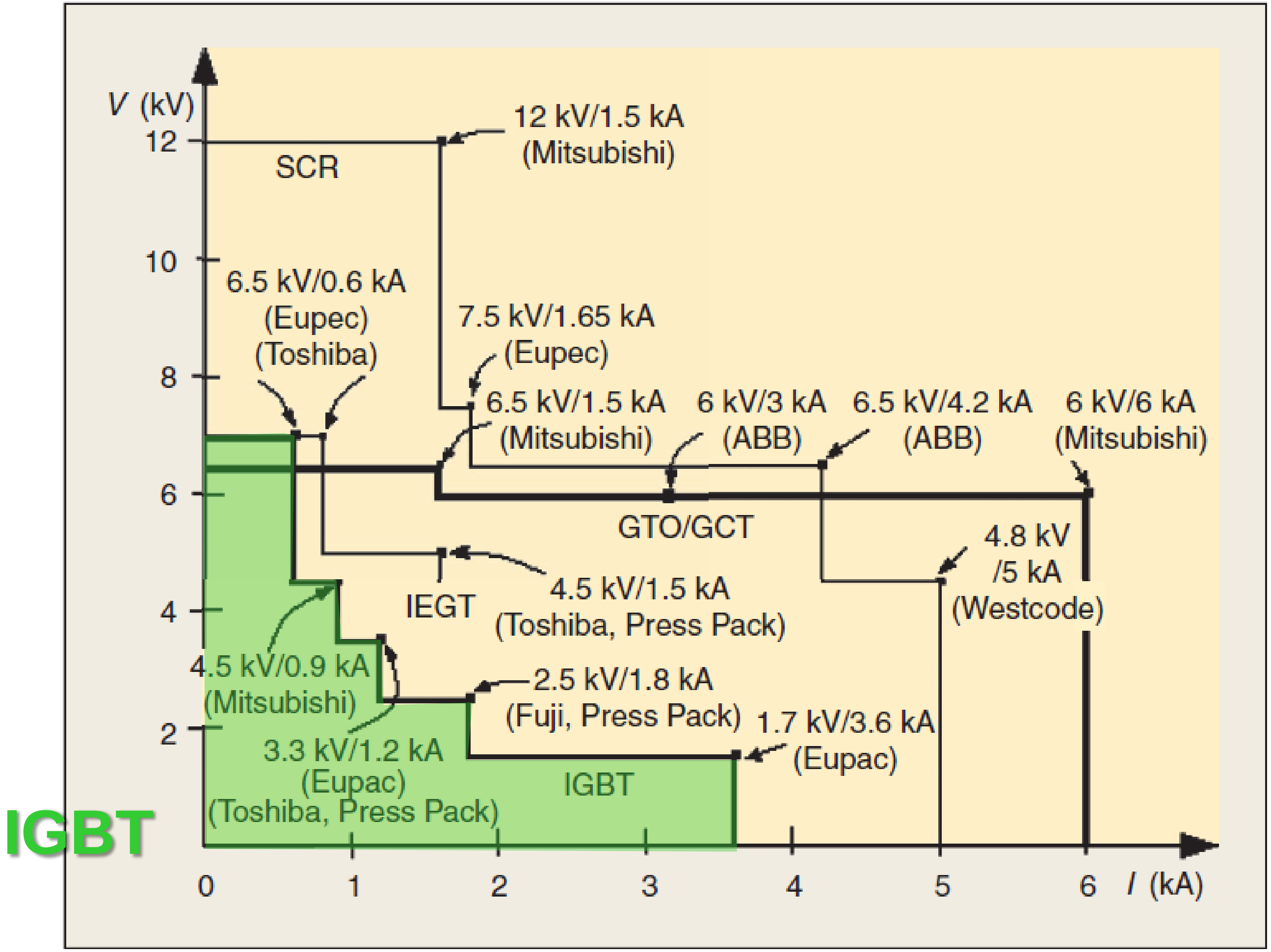
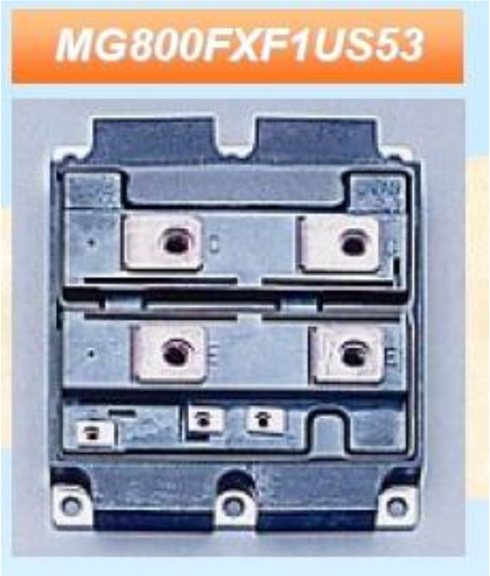


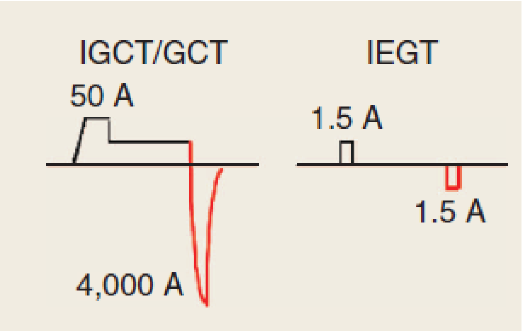
FIGURE 5 – Voltage and current ratings of high-power semiconductor devices. Figure reprinted with permission from IEEE and John Wiley and Sons [7].

INJECTION-ENHANCED GATE TRANSISTOR

IEGT is basically an advanced high voltage, high-power IGBT with special gate construction, commercially developed by Toshiba in 1999



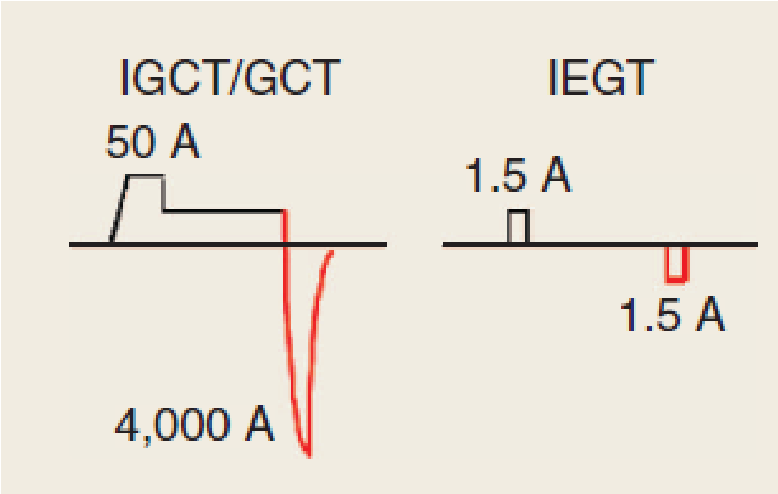
3.3 KV IEGT MODULE



INJECTION-ENHANCED GATE TRANSISTOR

It is designed in such a way that a large number of electrons accumulate at its electrodes, and it exhibits low on-state voltage (compared with IGBTs and GTOs of the same rating).

EASY GATE DRIVER
is less than 1/200 in gate power compared with that for GTO/IGCT



TWO MAIN ADVANTAGES:

1>>>IEGT has the potential to achieve higher output frequencies than the IGCT/GCT.

2>>>Another advantage over the IGCT is the power required to turn the device on and off

INJECTION-ENHANCED GATE TRANSISTOR

on-state voltage

It is designed in such a way that a large number of electrons accumulate at its electrodes, and it exhibits low on-state voltage.

The on-state voltage drop across this device is of the order of 3.0 V

much less than that of IGBT or GTO

NO SNUBBER REQUIRED

neither turn-on nor turn-off snubber is required for each IEGT

However, each IEGT leg needs simple and efficient clamp circuits to eliminate the snubbers.

INJECTION-ENHANCED GATE TRANSISTOR

YEAR 2000:

Toshiba supplied 8-MVA IEGT-based three-level inverter systems with an efficiency of 98.5%

2% more than that of an equivalent GTO based system

INJECTION-ENHANCED GATE TRANSISTOR

IEGT

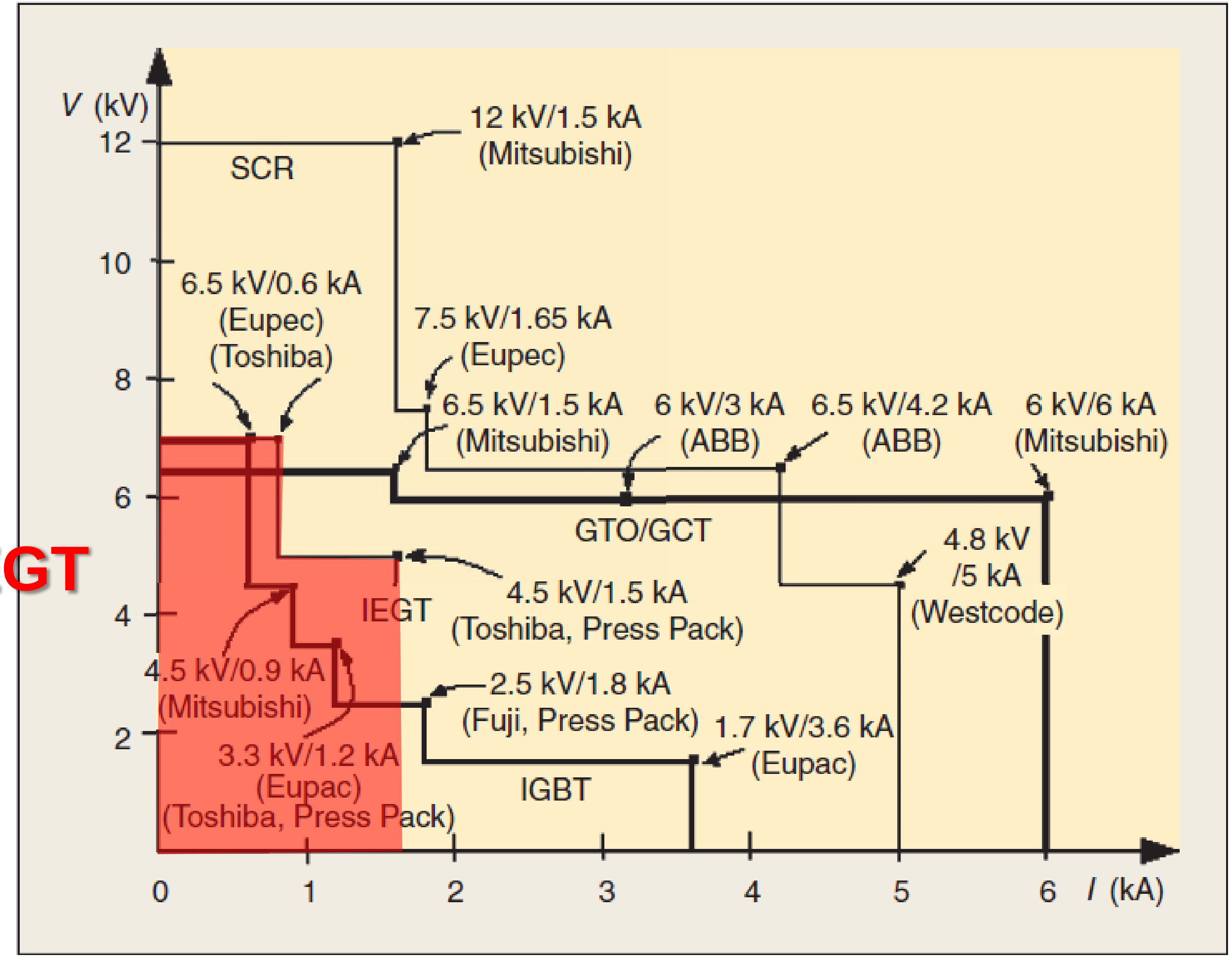
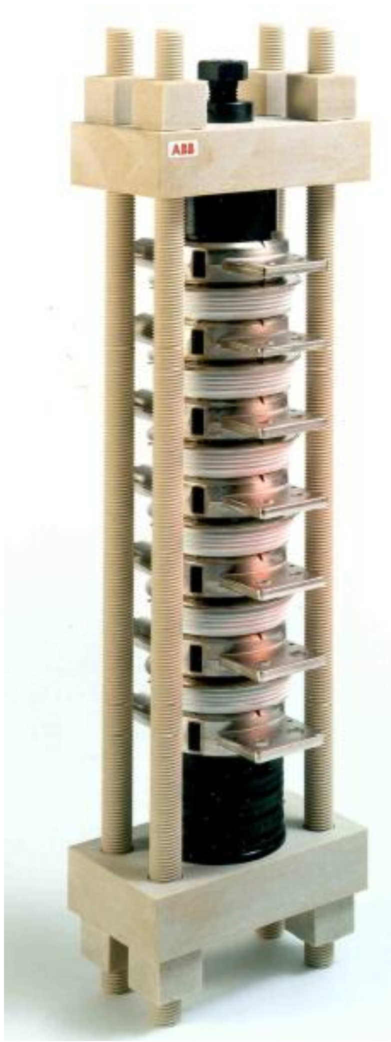
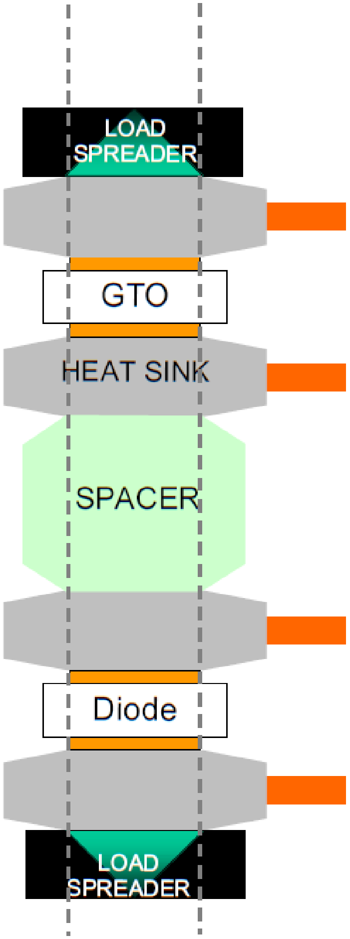


FIGURE 5 – Voltage and current ratings of high-power semiconductor devices. Figure reprinted with permission from IEEE and John Wiley and Sons [7].

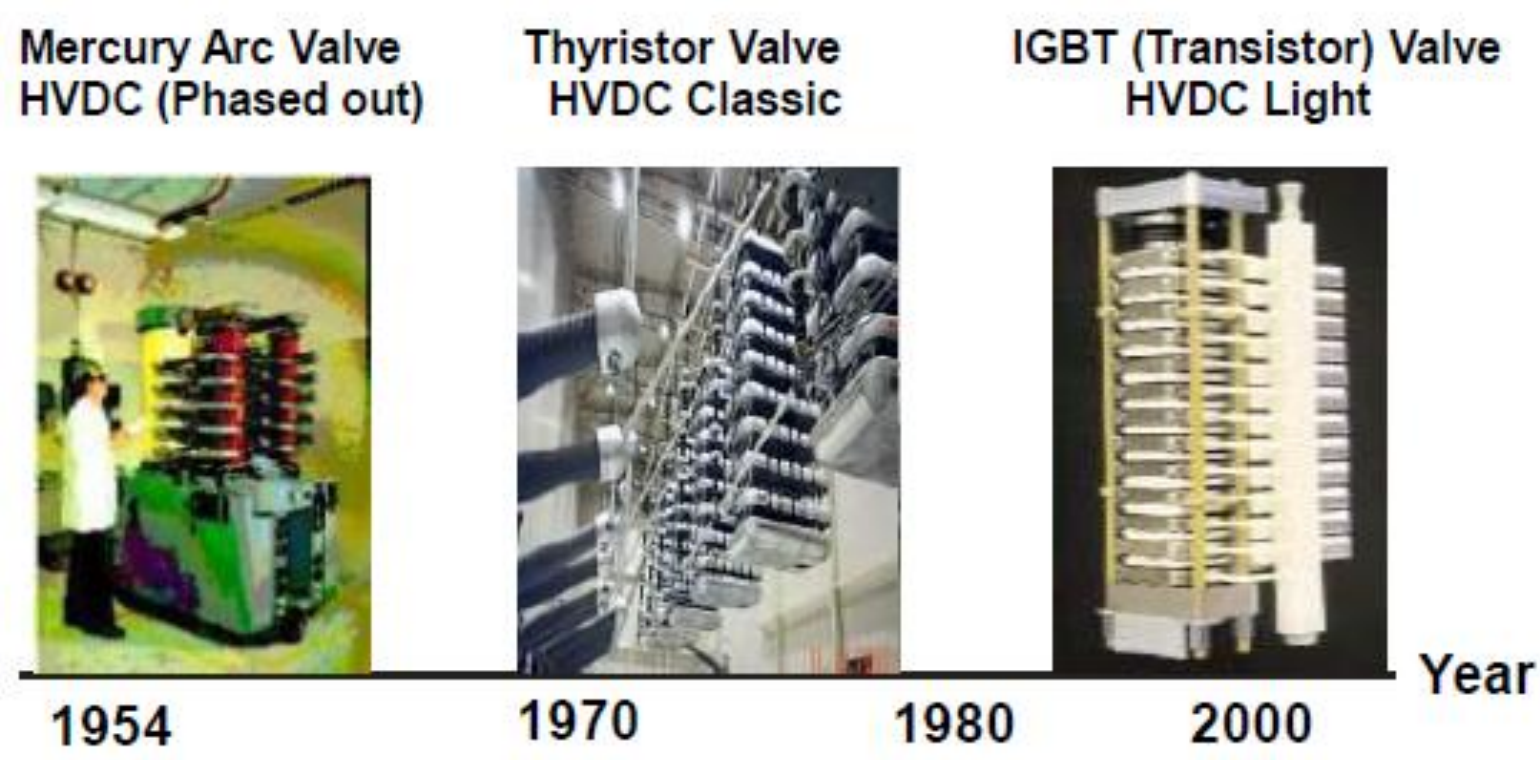




LA EVACUACIÓN DE CALOR ES MUY IMPORTANTE

Cortesía de ABB

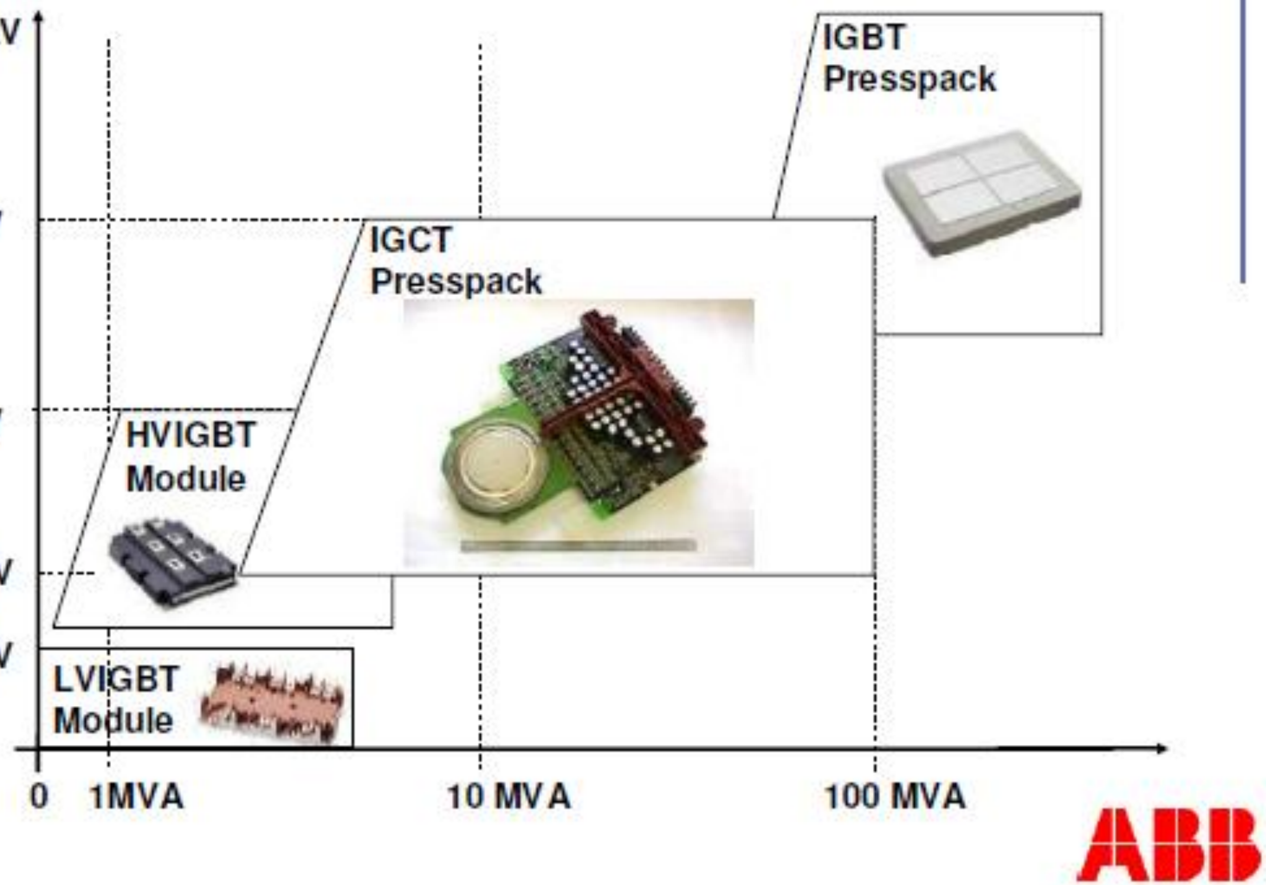
VAMOS MEJORANDO CON LOS AÑOS

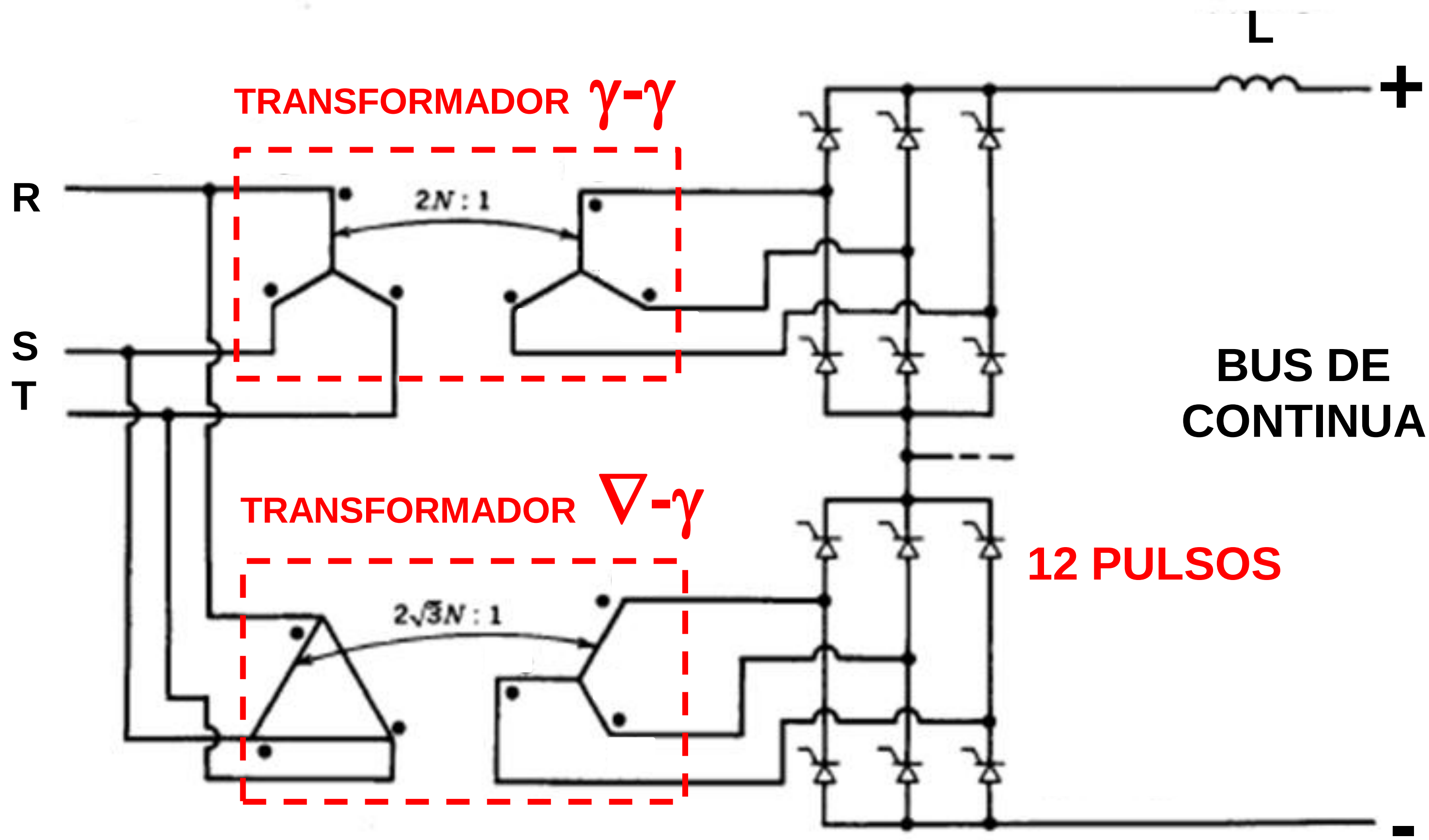


Turn-off Power semiconductors

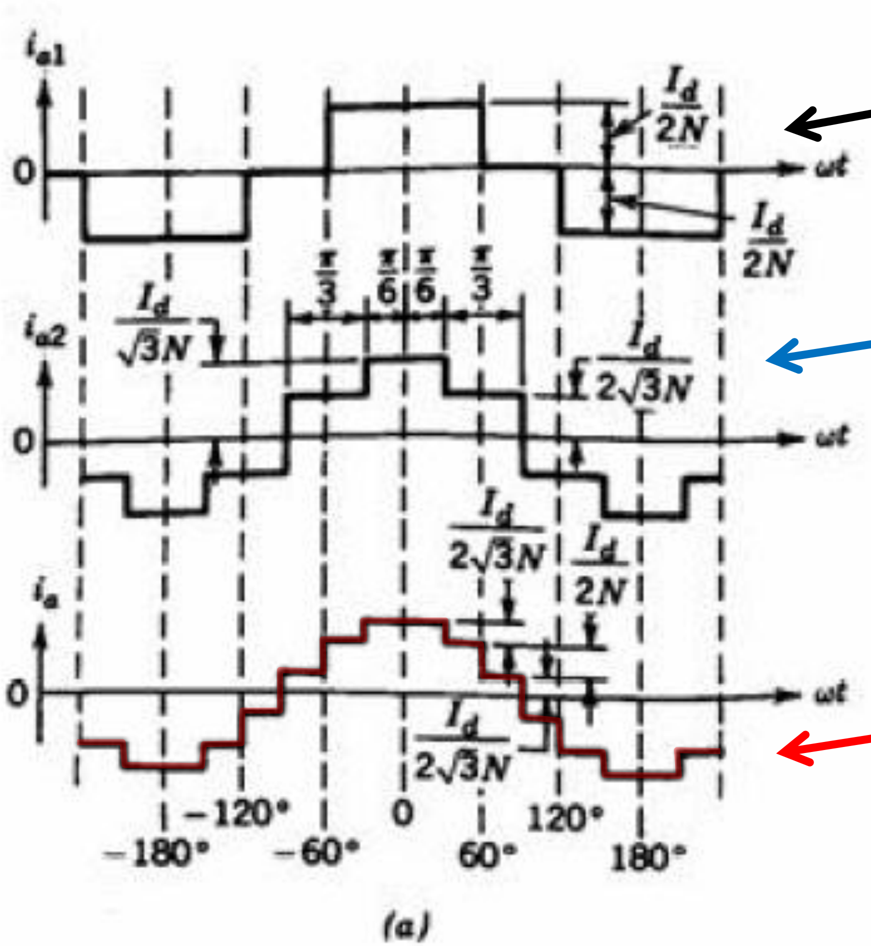
	 IGBT Modul	 IGCT Presspack	 IGBT Presspack
Application	LV & MV	MV (up to 15 kV)	MV & HV. (up to +/- 150kV)
Power	1 – 5 MW	**5 – 100 MW**	50 – 300 MW
Scalability	Parallel	Parallel & Series (with snubber)	Parallel & Series
Losses	Medium	Low	Medium
Costs / kVA	Low	**Low**	Medium
Failure type	Open (Plasma)	**Short-circuit**	Short-circuit
	LV drives **Traction** Power Quality	**MV drives** Interties FACTS	**HVDC light**

Turn-off power semiconductors





INTRODUCCIMOS TRANSFORMADORES PARA MEJORAR LA CORRIENTE EN LA RED



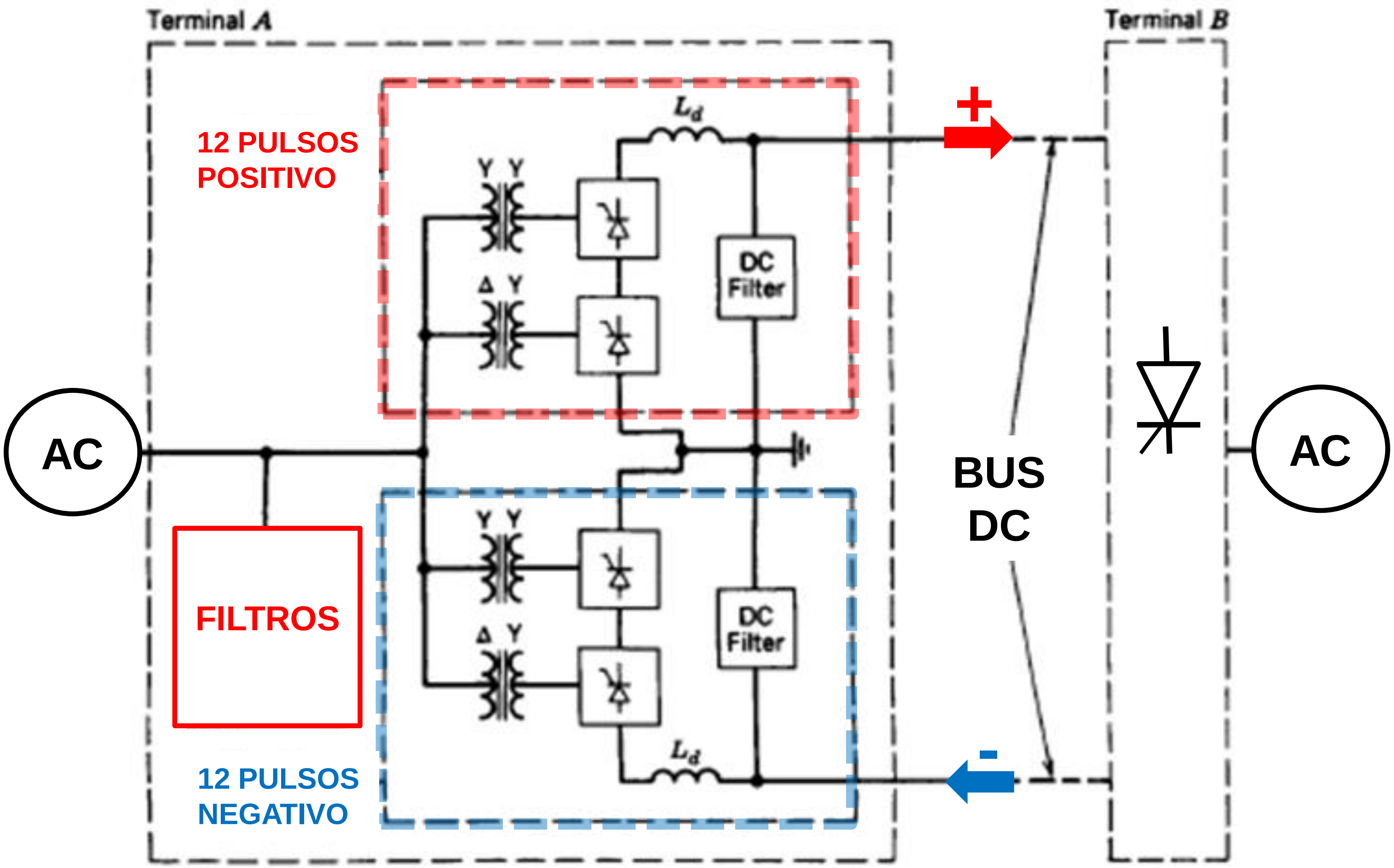
TRANSFORMADOR ESTRELLA-ESTRELLA

TRANSFORMADOR ESTRELLA-TRIANGULO

CORRIENTE DE LINEA CON 12 PULSOS

LA TRASMISIÓN HVDC TRADICIONAL (BASADA EN SCR)

ELECTRÓNICA DE POTENCIA EN EL TRANSPORTE DE LA ENERGIA A TIERRA

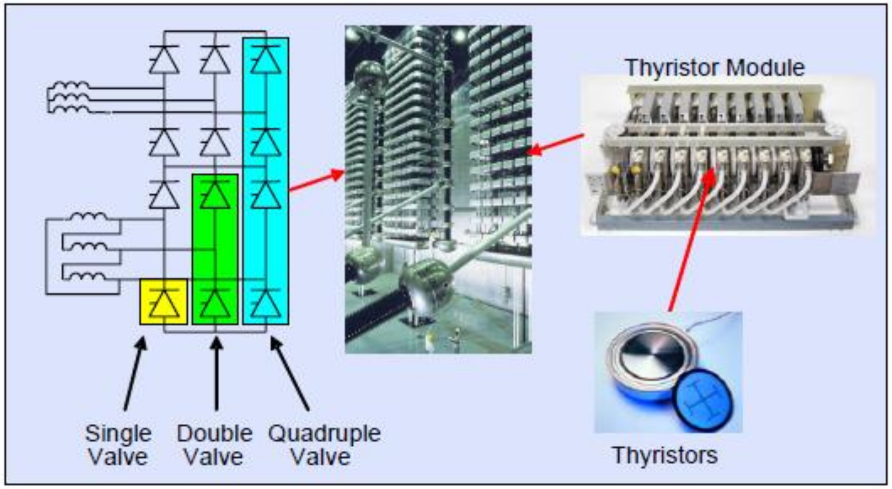


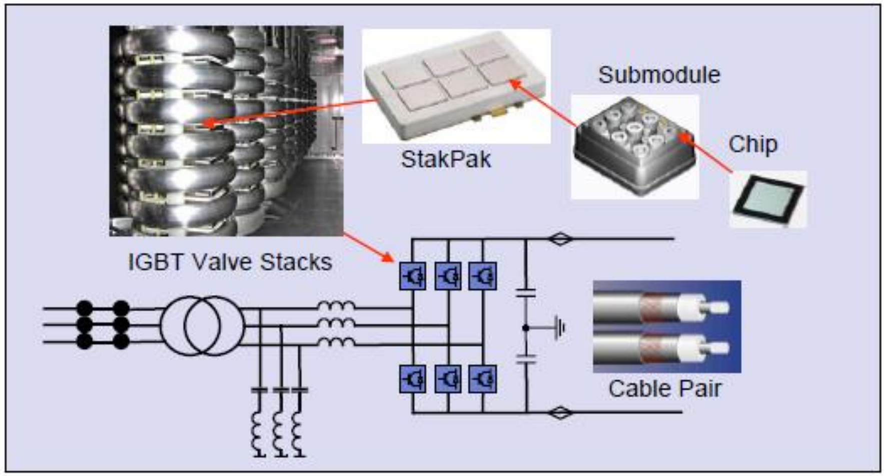
ESTRUCTURA TÍPICA: DOS DE 12 PULSOS Y FILTROS

Datos Principales:

- Tecnología LCC
- 250 km
- Dos polos +/- 250 kV
- 400 MW
- Cable de retorno 25 kV

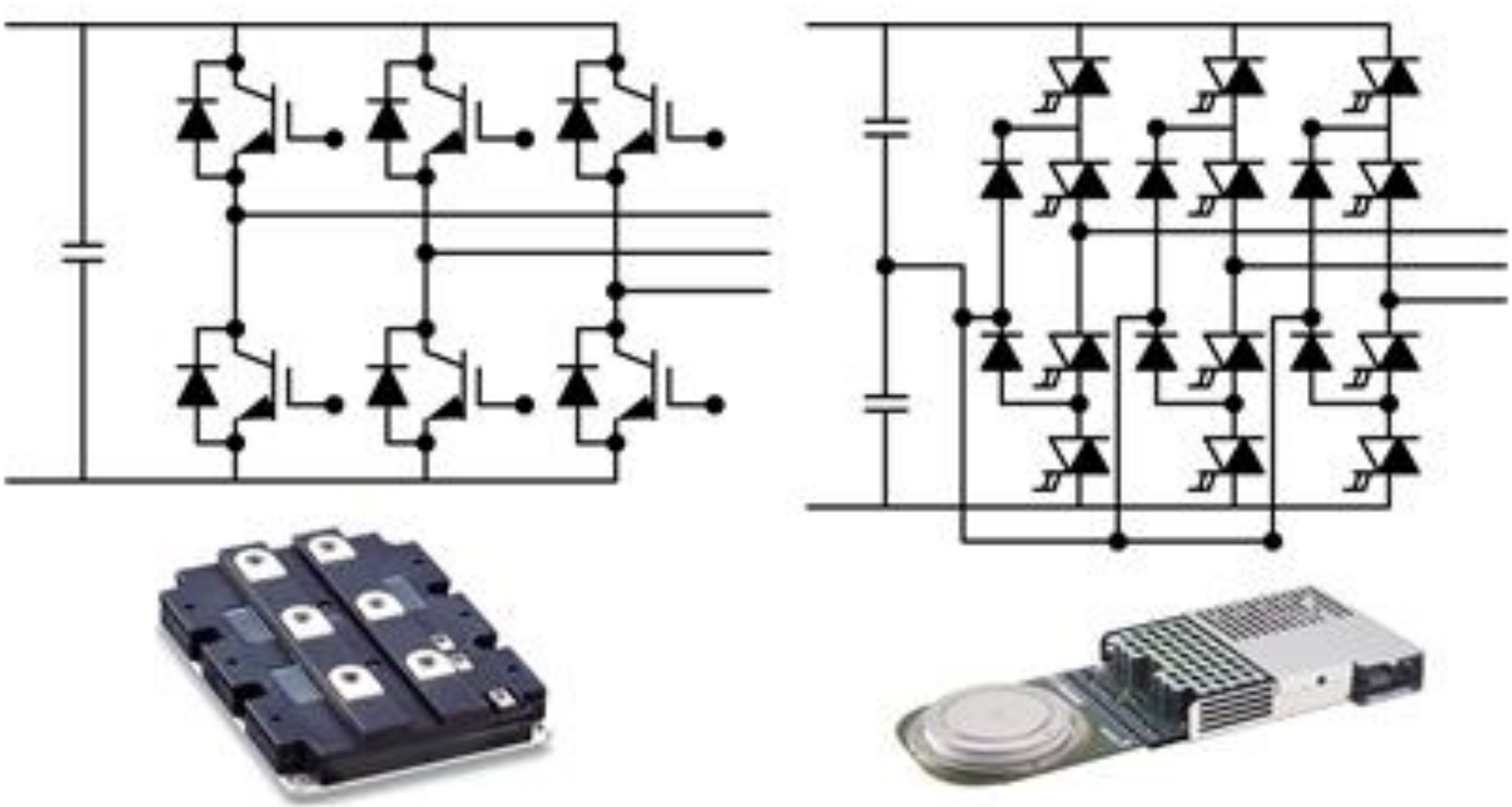
UN PROYECTO DE HVDC EN ESPAÑA
(PROYECTO RÓMULO – COMETA)
(ENLACE VALENCIA – MALLORCA)
Cortesía de Siemens





HVDC: SCR versus IGBT

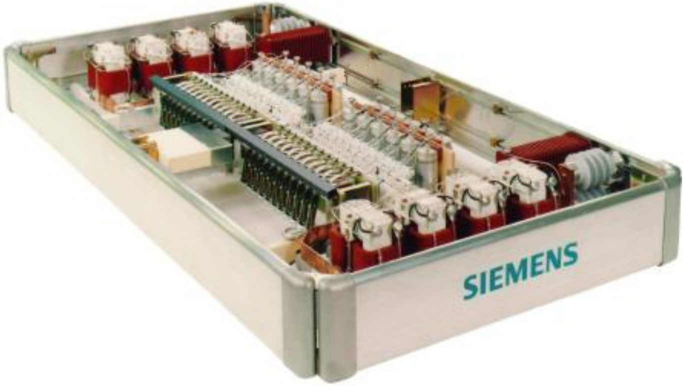
IGBT versus IGCT

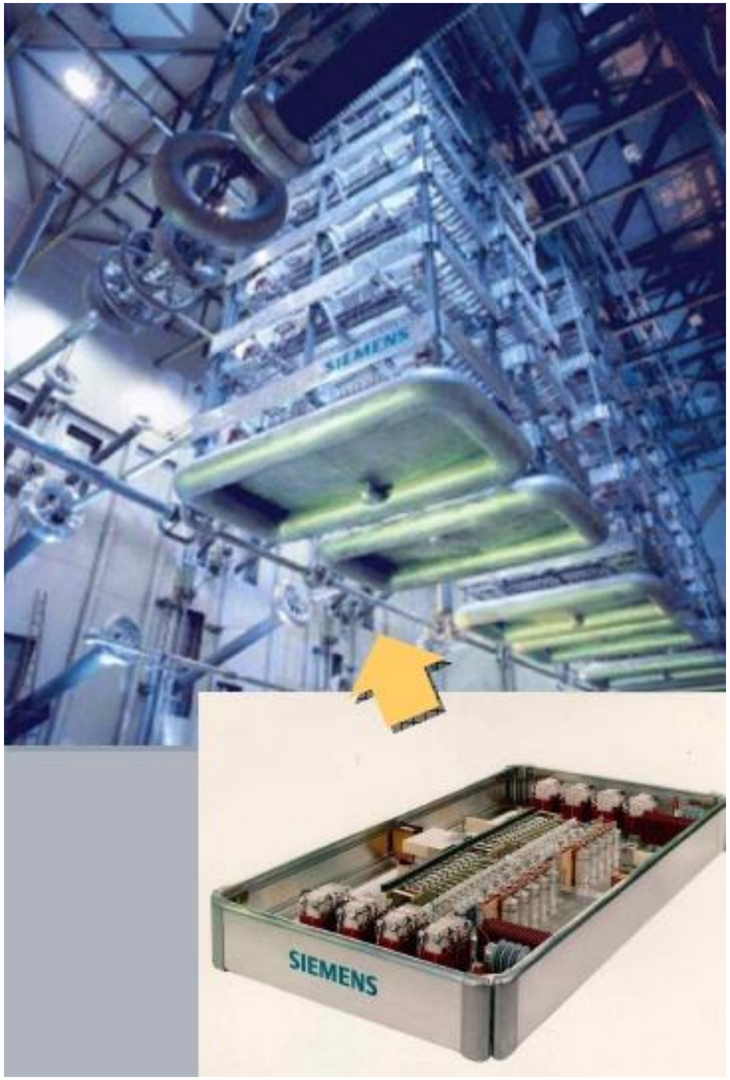


The 2 and 3 level topologies

LO CLÁSICO

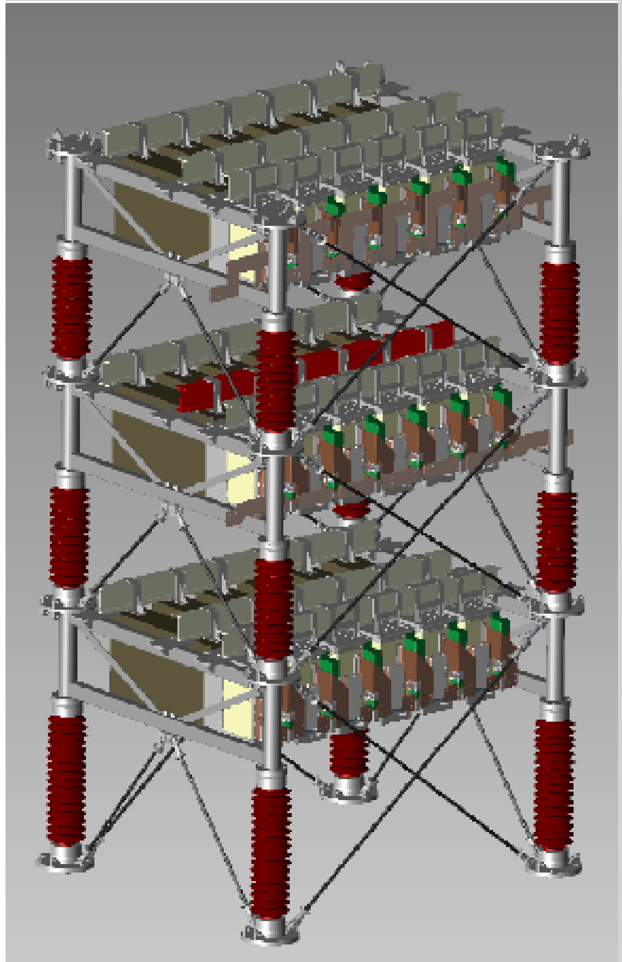
HVDC "Classic" (LCC) based on Thyristor Technology

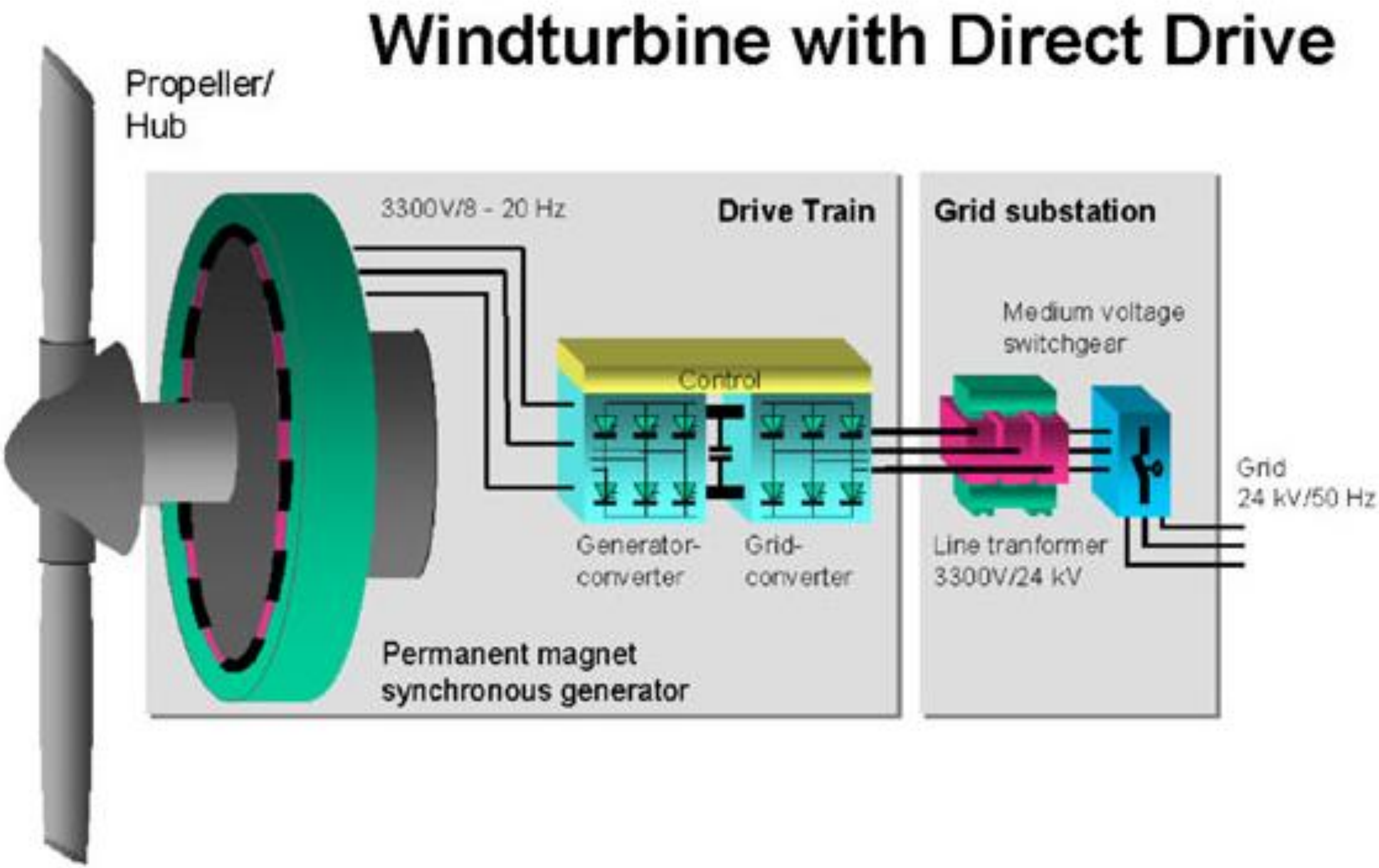




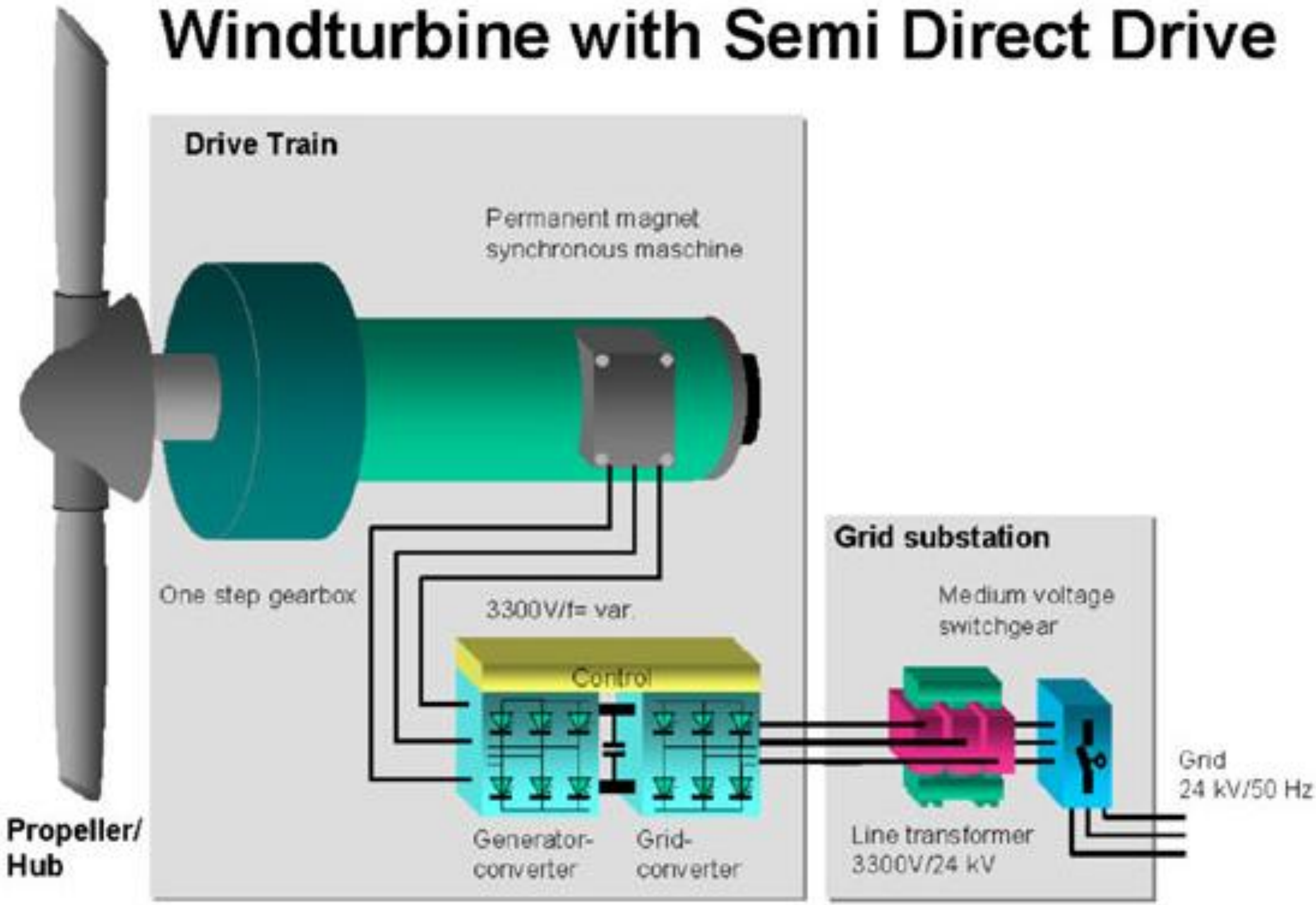
LO MODERNO

HVDC PLUS (VSC) based on IGBT Technology




Windturbine with Direct Drive
Propeller/
Hub
3300V/8 - 20 Hz
Drive Train
Grid substation
Medium voltage
switchgear
Control
Grid
24 kV/50 Hz
Generator-
converter
Grid-
converter
Line tranformer
3300V/24 kV
Permanent magnet
synchronous generator

Windturbine with Semi Direct Drive



CON IGBT

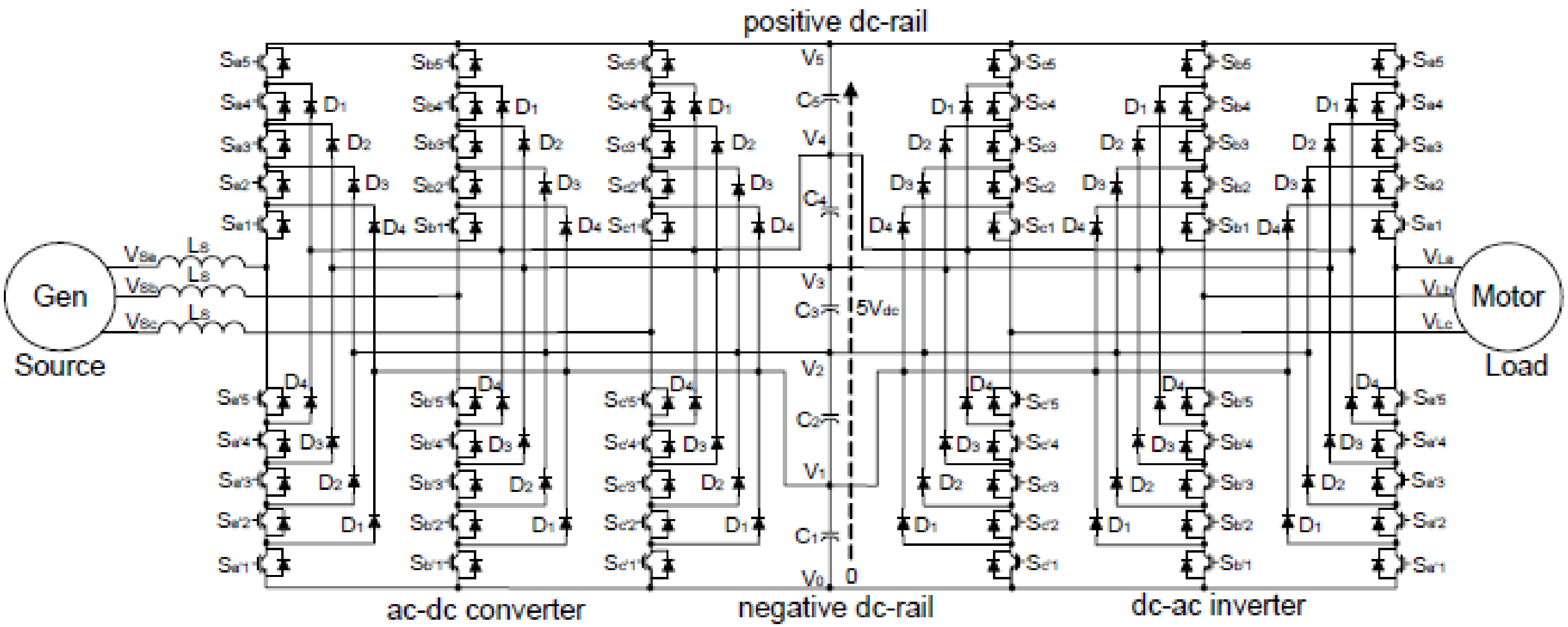


Figure 31.12. Six-level diode-clamped back-to-back converter structure.

CON IGCT

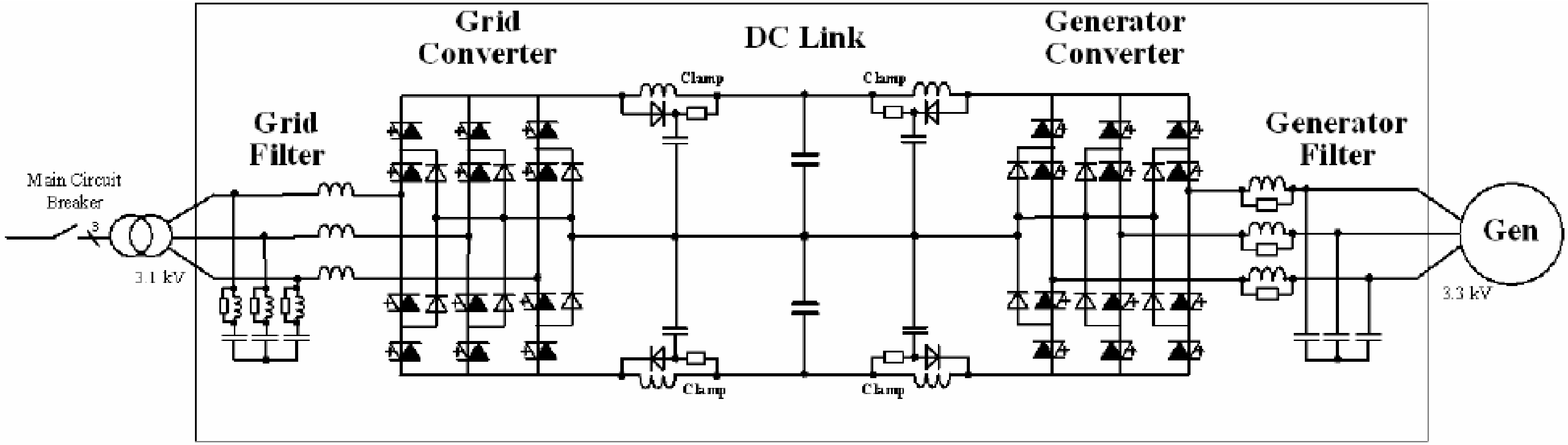
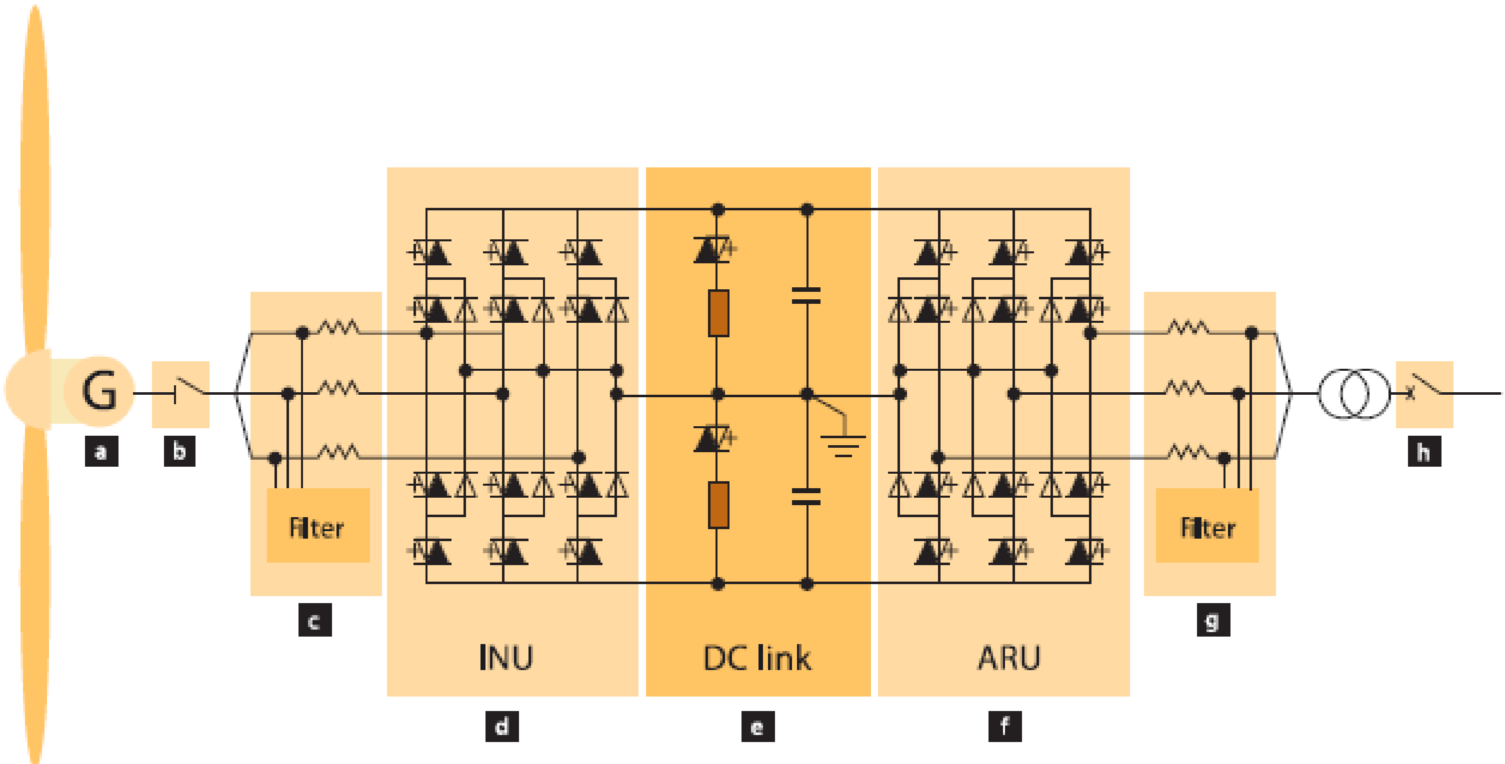


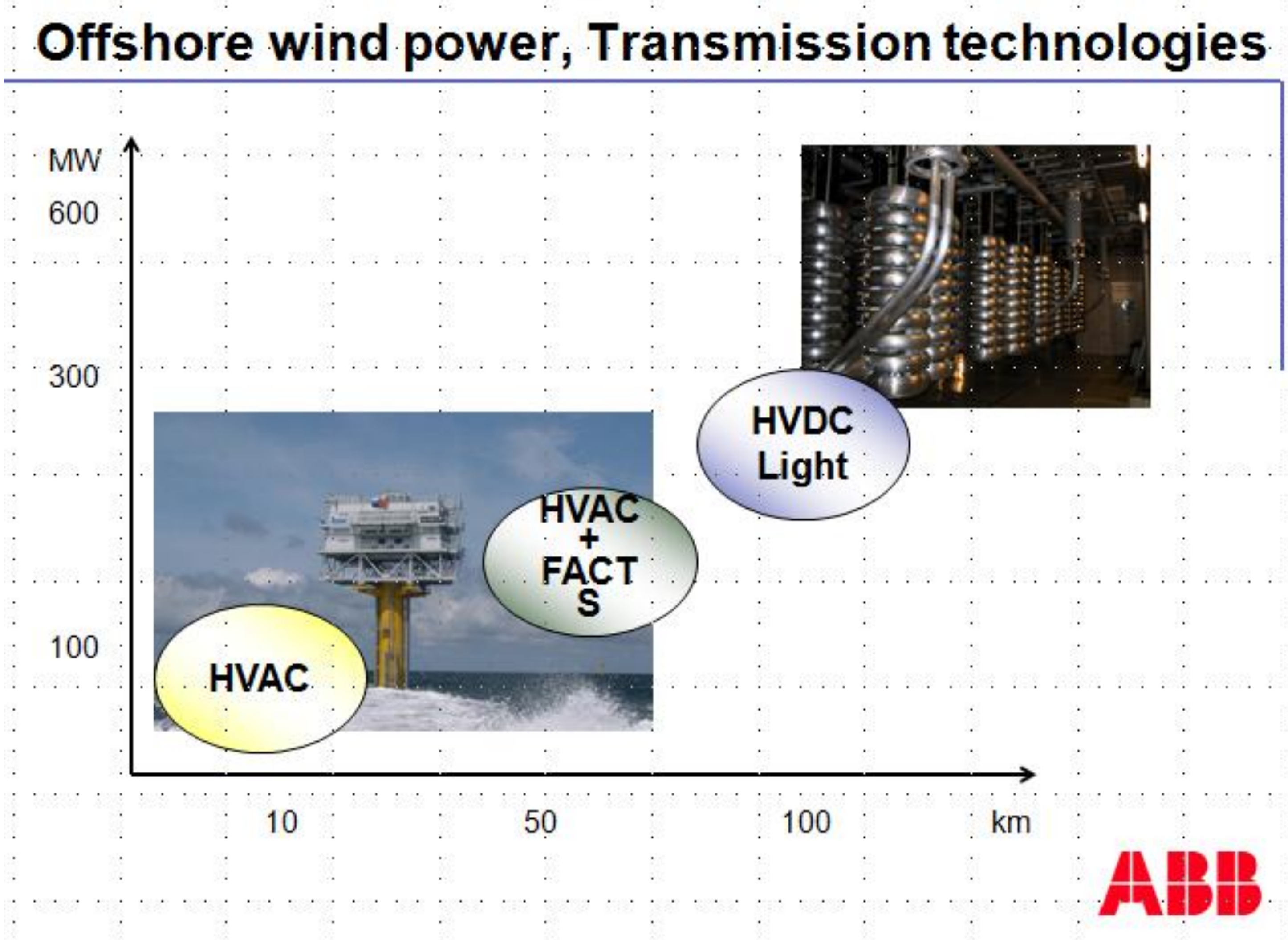
Figure 5: Basic circuit diagram of the 4-quadrant wind power converter

CON IGCT



- **a** Generator
- **b** Load breaker
- **c** dV/dt filter
- **d** Generator converter
- **e** DC link / brake chopper
- **f** Grid converter
- **g** Grid filter
- **h** Circuit breaker / transformer

¿COMO INFLUYE LA TECNOLOGÍA EN MAS POTENCIA Y MAS DISTANCIA?



TRACCIÓN ELÉCTRICA

GENERACIÓN, TRANSPORTE

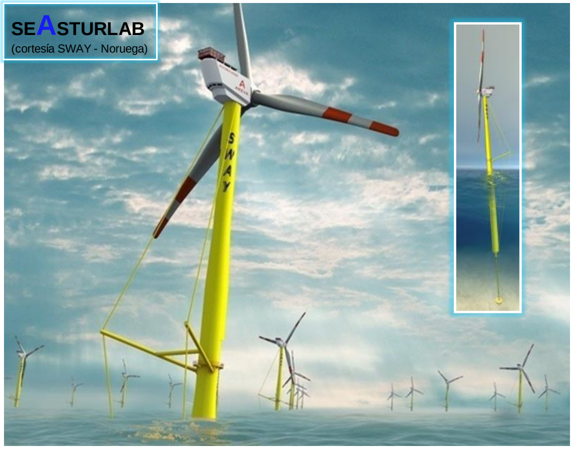
ALMACENAMIENTO DE ENERGÍA ELÉCTRICA

Potencia: 1 MW

AC 1.5 kV, 600 Hz

Potencia: 2,4 MW

AC 3 kV, 600 Hz



Potencia:1 MW – 5 MW

AC 132 kV, 50/60 Hz

DC ±250 KV