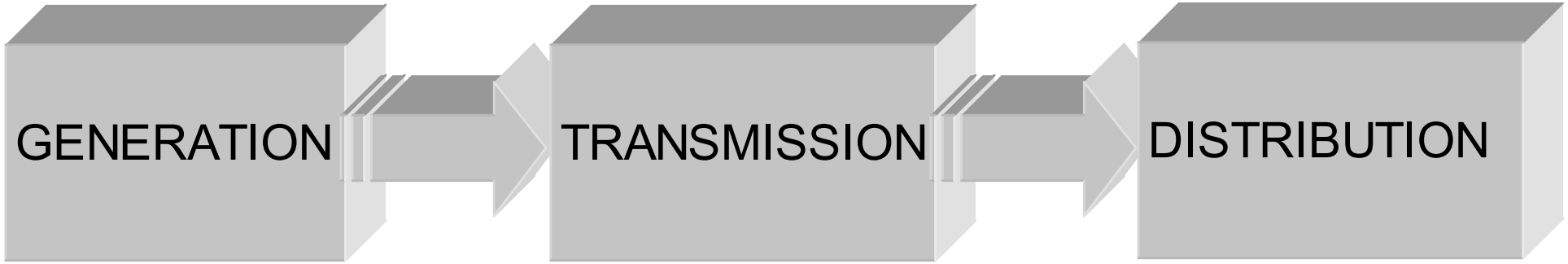
FACTS
Flexible AC Transmission System

Presented by:
Dr Ahmed Massoud

FACTS

1. POWER SYSTEMS
2. FACTS definition
3. FACTS controllers
4. Parallel controllers
5. Series controller
6. Series-parallel controllers
7. HVDC
8. Others

POWER SYSTEM



Characteristics of Transmission Bottlenecks

- **Steady-State Power Transfer Limit**
- **Voltage Stability Limit**
- **Transient Stability Limit**
- **Thermal Limit**
- **Short-Circuit Current Limit**

Conventional System Solutions to enhance Transmission capability

- **Series Capacitors (X)**
- **Switched Shunt-Capacitor and Reactor (V)**
- **Transformer LTC's (V)**
- **Phase Shifting Transformers (δ)**
- **Synchronous Condensers (V)**

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*F*lexible *A*lternating *C*urrent *T*ransmission *S*ystems (FACTS)

FACTS

AC transmission systems incorporating the power electronic-based to enhance controllability and increase power transfer capability.

FACTS Controllers

A power electronic based system & other static equipment that provide control of one or more AC transmission parameters.

Power Electronics Devices For FACTS Controllers

Line-Commutated

- **Thyristors**
- **Electrically Triggered (ETT)**
- **Light Triggered (LTT)**

Self-Commutated

- **Gate-Turn Off Thyristors (GTO)**
- **Insulated Gate Bipolar Transistors (IGBTs)**
- **Integrated Gate Commutated Thyristors (IGCTs)**

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FACTS controllers

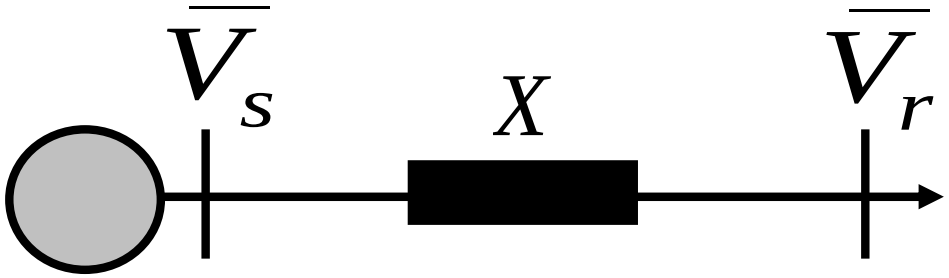
line commutated

Series	Shunt
thyristor controlled series capacitor (TCSC)	thyristor controlled reactor or switched capacitor (TCR or TSC)
Back-to-back conventional HVDC	**Series-series** interline power flow controller (IPFC)

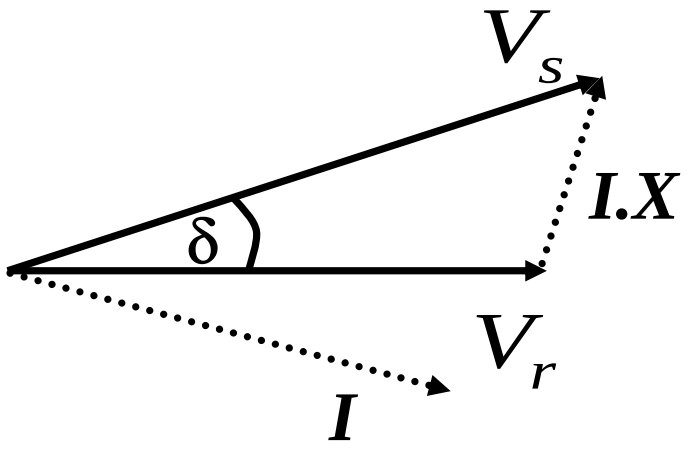
forced commutated

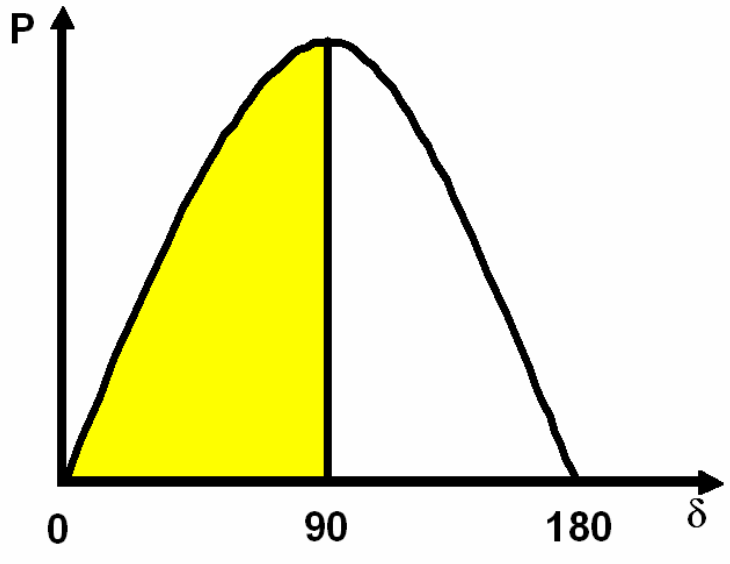
Series	Shunt
static synchronous series compensator (SSSC)	static synchronous compensator (STATCOM)
Shunt-Series unified power flow controller (UPFC)	**Series-series** interline power flow controller (IPFC)
Battery energy storage (BESS)	Superconducting Magnetic Energy Storage (SMES)

Back-to-back
light HVDC



$$P = \frac{V_s . V_r}{X} \sin \delta$$





Controllable parameters

Control of the line impedance

current and active power control

Control of angle

current and active power control

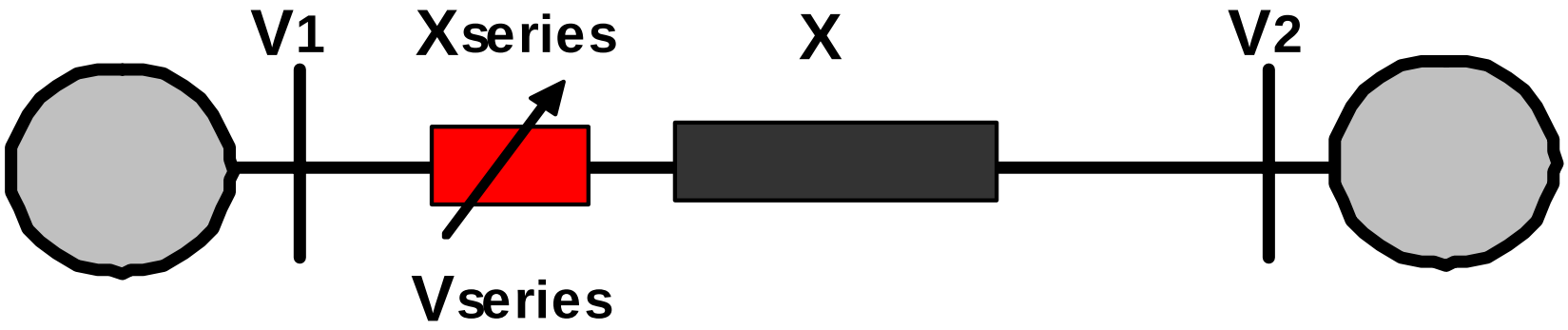
Series voltage injection

Current, active, and reactive power control

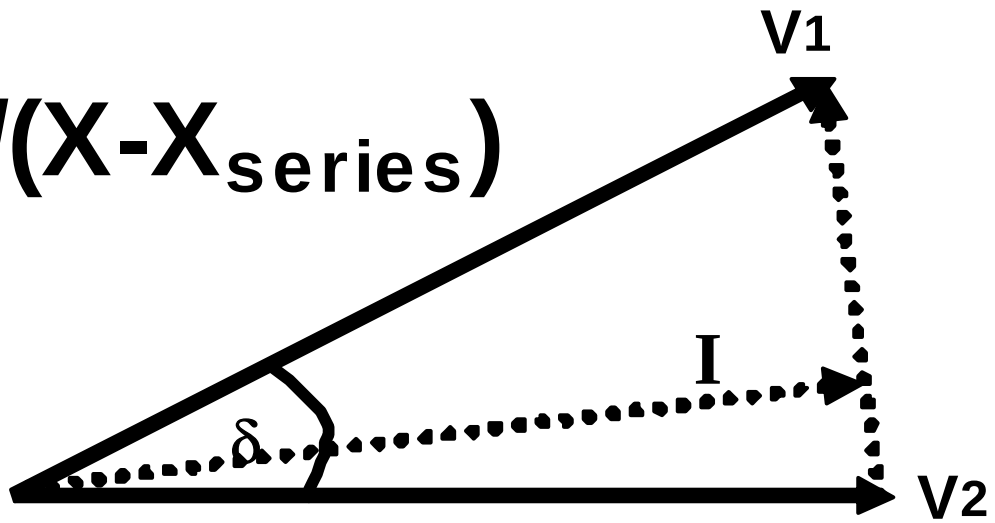
Parallel voltage injection

Current, active, and reactive power control

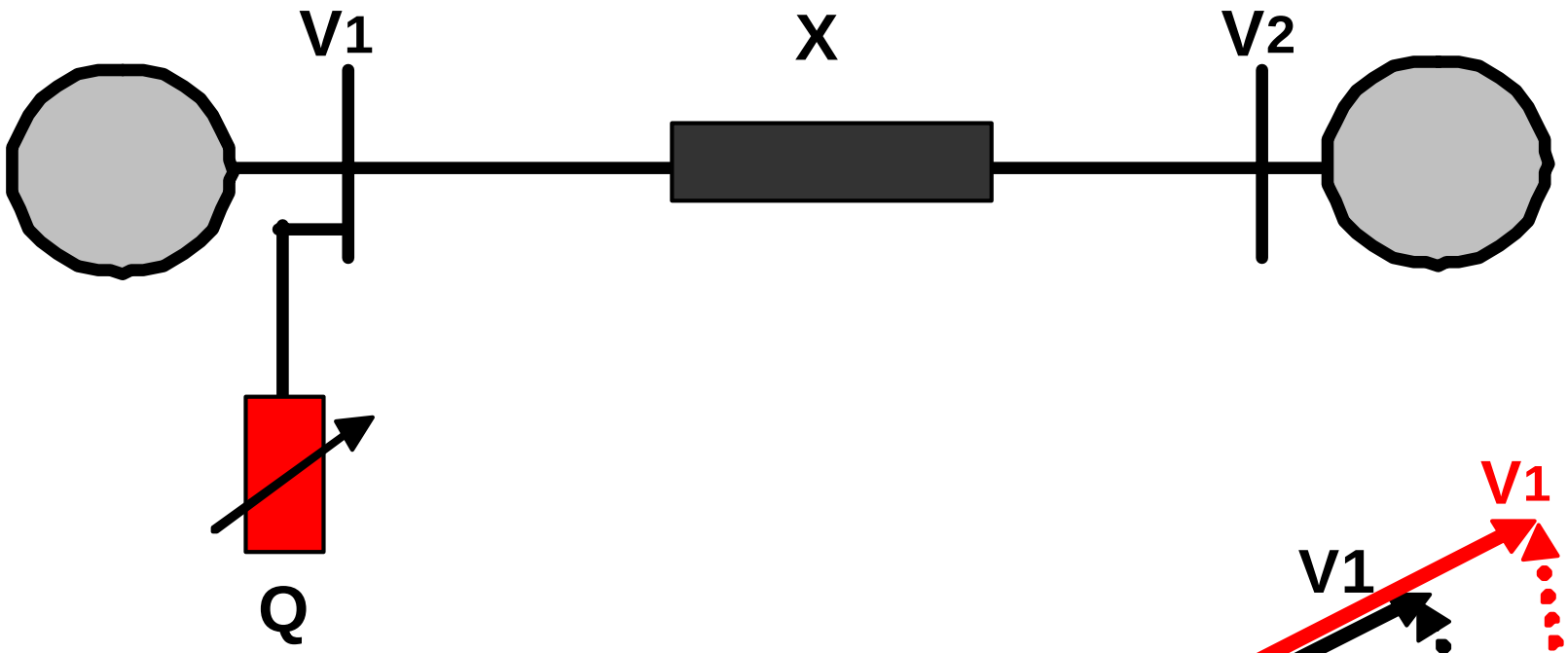
Series control



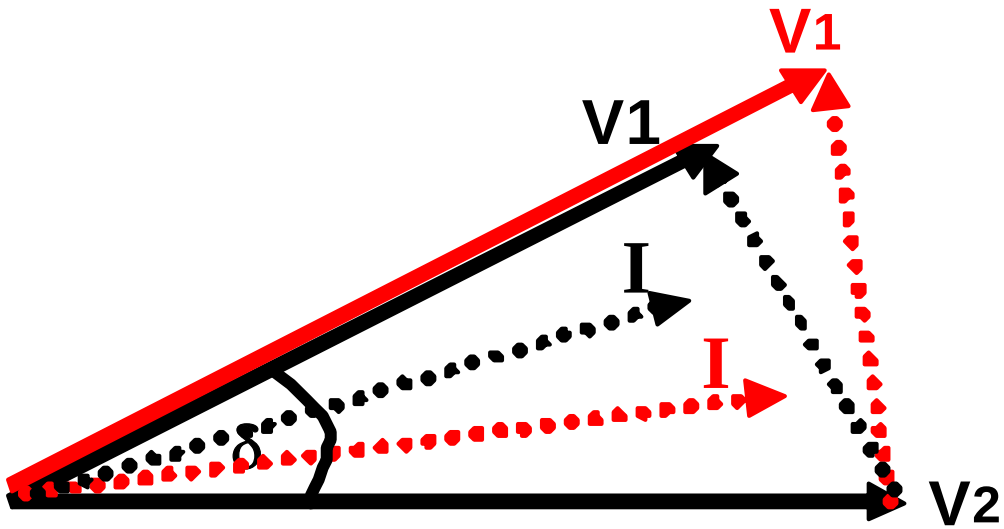
$$P = V_1 . V_2 . \sin(\delta) / (X - X_{series})$$



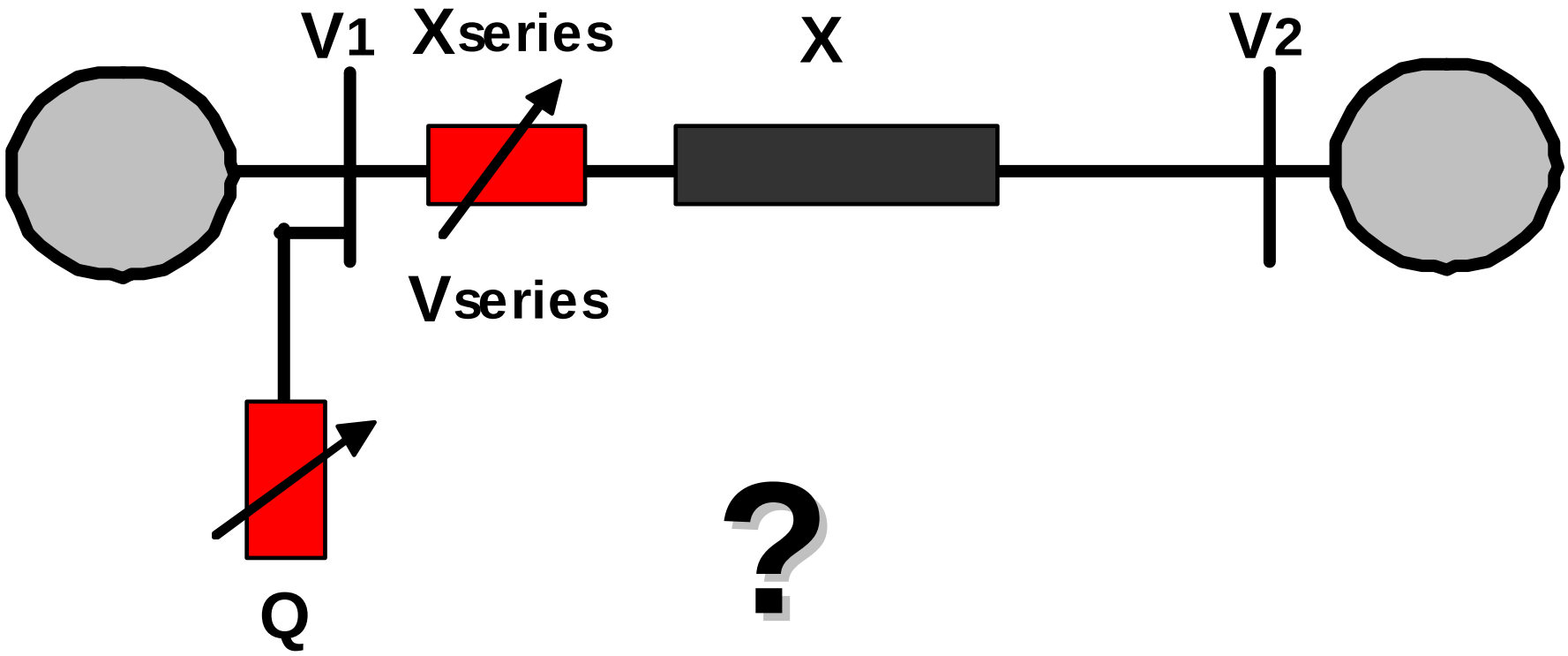
Parallel control



$$P = V_1 . V_2 . \sin(\delta) / X$$



Series and parallel control



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Static VAR compensator

- **TCR = Thyristor Controlled Reactor**
- **TSR = Thyristor Switched Reactor**
- **TSC = Thyristor Switched Capacitor**
- **MSC = Mechanically-Switched Capacitor**
- **MSR = Mechanically-Switched Reactor**
- **FC = Fixed Capacitor**
- **Harmonic Filters**

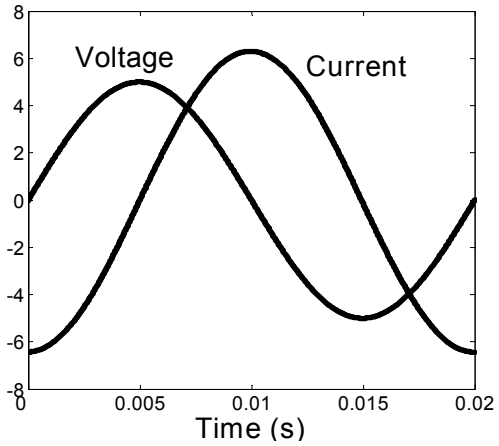
Thyristor Controlled Reactor (TCR)

Parallel-connected static var generator or absorber

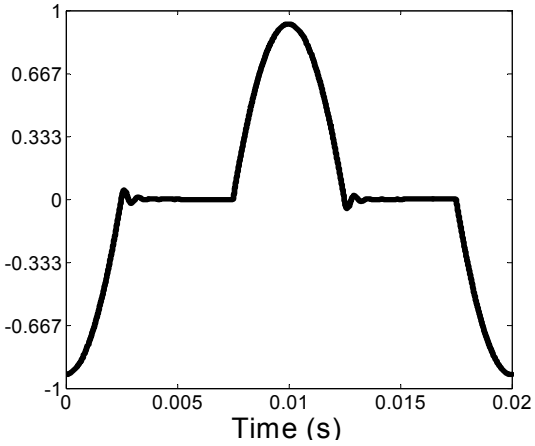
- Output is adjusted to exchange capacitive or inductive current
- Maintain or control specific parameters of the electrical power system

  (typically bus voltage).
- Thyristor-based Controllers
- Lower cost alternative to STATCOM

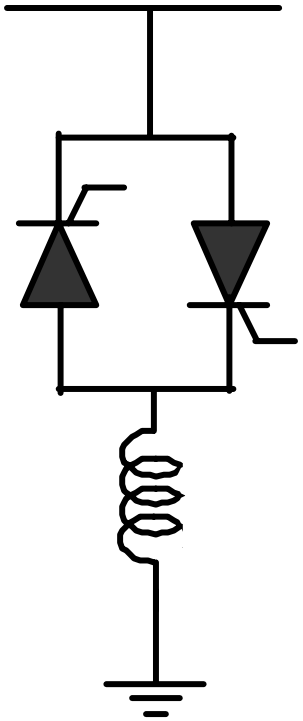
Thyristor Controlled Reactor



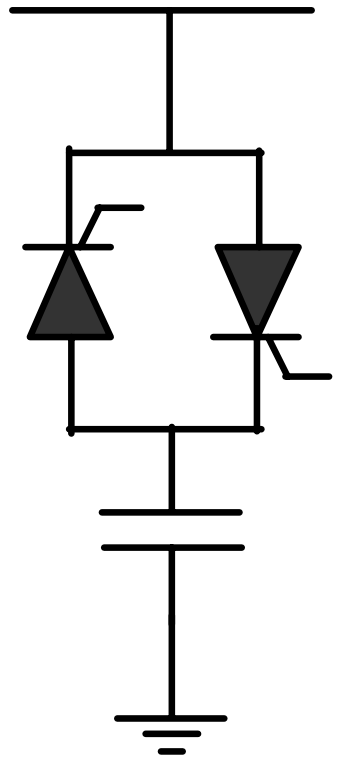
Firing angle of 90



Firing angle of 135

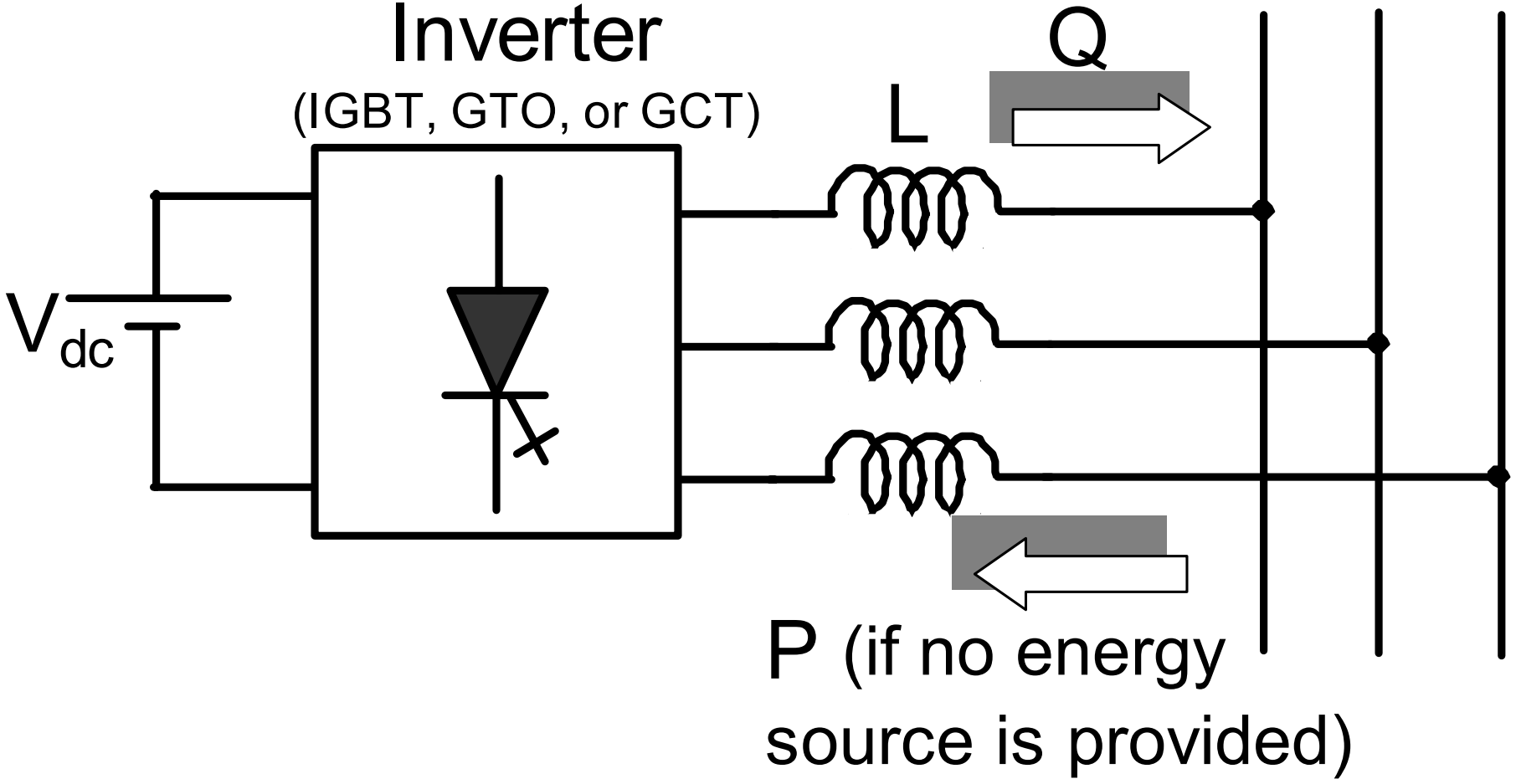


Thyristor Switched Capacitor (TSC)



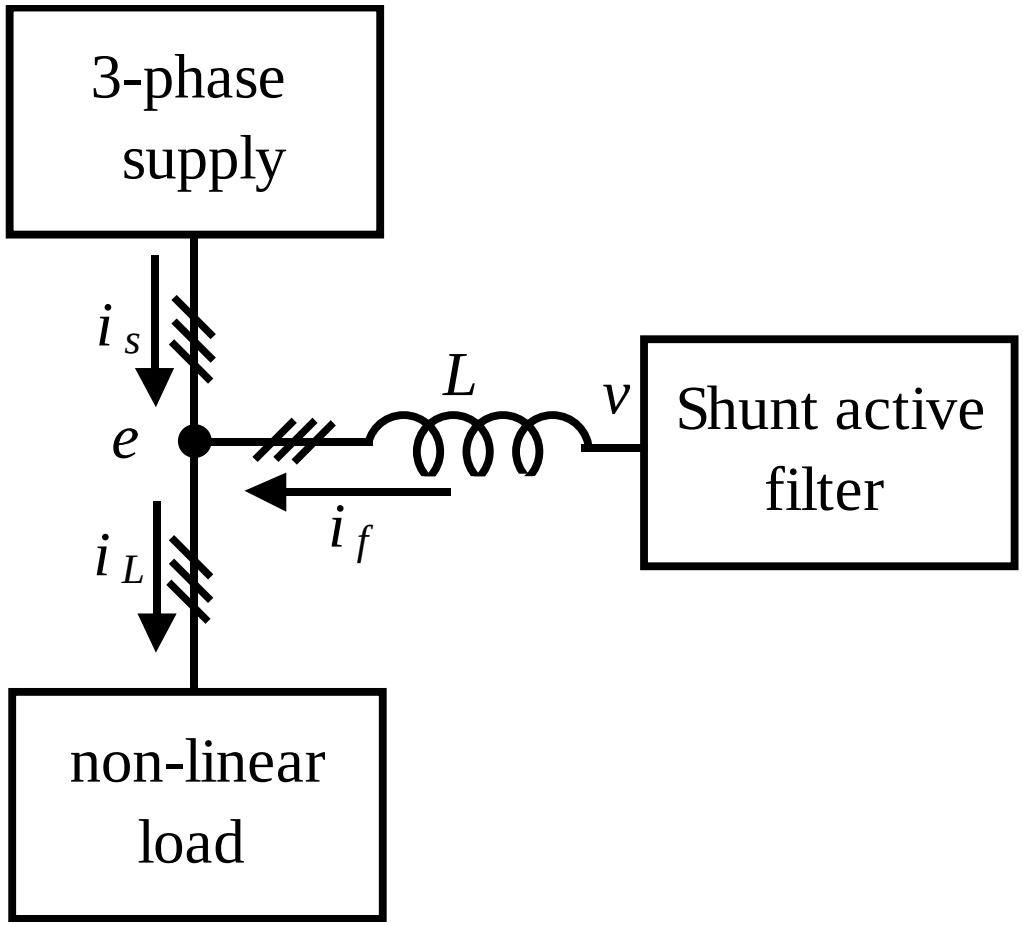
Static Synchronous Compensator (STATCOM)

- Parallel-connected static var compensator
- Capacitive or inductive output current controlled independently of the ac system voltage

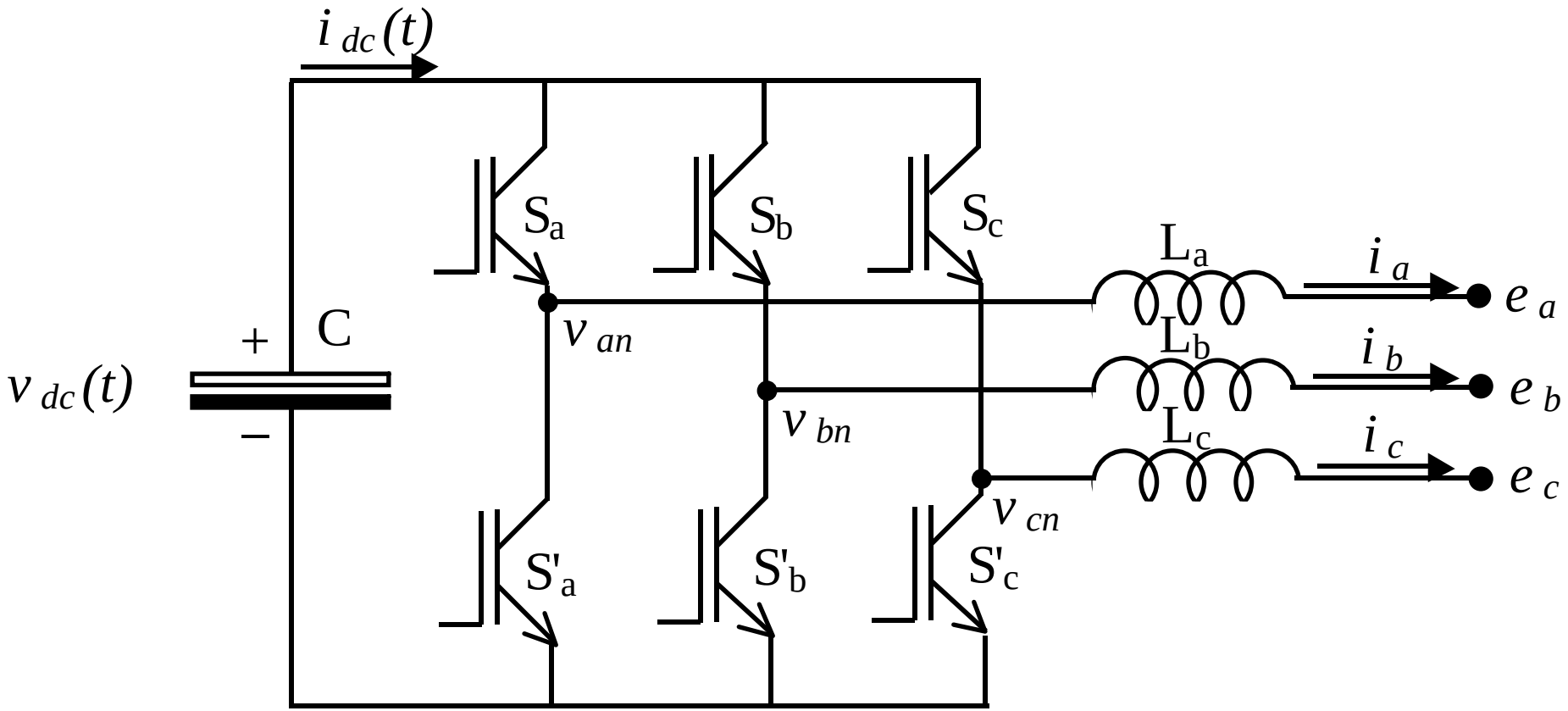

Inverter
(IGBT, GTO, or GCT)
Q
L
V_{dc}
P (if no energy source is provided)

Parallel Active Power Filters (Parallel APF)

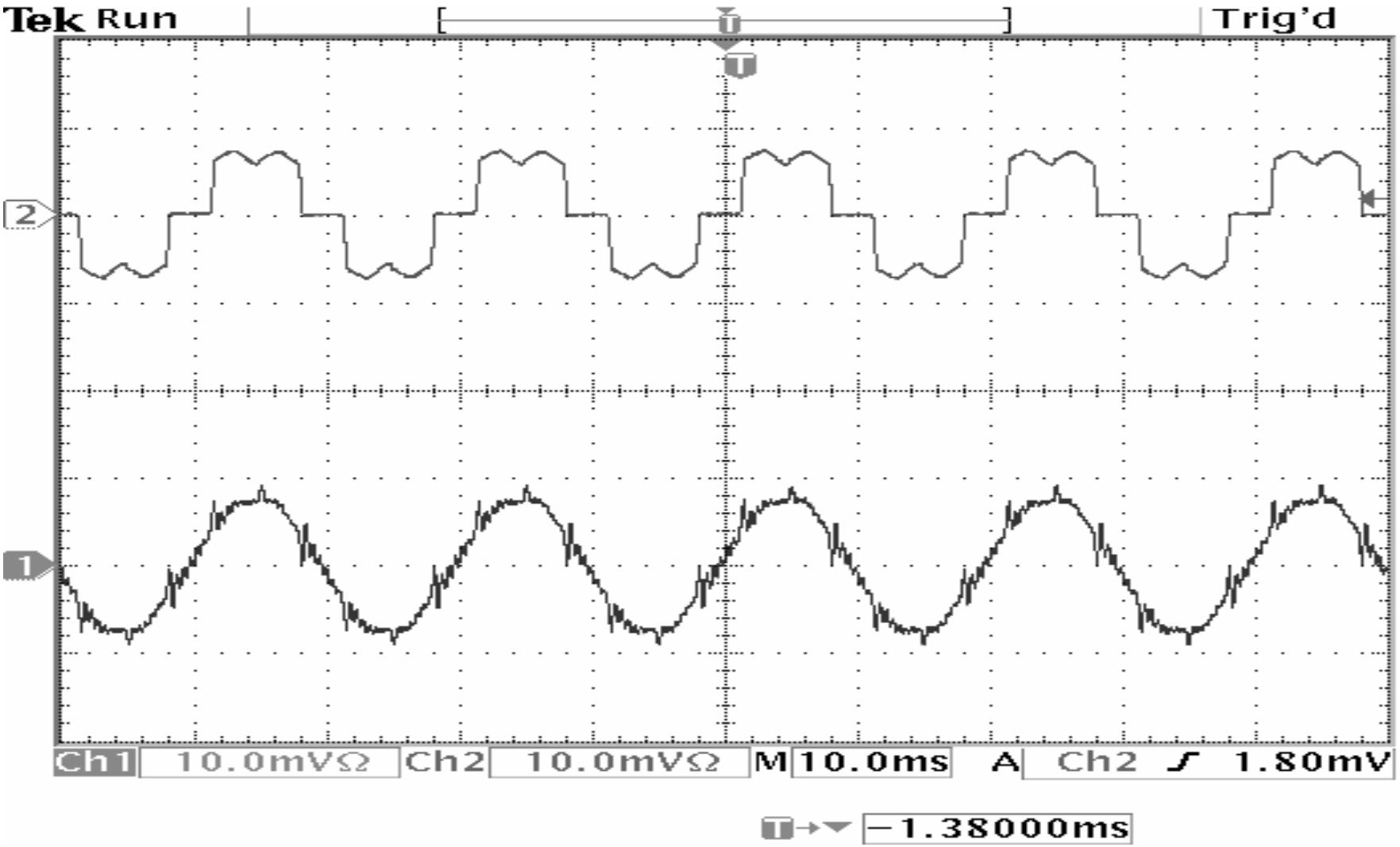
- Reactive power
- Compensation
- Source current's higher
- Harmonics compensation
- DC element voltage control



Shunt active power filter single line diagram



Two level voltage source inverter


Tek Run
Trig'd
2
1
Ch1 10.0mVΩ Ch2 10.0mVΩ M 10.0ms A Ch2 1.80mV
T→ −1.38000ms

Voltage source inverters

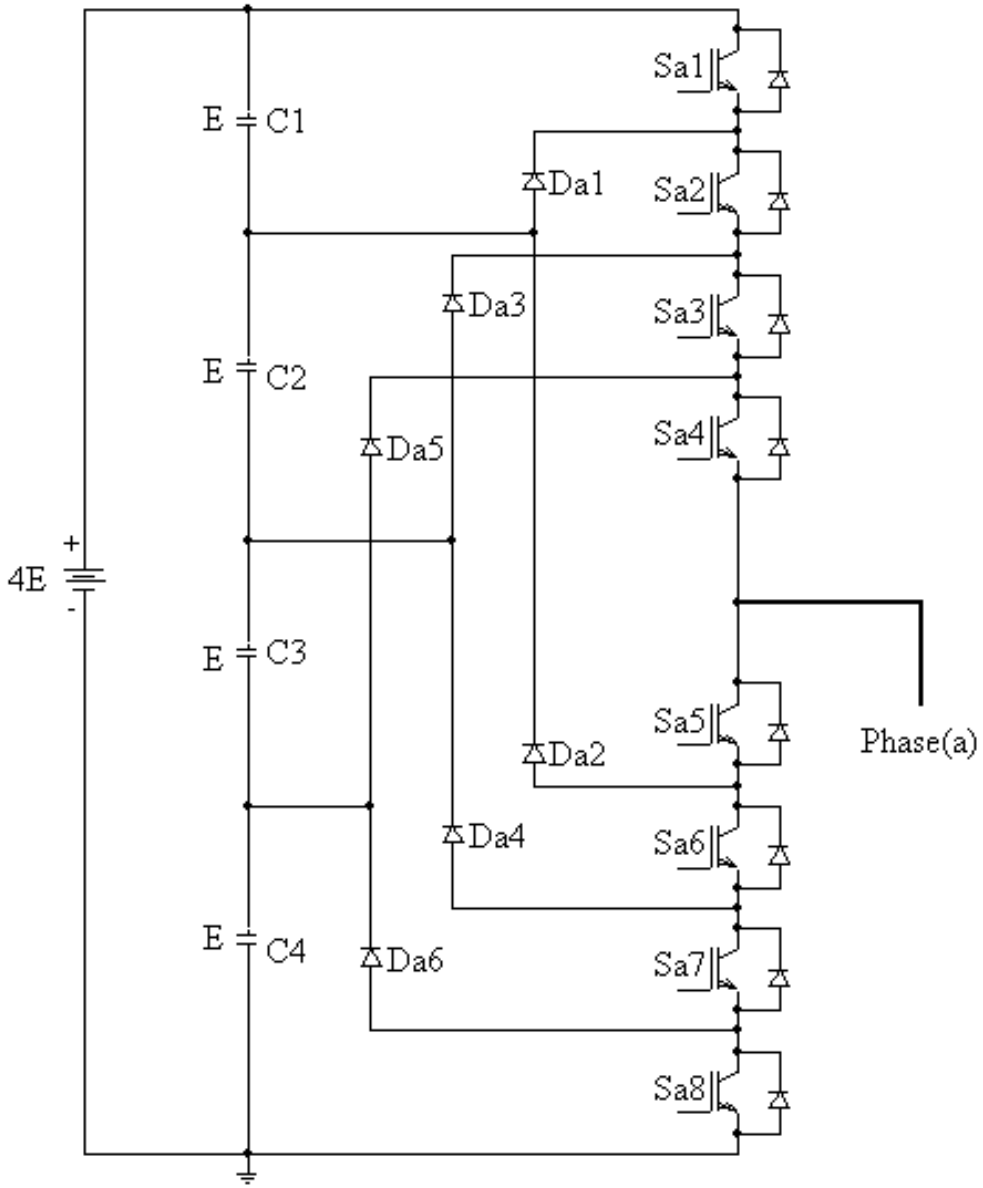
1. Two level Voltage source inverter
2. Multilevel voltage source inverter
3. Series connection

Current source inverter ?

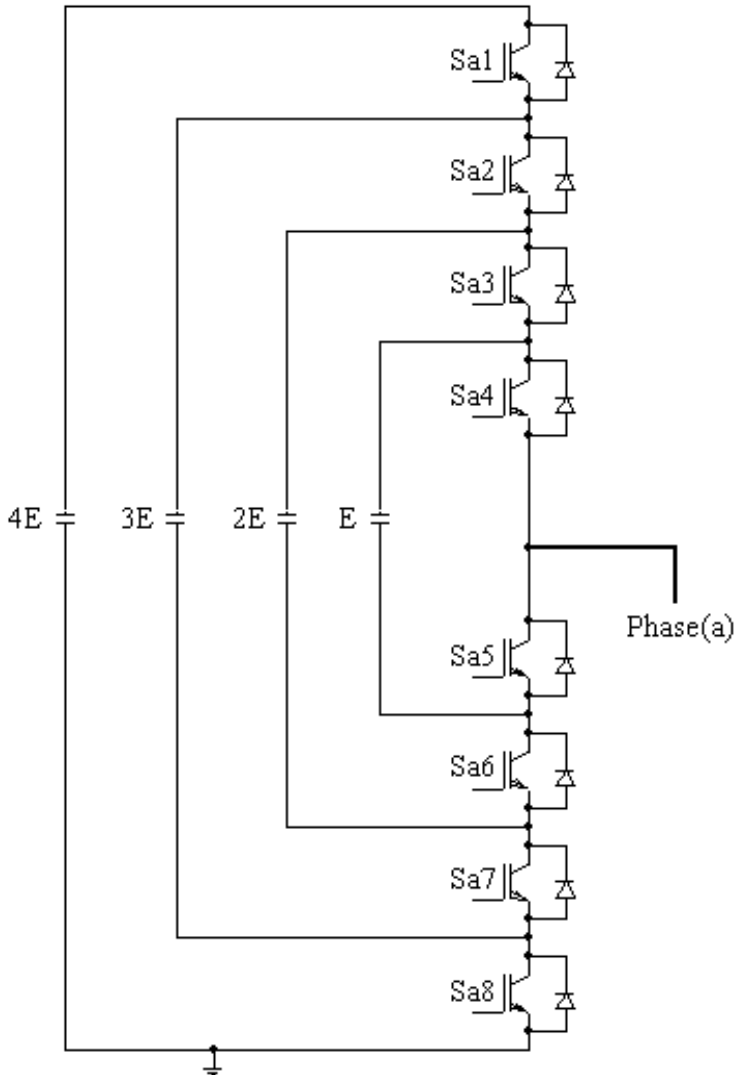
Multilevel inverter

1. Neutral point clamped
2. Cascaded
3. Flying capacitor

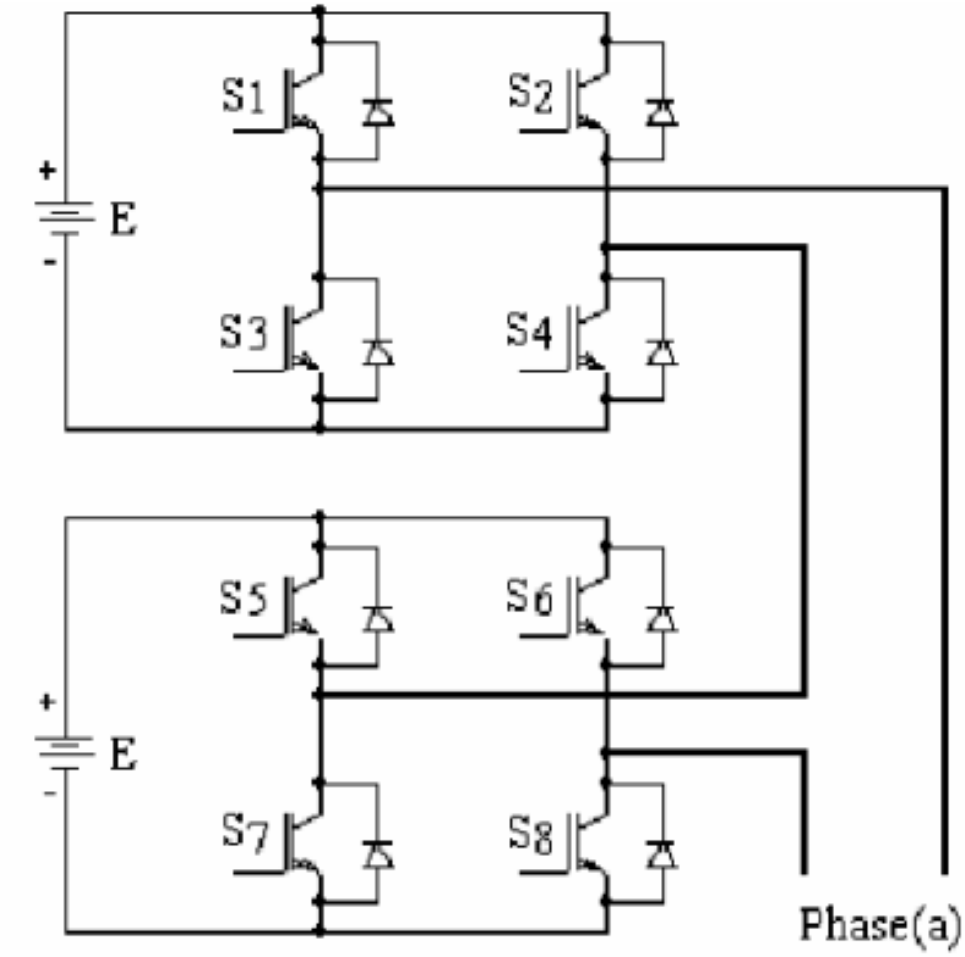
Neutral point clamped



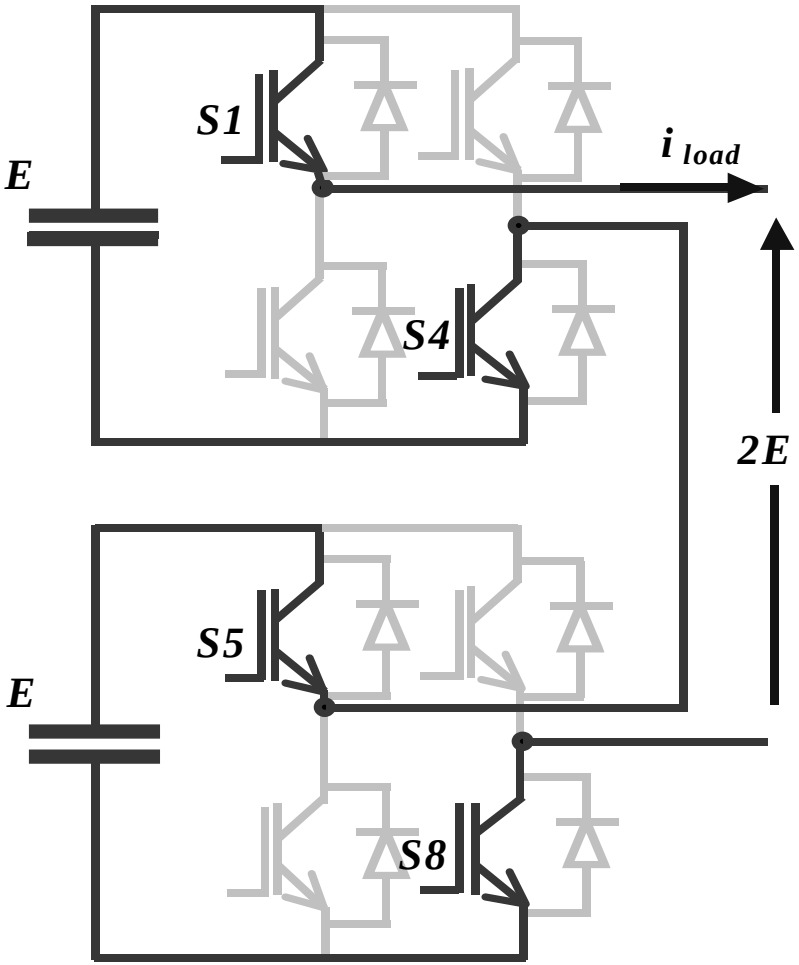
Flying capacitor



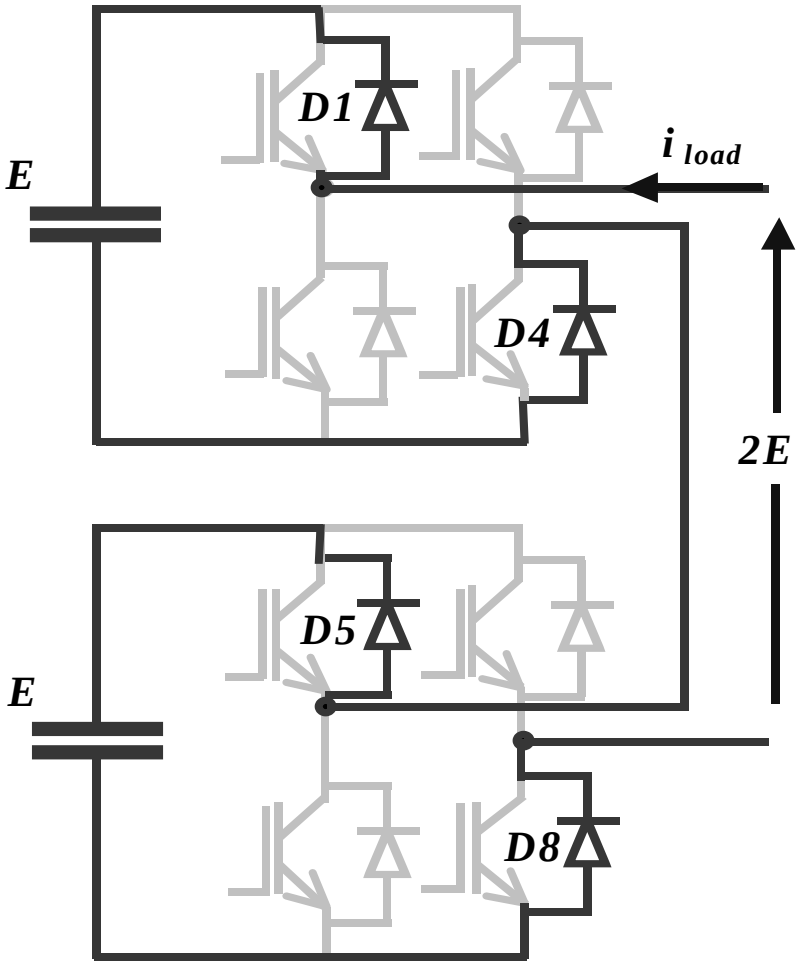
Cascaded



2E volt

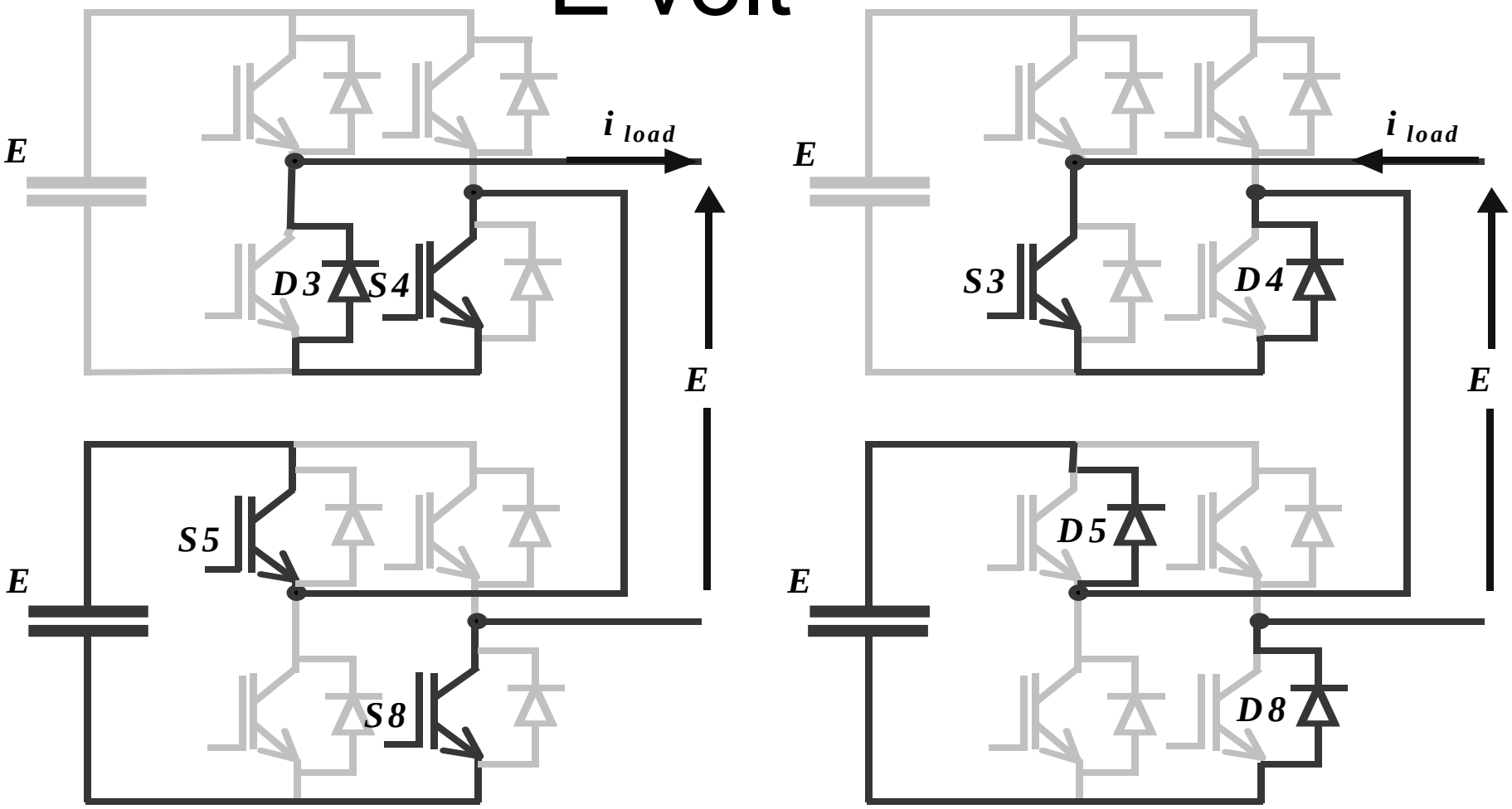


$i_{load} > 0$



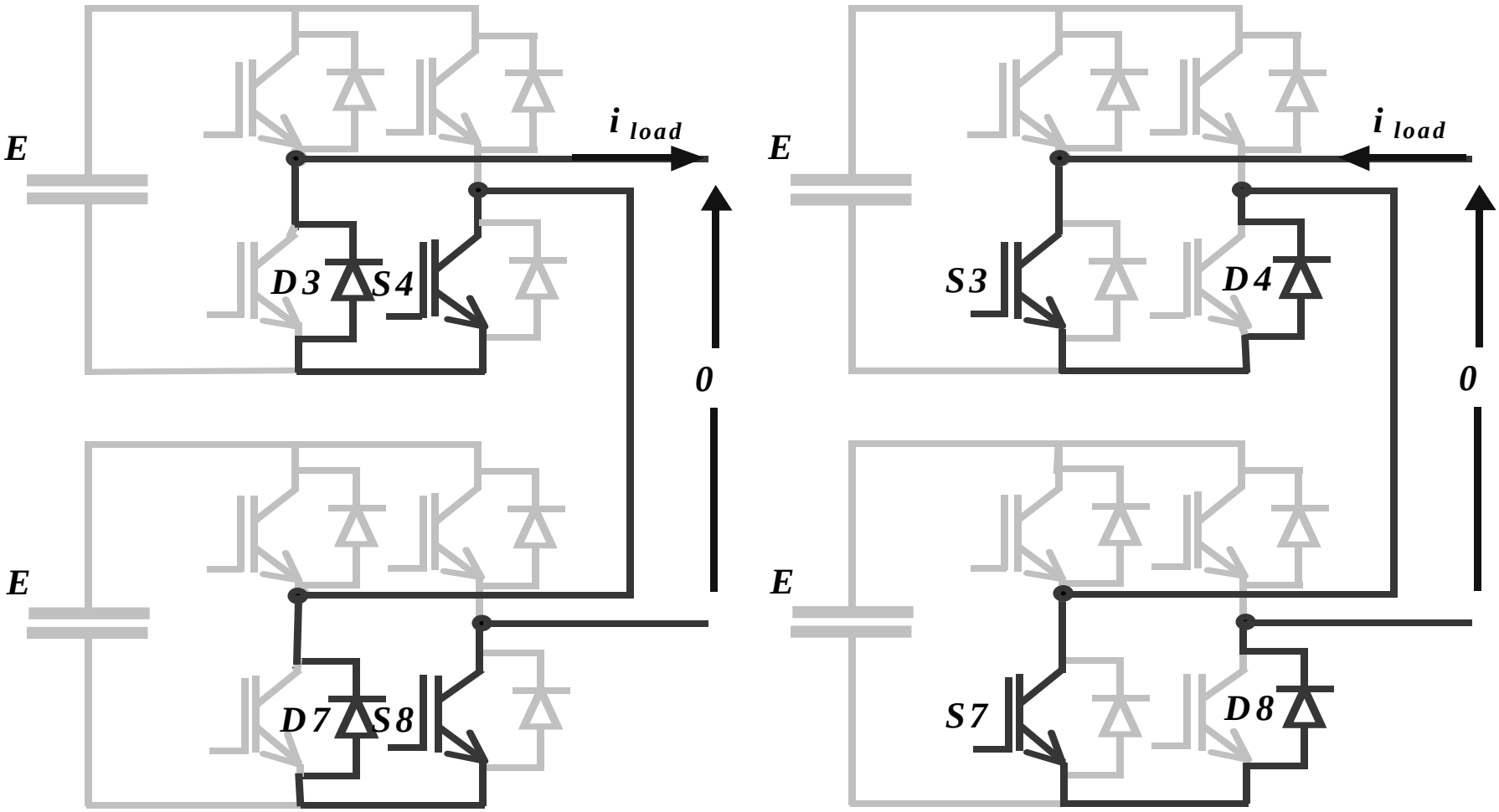
$i_{load} < 0$

E volt



$i_{load} > 0$ $i_{load} < 0$

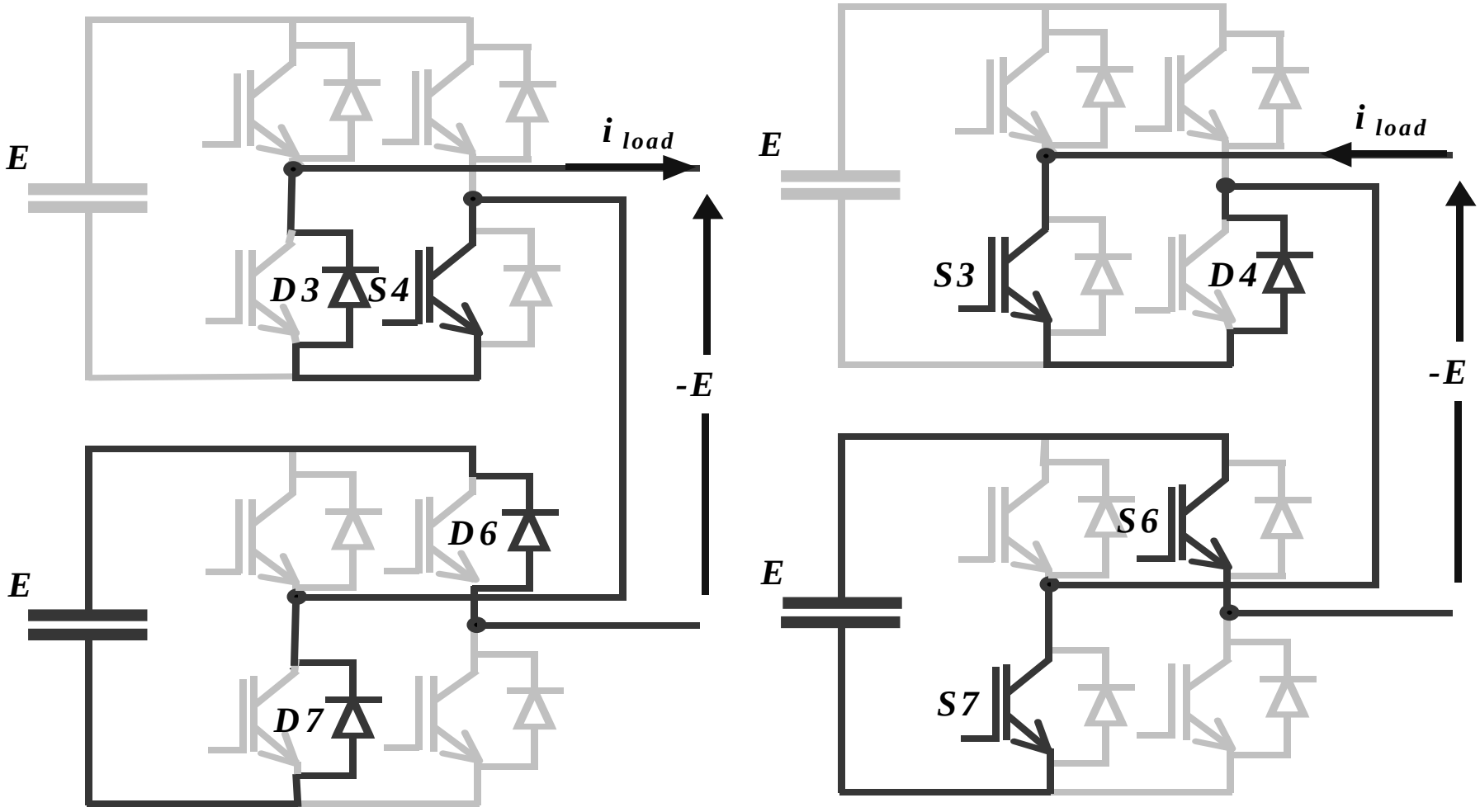
0 volt



$i_{load} > 0$

$i_{load} < 0$

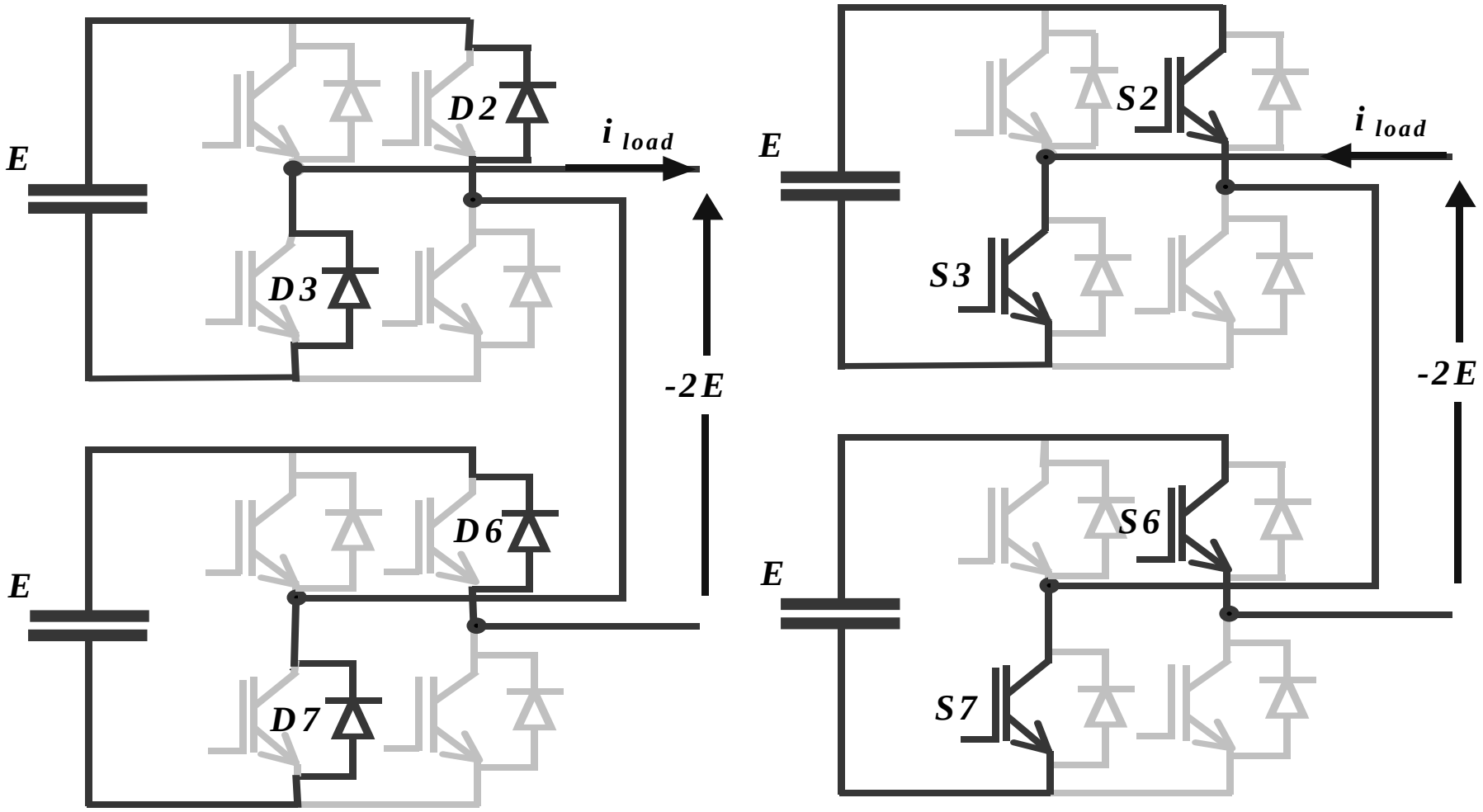
-E volt



$i_{load} > 0$

$i_{load} < 0$

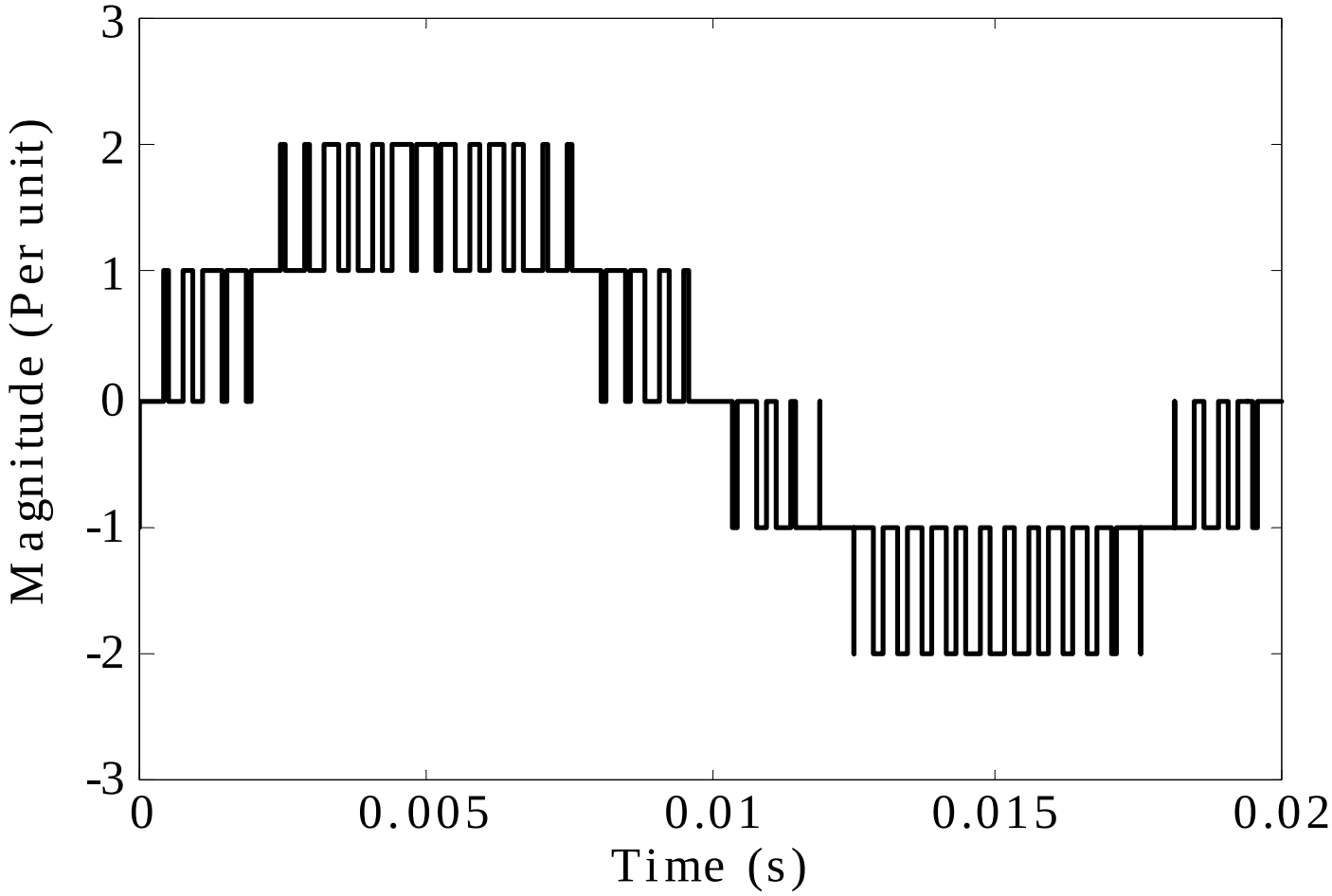
-2E volt



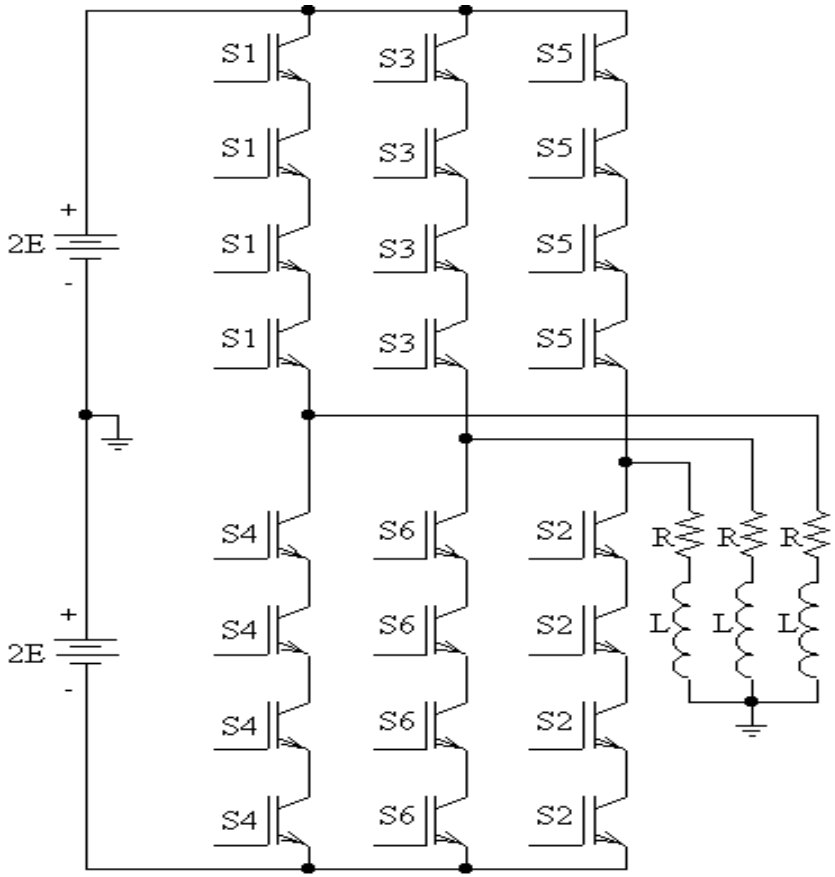
$i_{load} > 0$

$i_{load} < 0$

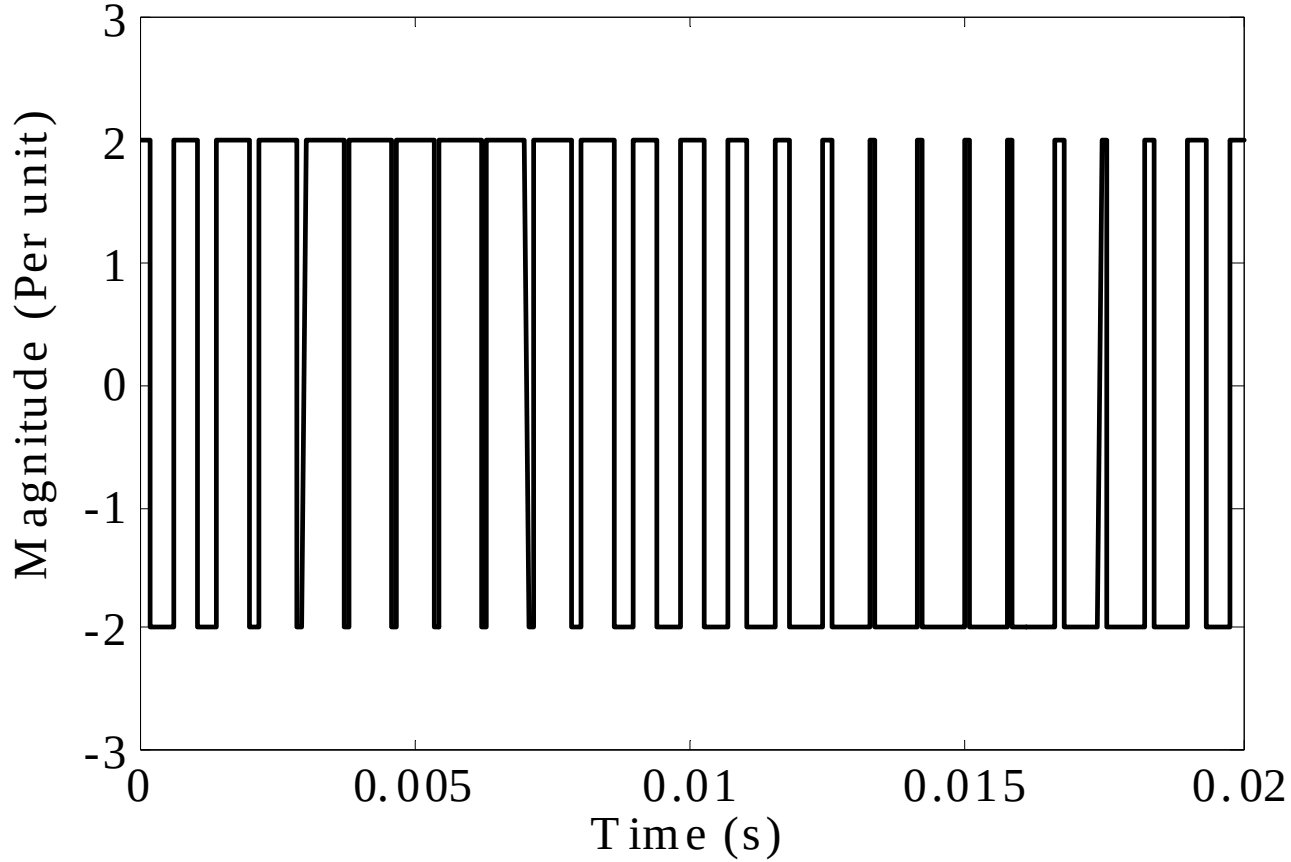
Output of 5-level inverter (PWM)



Series connection of IGBT



Output of two-level inverter (PWM)



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Series Capacitors Applied For:

Increasing Power Transfer

Increasing Stability Limits

Improving Voltage Profile

Improving Load Division

Series Active Power filter (Series APF)

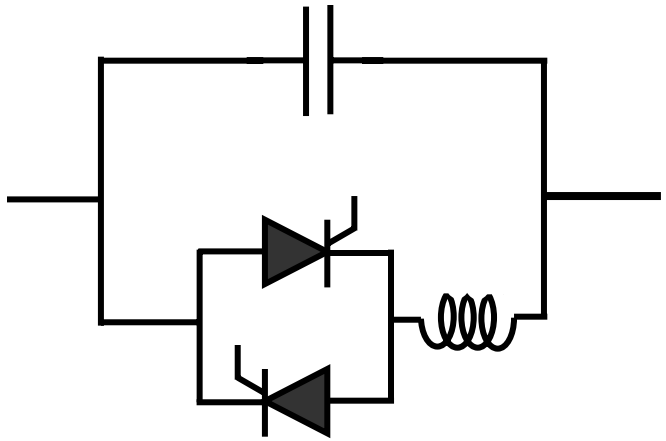
- Voltage harmonics compensation
- Stability improvement
- Current harmonics blocking

Static Synchronous Series Compensator (SSSC)

- Output voltages in quadrature with, and controllable independently of, the line current
- Control the transmitted electric power.
- May include energy storage to enhance the dynamic behavior of the power system by additional temporary real power compensation, to increase or decrease momentarily, the overall real (resistive) voltage drop across the line.

Thyristor Controlled Series Capacitor (TCSC)

- Smooth control of series capacitive reactance



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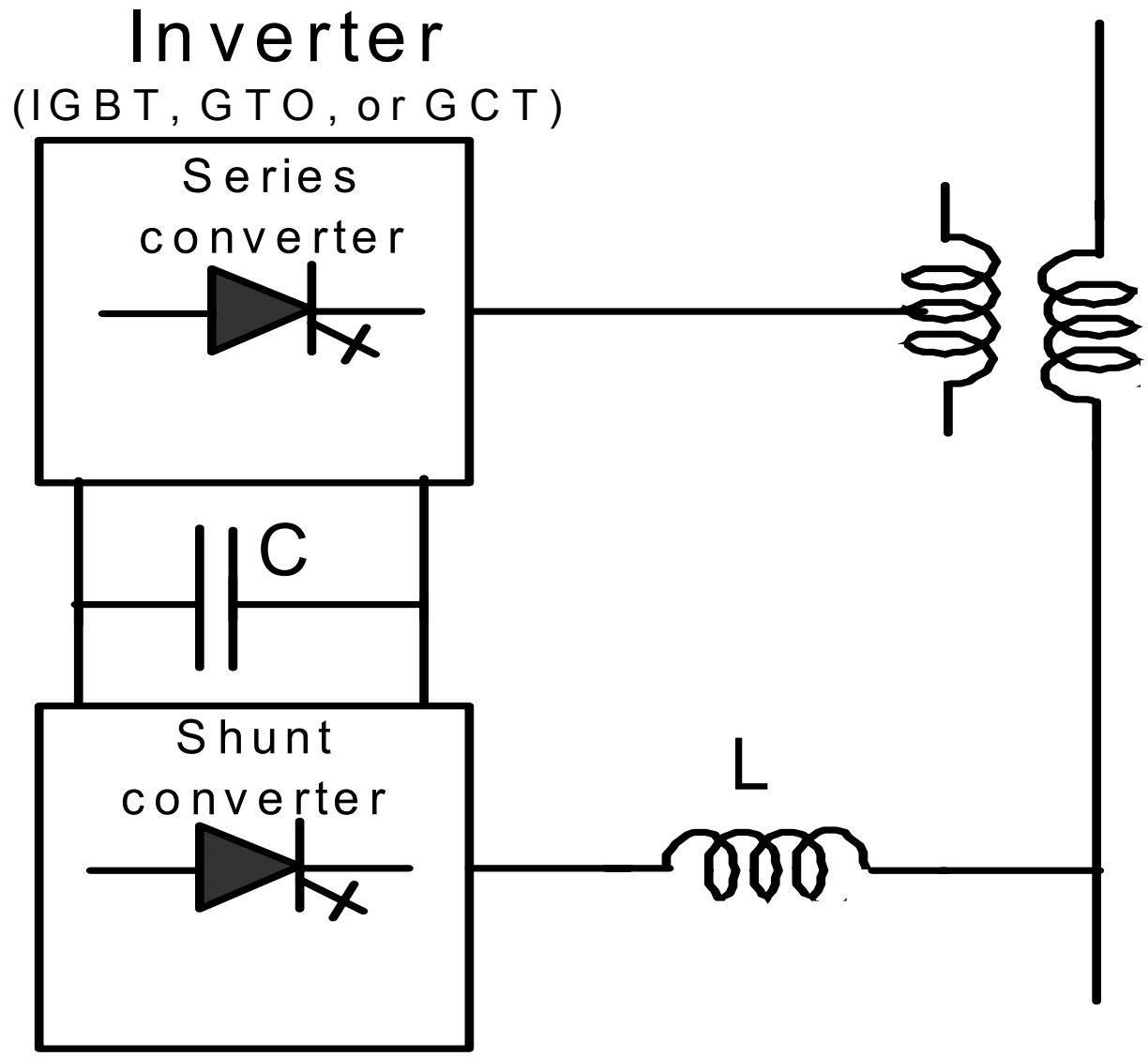
Unified Power Flow Controller (UPFC)

- A combination of STATCOM and SSSC coupled via a common dc link
- Bi-directional flow of real power between the SSSC and the STATCOM

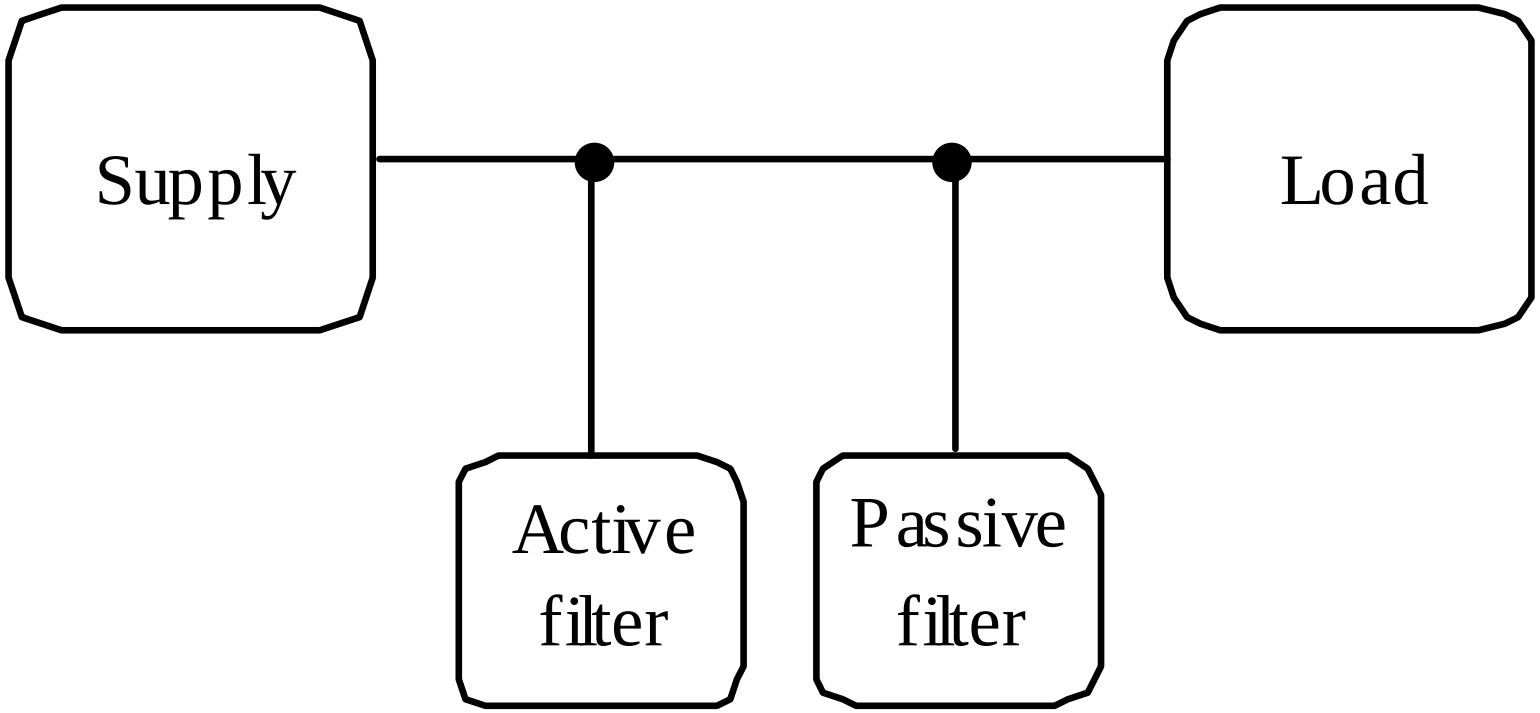
Unified Power Flow Controller = Static Synchronous Series Compensator + STATCOM


Inverter
(IGBT, GTO, or GCT)
Series
converter
C
Shunt
converter
L

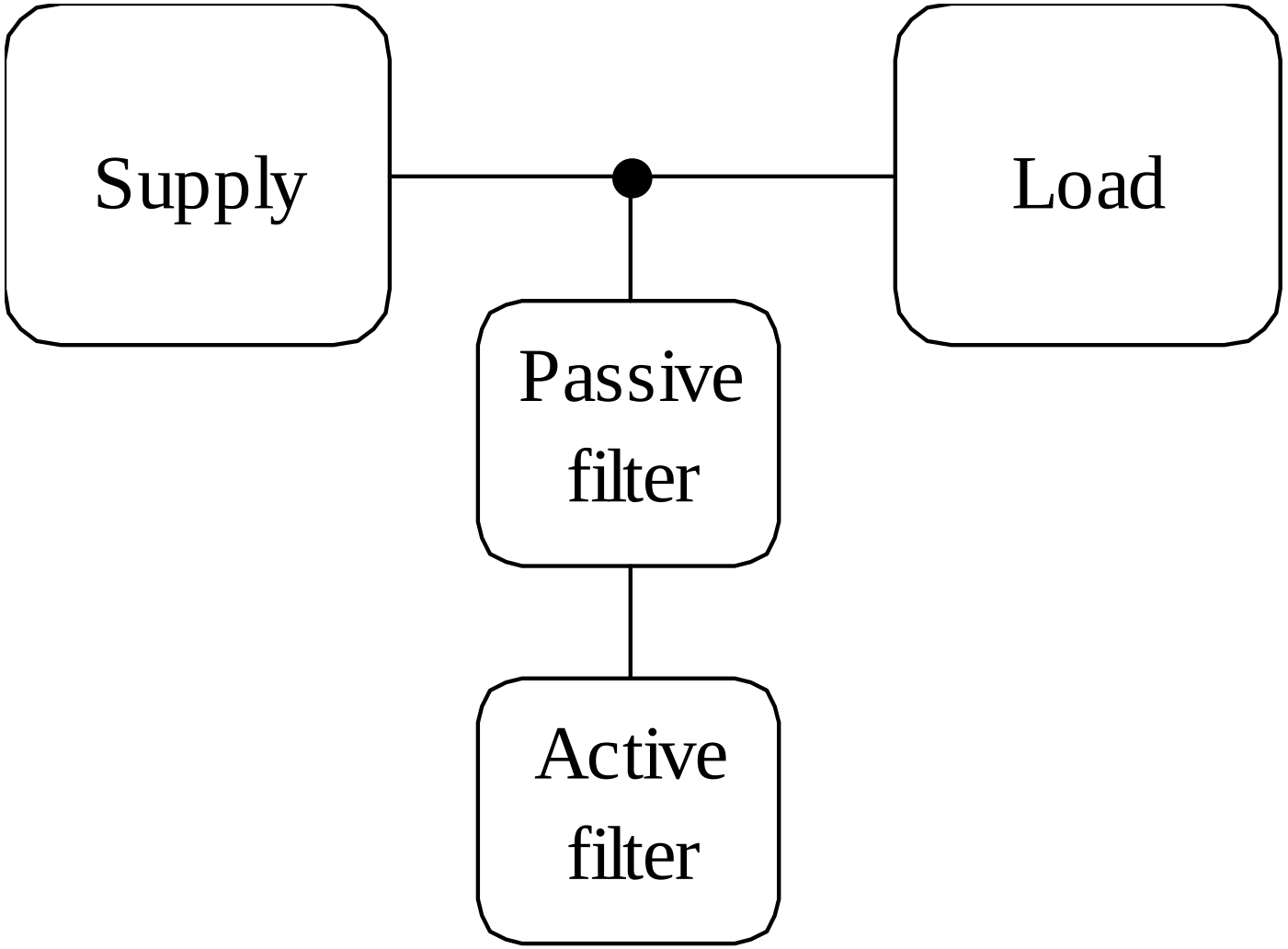
Unified Power Quality Conditioner (UPQC)

- Source current harmonics compensation
- System stability improvement
- Reactive power compensation
- DC element voltage control
- Voltage harmonics compensation

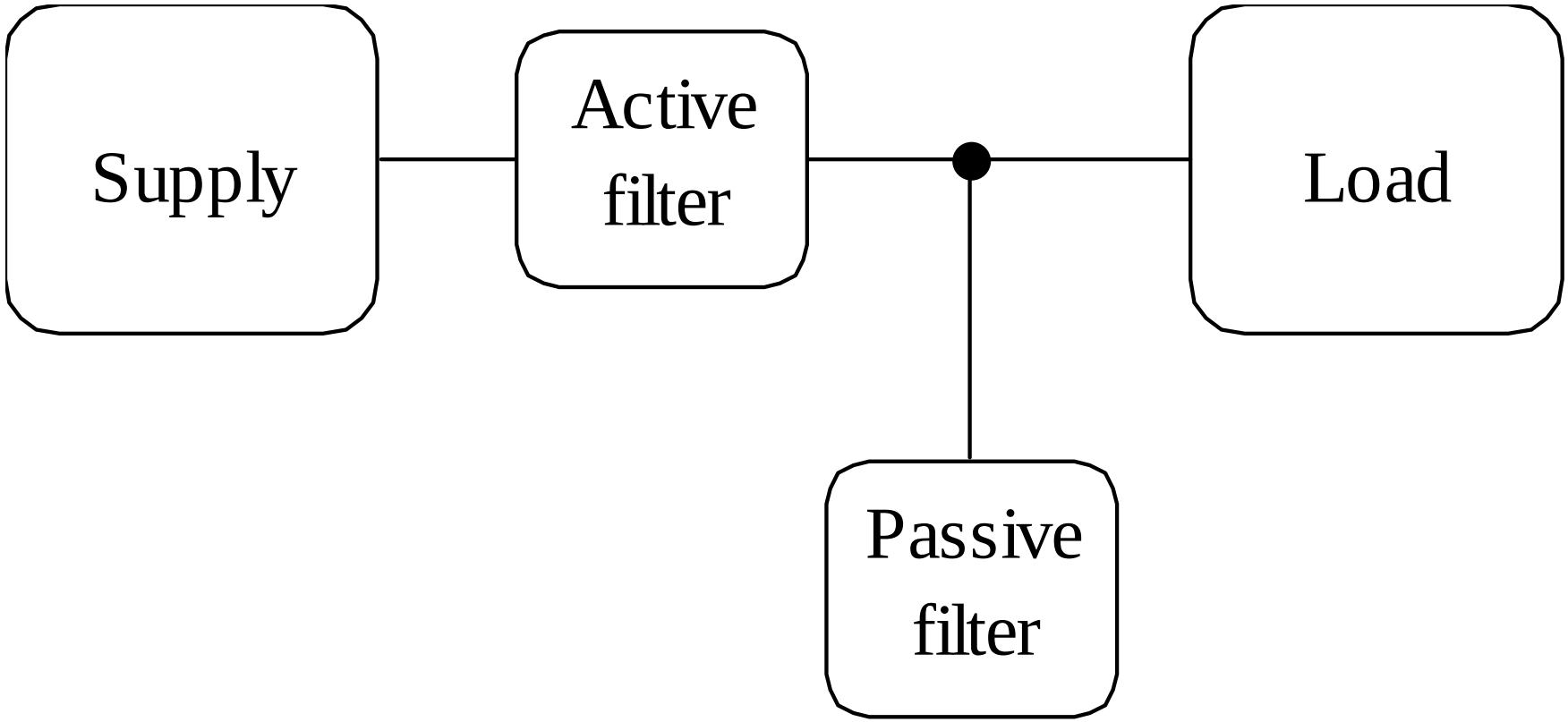
Combination of active power filter and passive filter



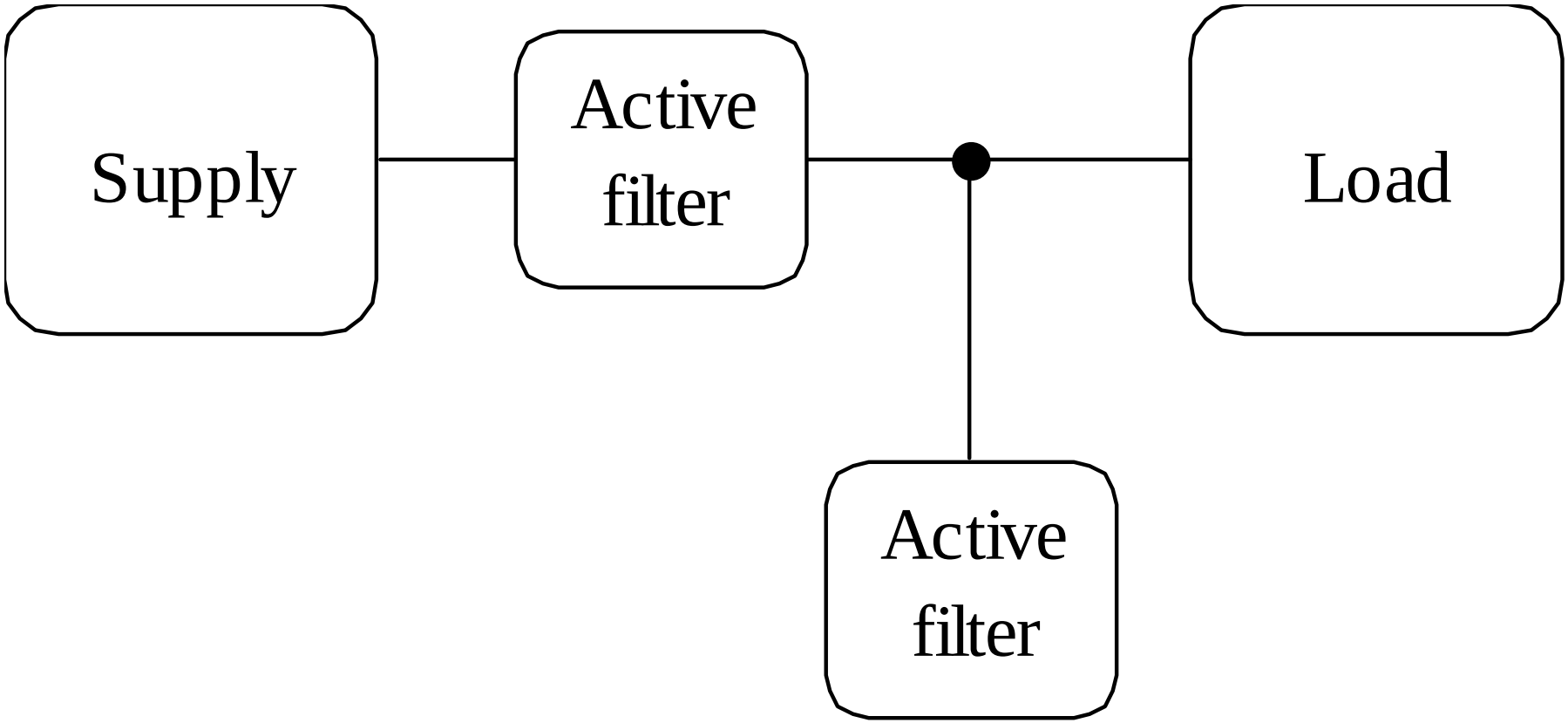
Parallel active power filter and passive filter



Parallel active power filter in series with passive filter



Series active power filter and parallel passive filter



Series and parallel active power filter (unified power quality conditioner UPQC)

Series VS. Parallel

- Series is more powerful in controlling the current/power flow and damp oscillations
- Parallel is more effective in voltage control and damping of voltage oscillations

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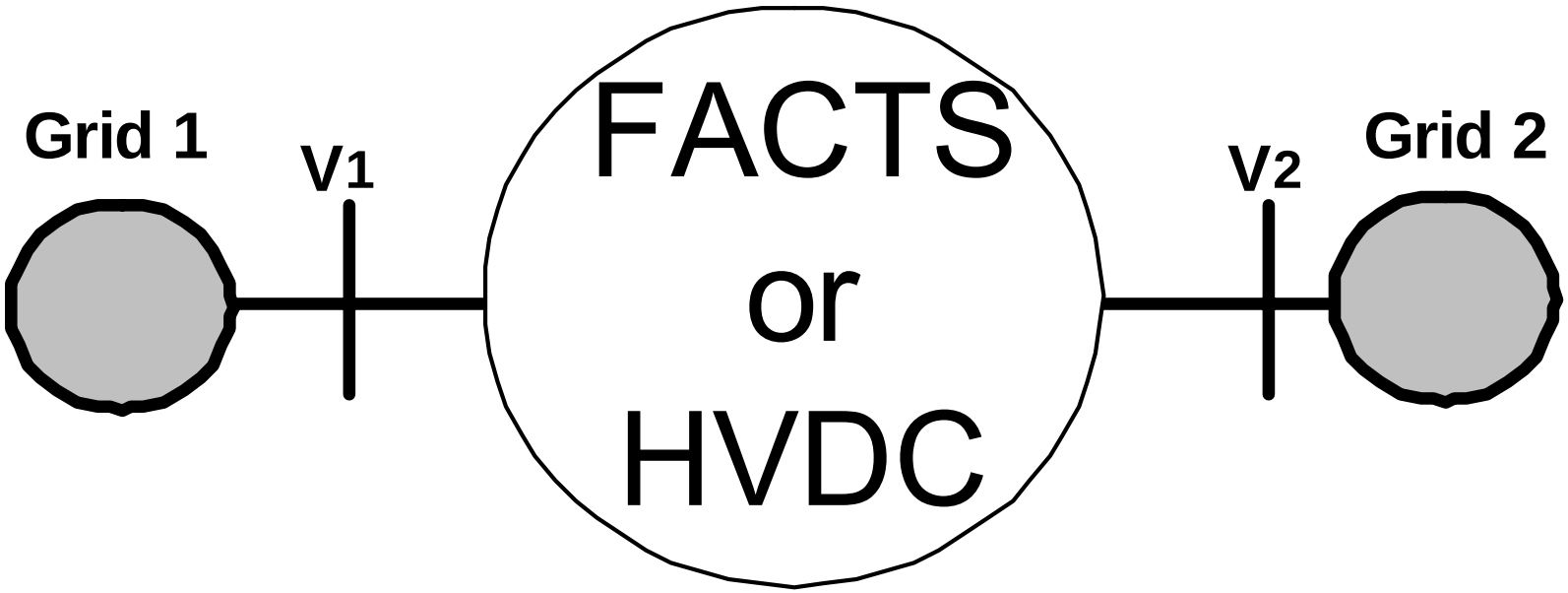
FACTS and HVDC



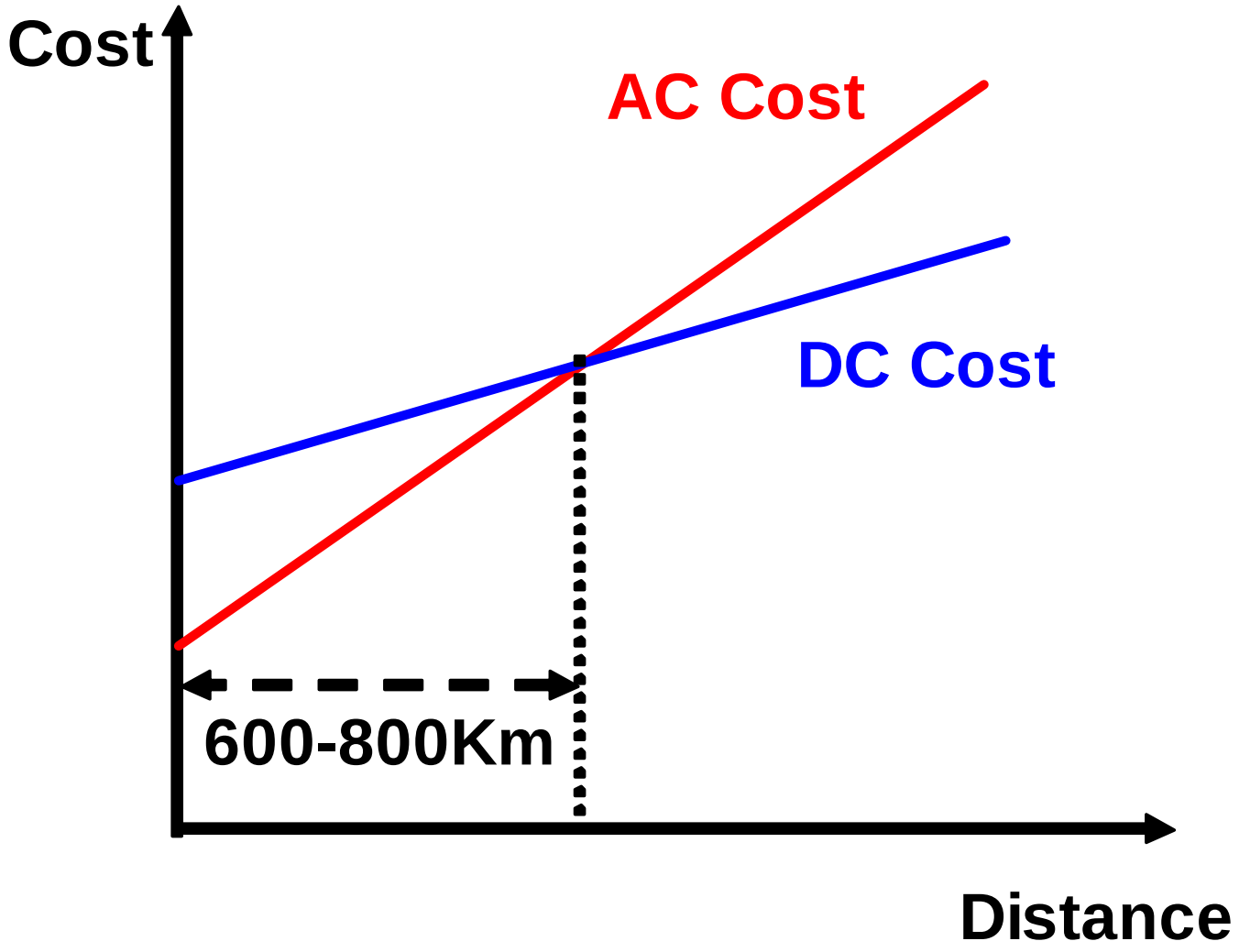
High voltage DC transmission (HVDC)

It is economically attractive:

- over a long distance from a remote generating to the load centre (>300 miles)
- underwater transmission
- when connecting two AC systems at two different frequencies

Advantages of HVDC

- No limits in transmitted distance.
- Fast control of power flow, which implies stability improvements.
- Direction of power flow can be changed very quickly.
- HVDC can carry more power for a given size of conductor
- improved transient stability
- dynamic damping of the electric system oscillations
- Require less space compared to ac for same voltage rating and size
- Ground can be used as a return conductor
- No charging current
- HVDC transmission limits short circuit currents

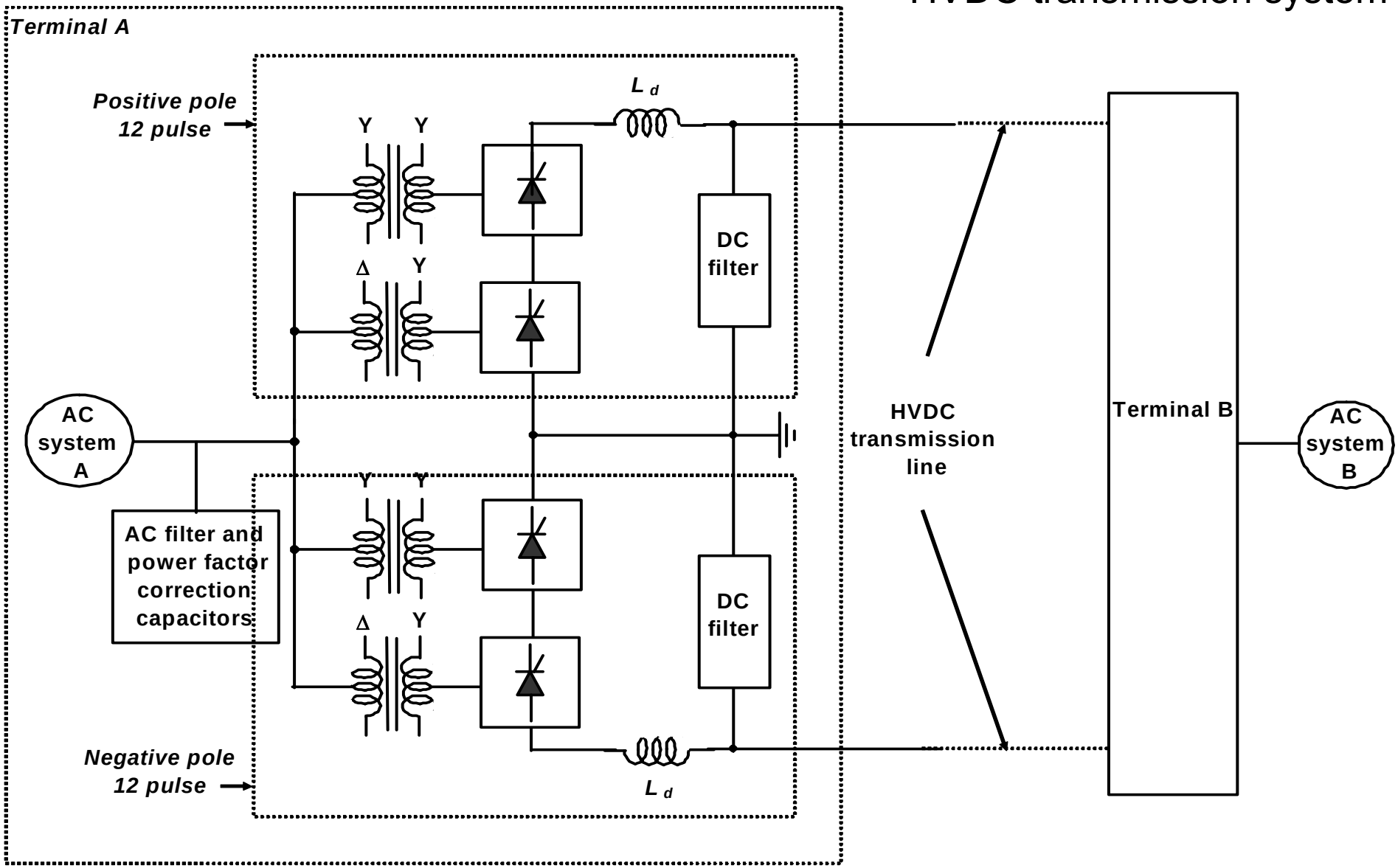

Cost
AC Cost
DC Cost
600-800Km
Distance

The HVDC technology

The fundamental process that occurs in an HVDC system is the conversion of electrical current from AC to DC (rectifier) at the transmitting end, and from DC to AC (inverter) at the receiving end.

1. Natural Commutated Converters. The component that enables this conversion process is the thyristor (high power and low switching frequency).
2. Forced Commutated Converters. It uses GTO or IGBT. They are known as VSC (Voltage Source Converters).

HVDC transmission system



Components of HVDC

1. Converter: at one side rectifier and the other inverter each converter consists of a positive pole and a negative pole each pole consists of 6 pulse converters connected through star-delta and star-star transformer to yield 12 pulse converter
2. On the AC side:
   * AC filters to reduce the current harmonics generated from the converters
   * Power factor correction capacitors to supply the lagging reactive power
3. On the DC side: smoothing reactor and DC filters to filter the ripple in the DC currents

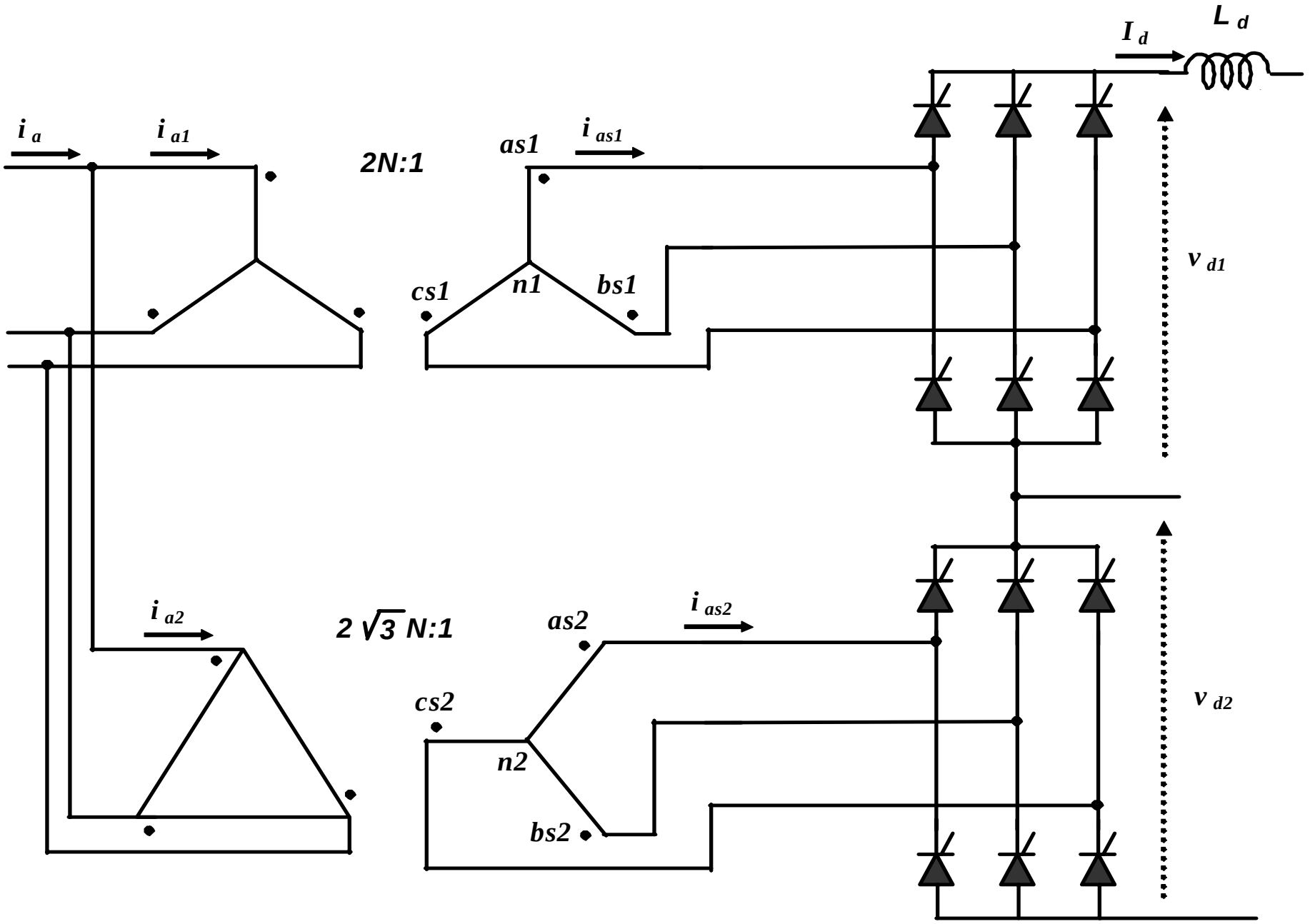
12 pulse line frequency converter

Objectives:

1. Reduce current harmonics on AC side
2. Reduce voltage ripple on DC side
3. High power

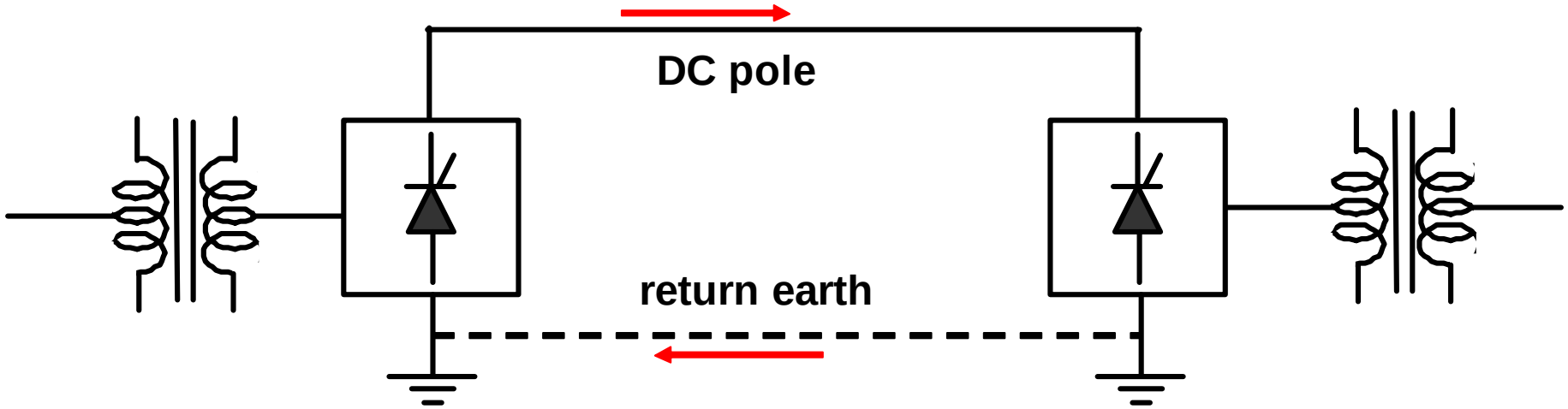
12 pulse converter consists of two six-pulse converters connected through star-star and delta-star transformer

The 2 converters are connected in series from the DC side and parallel from the AC side

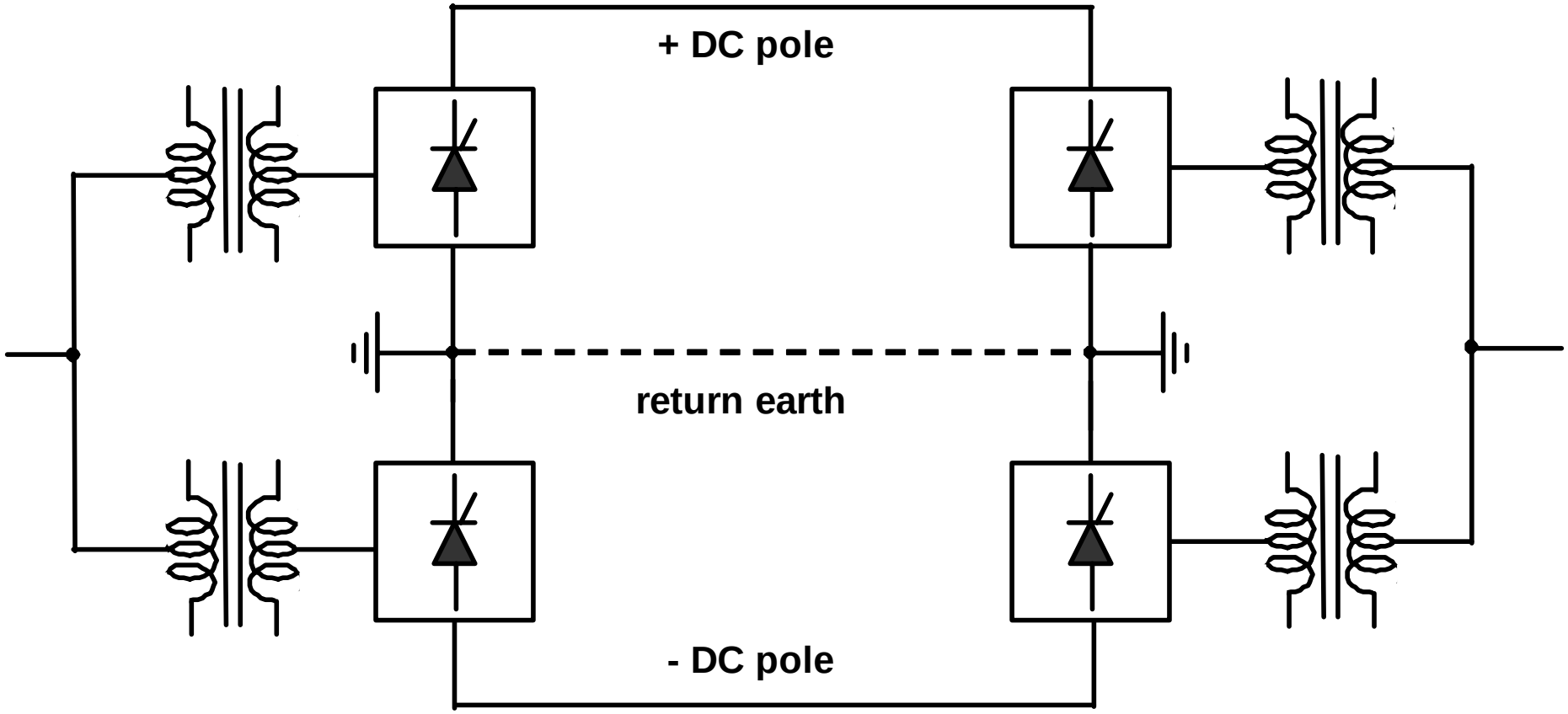

I_d
L_d
i_a
i_{a1}
2N:1
as1
i_{as1}
cs1
n1
bs1
v_{d1}
i_{a2}
$2\sqrt{3}$ N:1
as2
i_{as2}
cs2
n2
bs2
v_{d2}

Types of HVDC links

1. Monopolar: Having one conductor and the ground is the return path



2. Bipolar: There are two conductors (poles). One operates with positive polarity and the second with negative. During fault of one them, the bipolar acts as a monopolar



HVDC Light

1. HVDC Light unit sizes range from a few tens of MW to presently 350 MW and for DC voltages up to $\pm$150 kV and units can be connected in parallel.
2. HVDC Light consists of two elements: converter stations and a pair of cables. The converter stations are Voltage Source Converters (VSCs) employing Self-commutated switch

FACTS

1. POWER SYSTEMS
2. FACTS definition
3. FACTS controllers
4. Parallel controllers
5. Series controller
6. Series-parallel controllers
7. HVDC
8. Others

Battery Energy Storage System

Super conducting material