Module 4 : Voltage and Power Flow Control

Lecture 18a : HVDC converters

Objectives

In this lecture you will learn the following

- AC-DC Converters used for HVDC applications.
- Introduction to Voltage Source Converters.

Thyristors

In the previous lecture, we have introduced the use of controlled rectifiers (AC-DC converters) to provide controllable field voltage to a synchronous generator. In the following lecture we shall consider their use again as a part of of HVDC systems.

Therefore in this lecture, we revise the operation of a typical AC-DC converter used in these applications. The treatment given in this lecture is not exhaustive, but is given to bring out some important functional characteristics of these converters which are important from a power systems perspective. A reader is encouraged to read a power electronics text for a rigorous analysis of AC-DC converters.

Power Electronic controllers are now very widespread and are present in computers and satellite power supplies, drives used in traction etc. Their use in extremely high power applications is not so well known. In fact, in many HVDC links, the total power handled ("converted") by a power electronic converter system exceeds 1 GW !

Power Electronic converters use semiconductor devices which are operated in " ON " and "OFF" states. In ON state, the voltage across the device is negligible, while in an OFF state, current flow through it is negligible. The state of a device is decided by the external circuit conditions and a (a low power) signal which is provided at the GATE terminal of the device. Diodes do not have a GATE terminal and their state is wholly determined by the external circuit (forward or reverse bias).

Currently, most power electronic converters used in power system applications, like HVDC, use a device known as a thyristor. Thyristors are available at ratings in excess of 10 kV, 8000 A. Many thyristors can be connected in series to yield larger equivalent voltage ratings which are required for power system applications.

An IDEAL thyristor has the following characteristics:

1. A thyristor turns ON if VAK > 0 *(forward bias)* and ig >0 *(firing)*.

2. Once a thyristor is ON, it remains ON even if ig becomes 0.

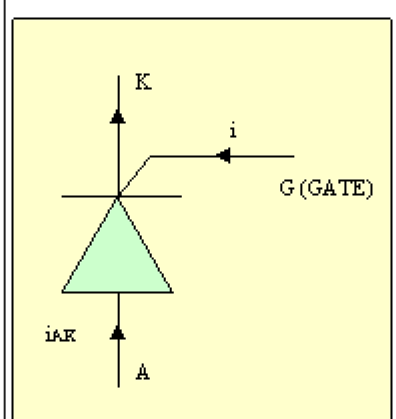
3. A thyristor which is ON, switches OFF if iAK falls to 0.

A practical device has the following limitations:

1. A thyristor requires some time to turn on after the application of the gating signal, known as turn on time, ton. This is usually quite small.

2. Once iAK falls to 0, positive VAK should not be applied for a duration, toff (called turn off time), otherwise the thyristor may turn on again even without application of a gate signal !

3. A thyristor should be protected against high diAK/dt and dvAK/dt otherwise it may damage the device.



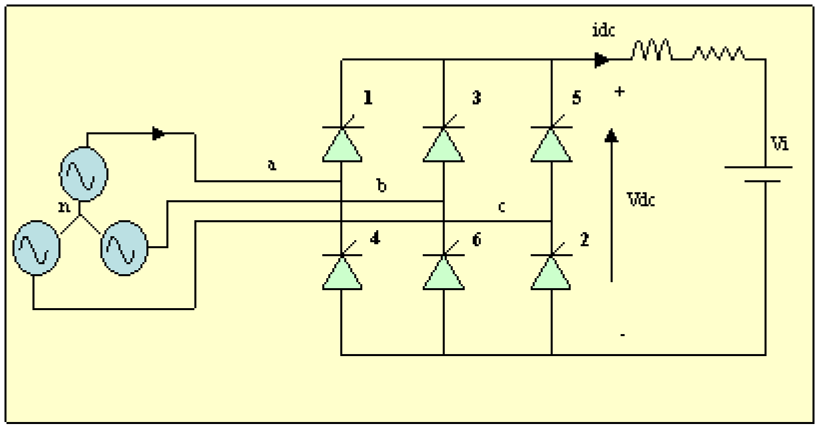
AC-DC converter control

Now suppose the thyristors are not fired as soon as they are forward biased, but fired after some delay.

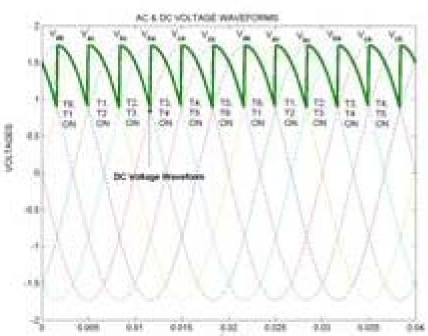
Let us define **delay angle** for thyristor T1 as the angular delay from the point at which Vac becomes greater than zero. Similarly the delay angle for the thyristors T2, T3..T6 is defined by the angular delay from the points at which Vbc, Vba, ... Vab become greater than zero respectively.

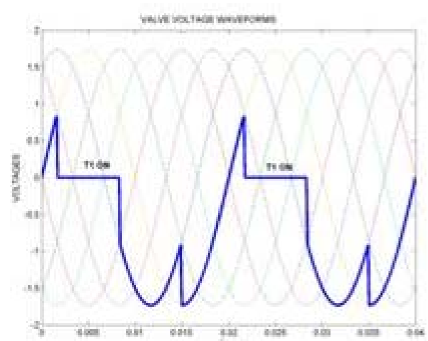
If all the thyristors are fired at a delay angle (a) of zero, then we get the waveforms as shown in the previous page. However, if we fire all thyristors at a delay angle of 30° we get the waveform shown below.

Similarly the waveforms for a = 90° and 150° are also shown.

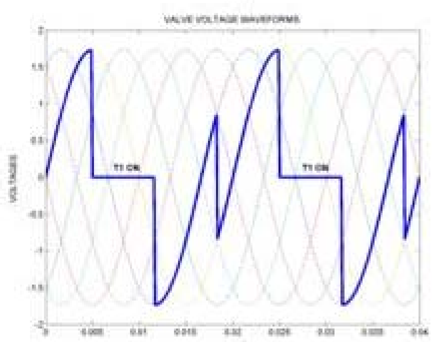


a = 30°

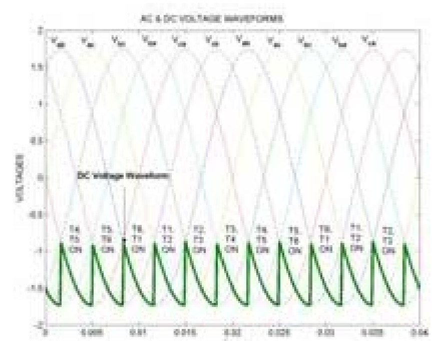


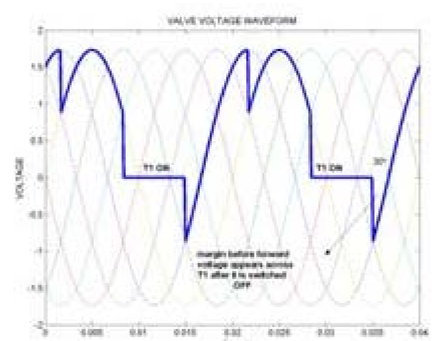


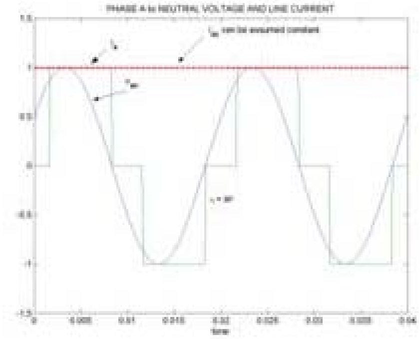
a = 90°

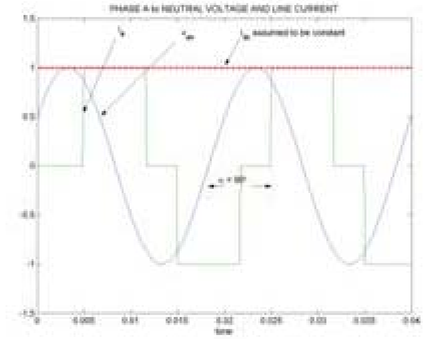


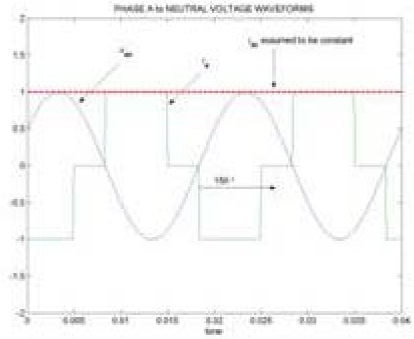
a = 150°











(click on images to enlarge)

Recall that for a thyristor:

" Once iAK falls to 0, positive VAK should not be applied for a duration, toff (called turn off time), otherwise the thyristor may turn on again even without application of a gate signal ! "

Therefore if the margin is less than the turn off time, then a thyristor will turn on again **unintentionally**, i.e., without a firing gate signal (commutation failure). This is generally avoided as it disturbs the current and voltages in an unacceptable way. So an important condition for inverter operation is that a should not be too close to 180°.

Some other important issues:

1. Harmonics: Both AC side currents and DC side voltages have harmonics (what are the lowest order harmonics for these two quantities ?). Filters are usually necessary on AC and DC side to reduce harmonics.

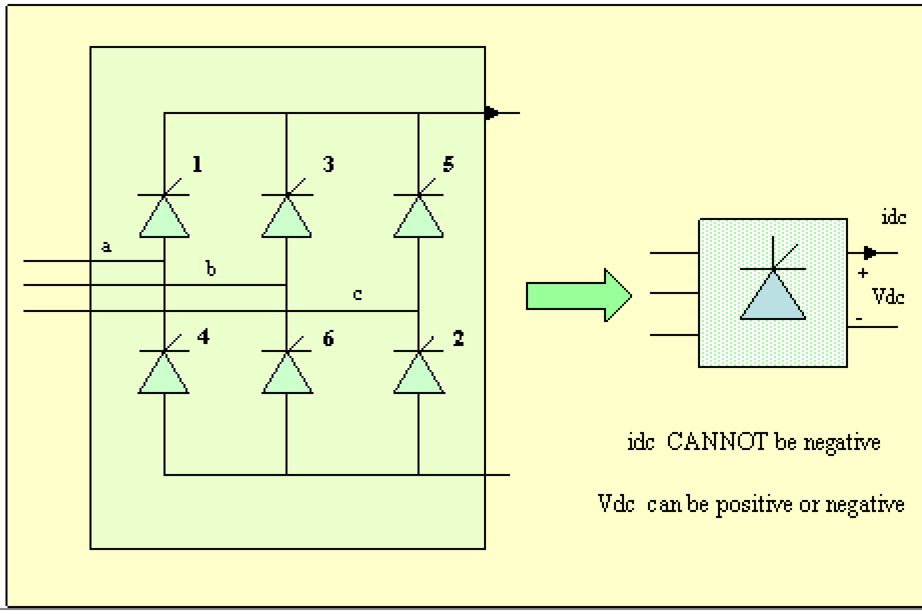
2. Reactive power: For reactive power drawal from AC side to be low, it is necessary to have a close to 0° for a rectifier and close (not too close) to 180° for an inverter.

HVDC link

In the previous page we have seen that a converter may be operated either as a rectifier or an inverter. For inverters, power is taken from the dc side and given to the AC side. Inversion occurs if Vdc becomes negative (note: current cannot become negative on the dc side since thyristors do not allow reverse conduction).

Vdc can be made negative if delay angle is > 90° and current is continuous -- it should not touch zero. The current can be kept continuous if dc source voltage Vi is more negative than the average negative value of Vdc (see previous page).

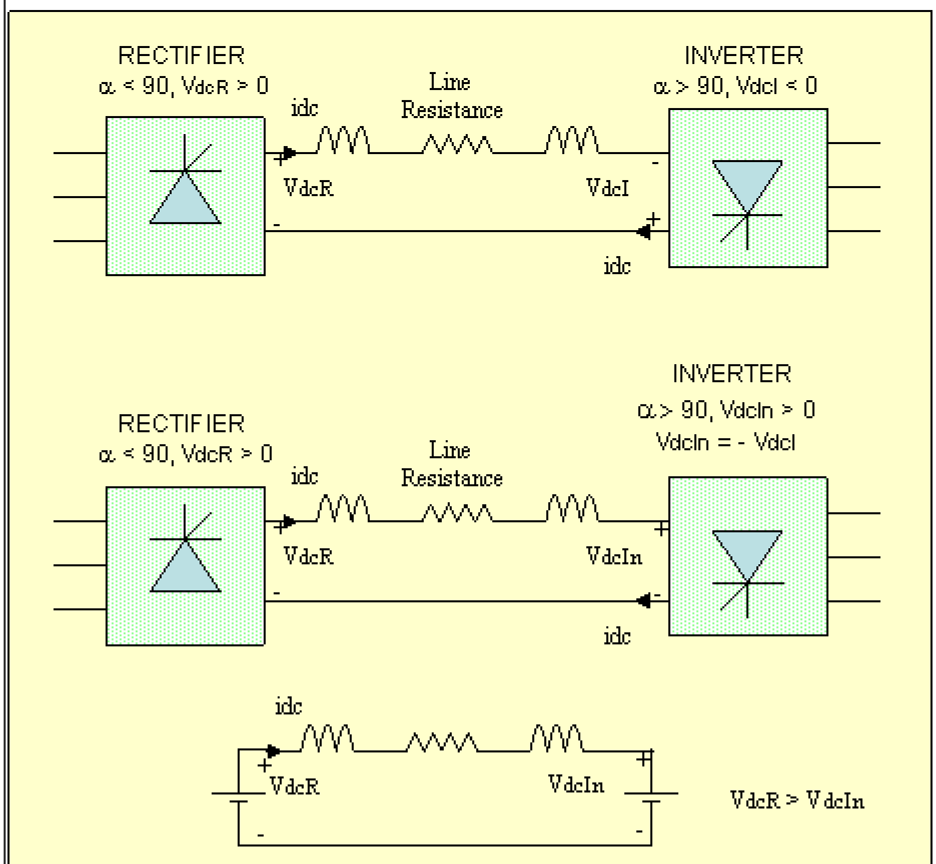
Let us represent a line commutated AC-DC converter as shown below:



An HVDC link consists of a rectifier and inverter connected together as shown in the figures on the right. Power flows from the rectifier to the inverter and is in effect transferred from the rectifier AC side to the inverter AC side. The rectifier voltage VdcR plays the "role" of the dc source, Vi, required for inverter operation as discussed above.

The magnitude of the inverter and rectifier voltages is determined by the firing angle. Current (or power) can be changed by changing the magnitude of either or both voltages. However, since they are constraints on the maximum value of delay angles for inverter, so in practice current is controlled by controlling the rectifier dc voltage.

Since the magnitude of the dc side voltages are dependent only on AC side voltage magnitudes, delay angles, power flow is NOT dependent on AC side system frequency or phase angle at either end.

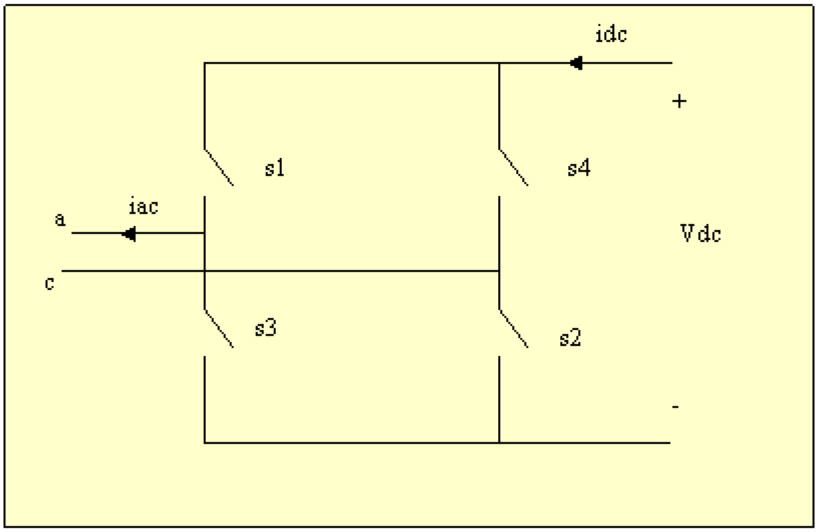


Note : AC side voltages are a must for the operation of a line commutated converter bridge. If AC side voltages are absent, the converter cannot be operated. This has significance in a power system: when the AC system voltages on either side are zero (due to a black out), power cannot be transferred via this link.

Can reverse the direction of power flow in an HVDC link ? how ?

AC-DC Voltage Source Converter: A brief introduction

The converter that we have studied is a "line commutated converter". The voltages required for commutation (turning off a device and switching on another) are obtained from the AC side. On the other hand, a **Voltage Source Converter** (VSC) uses a voltage source (or a capacitor whose voltage is maintained constant) on the DC side and switches with **turn off capability**. These switches can be turned on or off at will, if the voltage on the dc side is positive. The schematic of a single phase voltage source converter is shown below.



The voltage on the AC side is related to the DC side voltage depending on the switch positions:

s1 and s2 ON, s3 and s4 OFF : Vac = Vdc, idc = iac

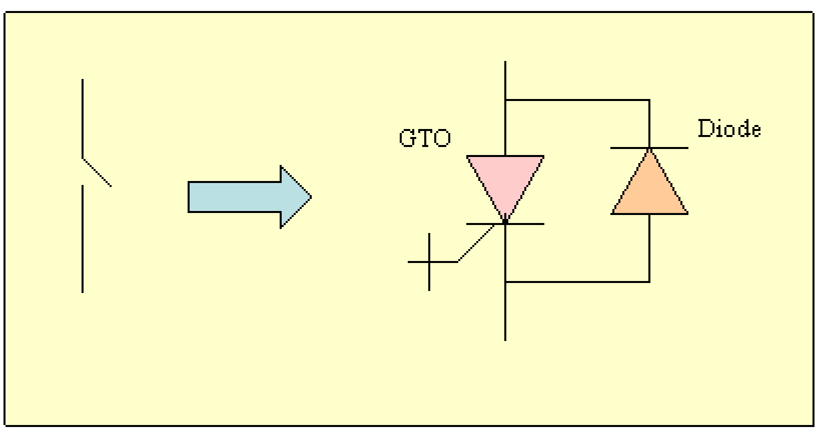
s3 and s4 ON, s1 and s2 OFF : Vac = - Vdc, idc = - iac

s1 and s4 ON, s3 and s2 OFF : Vac = 0, idc = 0

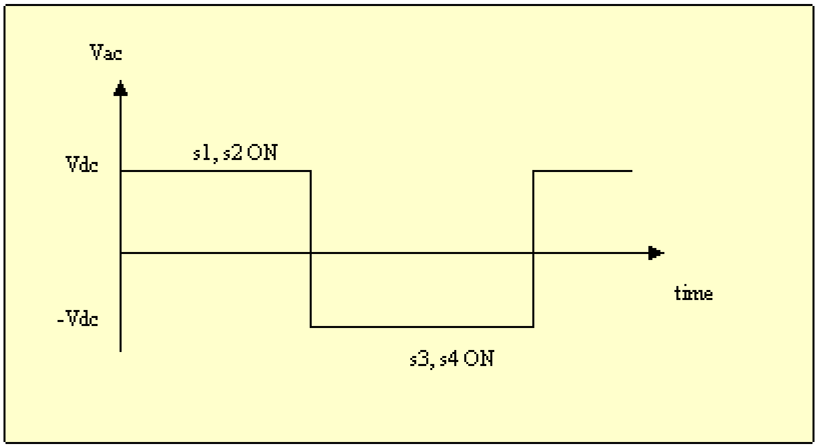
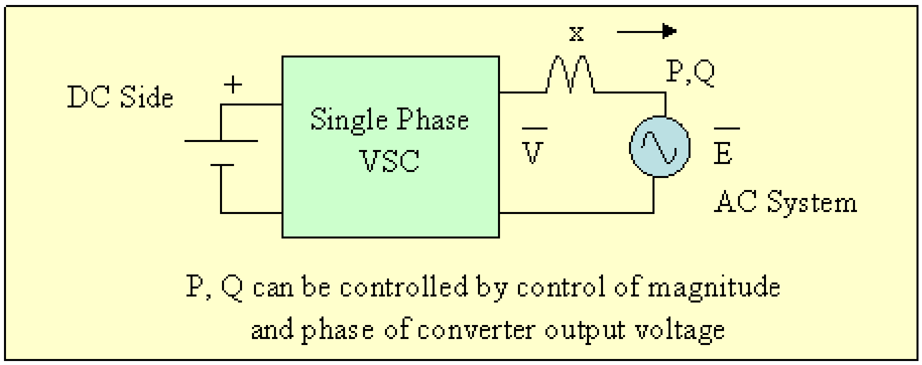
s2 and s3 ON, s1 and s4 OFF : Vac = 0, idc = 0

However, two switches in a leg (e.g. s1 and s3 in the figure above) should not be turned on simultaneously (why ?)

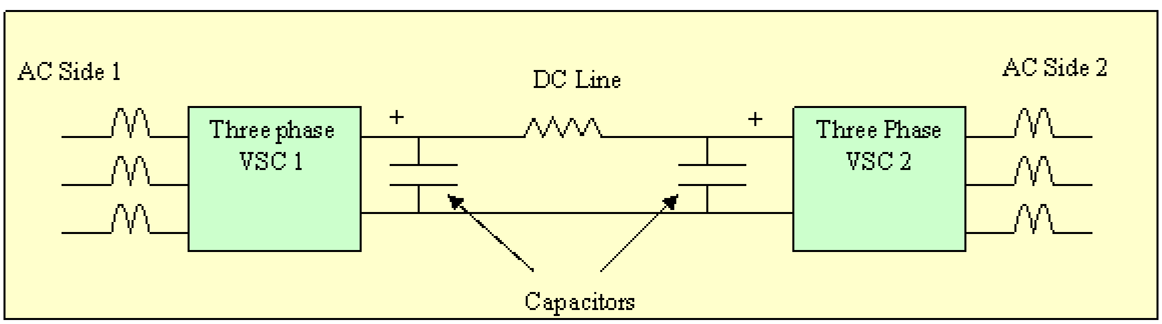
The direction of current on the dc side can be bidirectional, although dc voltage has to be unidirectional. The switches can be implemented using power electronic devices as shown below -- a device like a Gate Turn Off Thyristor (GTO) in parallel with a reverse connected diode. Note that devices like Gate Turn Off Thyristors can be switched off by a gate signal - a capability which an ordinary thyristor lacks. Devices like Insulated Gate Bipolar Transistor also may be used in a VSC instead GTOs.



If s1 & s2 and s3 & s4 are switched alternately, then the voltage on the ac side is a	

square wave as shown on the right. One could develop more elaborate switching schemes in order to yield ac side voltages with **lesser lower order harmonic content** as well as **control** the magnitude of the fundamental of the ac side waveform. These are called **PWM** (pulse width modulation) switching schemes. We do not cover them here, but an interested reader may consult any modern power electronics book for the same. Note that phase angle of the fundamental of the converter ac side voltages may be easily controlled by delaying or advancing the instants of switching. **Thus we can control *both* magnitude and phase angle of the converter AC side voltage independently.** This implies control of real and reactive power injected into the AC system:	 

A VSC has more flexibility from a power systems perspective due to independent control over magnitude and phase angle of the ac side waveforms. A schematic of an HVDC link based on VSCs is shown below.



Note that by appropriate control of voltage magnitude and phase angle at the AC terminals of the VSCs, one may draw/supply real and reactive power from the dc side. The two converter are controlled so that the real power drawn from AC side 1 is supplied to AC side 2 (minus the losses in the DC line resistance). If this balance is not maintained, then capacitor voltages cannot be maintained constant since they will get charged (or discharged) due to power surplus (or deficit) on the DC side.

Can power can be transferred via this VSC based link if the AC system at one end is blacked out ?

Recap

In this lecture you have learnt the following

- Special devices like Static VAR Compensators and tap changing transformers can be deployed in the network to improve voltage profile of a system

- Line -commutated rectifiers or inverters, employed in HVDC links, always absorb reactive power.

- Voltage control of a bus can be done by local reactive power injection.

Congratulations, you have finished Lecture 18a. To view the next lecture select it from the left hand side menu of the page.