Short Answer Questions :

EE6010 HIGH VOLTAGE DIRECT CURRENT TRANSMISSION

UNIT I INTRODUCTION

1. List out the applications of HVDC?

- Long distance bulk power transmission
- Underground or underwater cables
- Asynchronous interconnection of A.C systems operating at different frequencies.

2. What are the types of transmission system?

- High voltage AC electrical transmission system.
- High voltage DC electrical transmission system.

3. State the comparison of AC & DC transmission system?

S.NO	AC Transmission	DC Transmission
1.	It requires three conductors for transmission	It requires only 2conductors
2.	There skin effect is present in AC	There is no skin effect in DC Transmission
3.	More corona loss	Less corona loss
4.	Stability problem occurs.	No stability problem.

4. State the advantages in DC transmission?

- Full control over power transmitted
- The ability to enhance transient and dynamic stability in associated AC networks
- Fast control to limit fault current in DC lines
- Reduced transmission lines.
- Interconnection of systems operating at different frequencies

5. State the disadvantage in dc transmission?

- Inability to use transformer to change voltage levels
- High cost of converter equipment
- Generation of harmonics which requires AC and DC filters, adding to the cost of converters station

- Complexity of control

6. What are the types of DC link?

Monopolar link, Bipolar link, Homopolar link

7. What is the need of smoothing reactor?

Functions of smoothing reactor are :

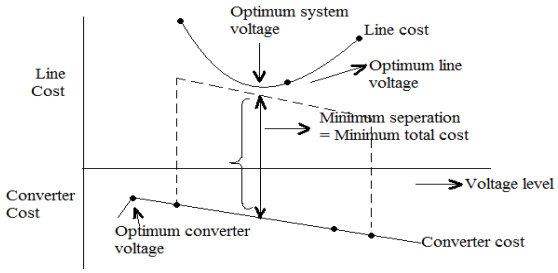
- Prevention of intermittent current
- Limitation of DC fault currents
- Prevention of resonance in the DC circuit
- Reducing harmonic currents including telephonic interference

8. What are the factors to be considered for planning of HVDC transmission?

The system planner must consider the factors are : Cost Technical performance and Reliability

9. Explain in two lines about choice of voltage level in DC transmission

In case of HVDC system, the choice of voltage level is done with an objective to minimize the sum of converter and line costs.



Optimum voltage level to minimize total cost for a fixed power level

10. What is DC breaker? How it will be useful?

DC breakers are used as protective devices in HVDC transmission. In order to limit the fault current in HVDC lines, the DC breaker current should not to exceed the full load ratings of Power converter devices.

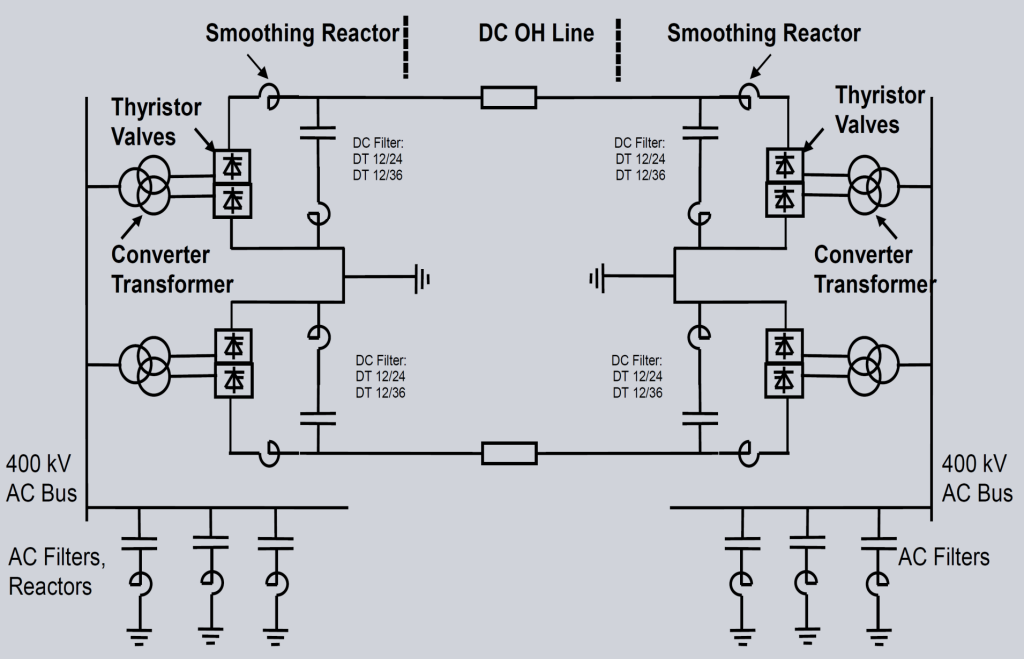
11. Name the new modern trends in DC transmission.

Modern trends in DC transmission include Light Activated SCRs, Digital control of power converters, DC protection systems.

12. What are the power semiconductor devices used in dc transmission?

1. Thyristor
2. Insulated fiats bipolar transistor
3. GTO-gate turn-off thyristor
4. LTT- Light hissered thyrisor
5. Mos-controlled thyristo(MCT)

13. Draw the converter station unit in hvdc transmission



14. How will overcome the disadvantages in dc transmission?

Advancements in microprocessors/microcontrollers, help in overcoming the complexity in control of power converters.

Developments in high power semiconductor devices help to transmit power at high voltages. Use of light activated power semiconductor devices overcomes the time delay in sending switching pulses. Also DC protective

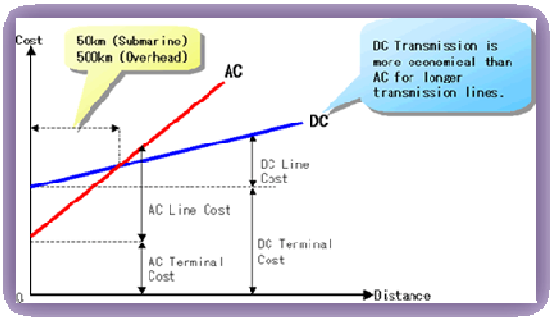
devices help in protecting the HVDC system.

15. State atleast four HVDC projects in India

S.NO	System/Project	Year of Commissioned	Supplier	Power Rating(mw)	Voltage (kv)
1.	National HVDC project-stage-I	1989	BHEL	100	100
2.	NHVDC-stage-II	2000	BHEL	100	200
3.	Rihand-Delhi	1991-92	ABB	750	±500
4.	Chandrapur-padghe	1998	ABB	1500	±500

16. Define break even distance- give its range of value for overhead line

The variation of costs of transmission with distance for AC and DC Transmission. For distances less them break even distance, AC tends to Be economical them DC. And costlier for longer distances. The break even Distances can vary from 500 to 800 km in overhead lines.



17. What is Energy Availability.

$$\text{Energy Availability} = 100\left(1 - \frac{\text{Equivalent outage time}}{\textit{total time}}\right)\%$$

Where equivalent outage time is the product of the actual outage time and The fraction of system capacity lost to outage.

18. Mention the some of HVDC projects from abroad?

1. Gotland 1 – 98km, 200kv, 20mw, 1954

2. HVDC Gotland 2 – vastervik (Sweden) to yipne (Sweden) 92.9km, 150kv, 130mw, 1983
3. HVDC back-to-back station – eagle pan (USA) - eagle pan (USA)(Texas) ±15.9kv,36mw,2000
4. Caprivi link – Namibia (gerus) to Namibia zembari 970km,500kv,300mw,2010

19. What are the potential applications of MTDC systems?

- Bulk power transmission from several remote generating stations to several load centers.
- Asynchronous interconnection between adjacent power systems. A MTDC system for interconnection is more flexible and economical than employing several two terminal DC links.
- Reinforcing of an AC network which is heavily loaded.

1. What are the typical problems considered for study of MTDC systems?

Some of the typical problems that have been considered for study are as follows:

- Operation of small inverter taps connected to weak AC systems.
- Integration of existing HVDC converter stations in MTDC systems without major modifications in control.
- Evaluation of communication, reactive power and filtering requirements.
- Power and reactive power modulation strategies in MTDC systems.

20. List the advantages of MTDC systems.

Advantages

- The power reversal in a converter is achieved by current reversal which is easily arranged by control action without mechanical switches.
- There is no problem of commutation failures.

- It can even supply passive loads.
- The use of Pulse Width Modulation (PWM) eliminates low frequency harmonics and simple AC filters can be supplied.
- There is no need for reactive power compensation of VSC. Actually, a VSC can supply reactive power and can help in the control of the AC voltage.
- High speed reversal of power is possible.
- Overall efficiency of the system increases.

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21. What is MTDC system?

A multi-terminal DC (MTDC) system is a HVDC system where more than two converter stations are connected. Some stations act as rectifiers and others as inverters .

22. Why are multiterminal DC systems needed

MTDC is a DC equivalent of AC grid which will have DC transmission network connecting more than two AC/DC converter stations. Hence it becomes inevitable to have a MTDC system where practically distributed generating stations and load centers are present.

23. What are different types of MTDC systems used?

There are two possible types of MTDC systems:

(i) Series

(ii) Parallel

The parallel MTDC systems can be further subdivided into the following categories:

(a) Radial

(b) Mesh

24. What are the drawbacks in voltage droop control in MTDC systems?

Operation of MTDC outside the voltage control dead-band will reduce the stability of the system during disturbances in large power systems.

25. Can we extend the two terminal system to multi terminal system?

Yes. It is possible

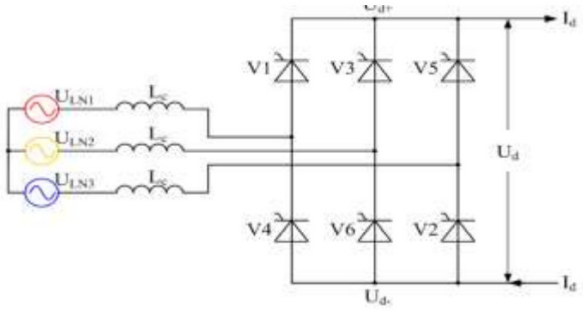
UNIT II ANALYSIS OF HVDC CONVERTERS

26. Define pulse number?

It is defined as the ratio of the base frequency of the DC voltage ripple to the fundamental frequency of the AC voltage is called pulse number.

$$pulse\ number = \frac{Base\ frequency\ of\ the\ DC\ voltage}{fundamental\ frequency\ of\ the\ AC\ voltage}$$

27. Draw the diagram Graetz bridge circuit



28. Write the equation of AC current and no load voltage?

No load DC output voltage across the load without firing angle control is given by

$$V_{do} = \frac{3\sqrt{3}V_m}{\pi} \text{ and}$$

RMS current value of secondary side of the converter transformer is given by

$$I_r = \sqrt{\frac{2}{3}} I_d$$

29. What is choice of converter configuration?

There are several configuration for a converter of a specified pulse number, we have in addition to the graetz bridge, six phase diametric Connection, cascade of three single phase fall wave converters, cascade

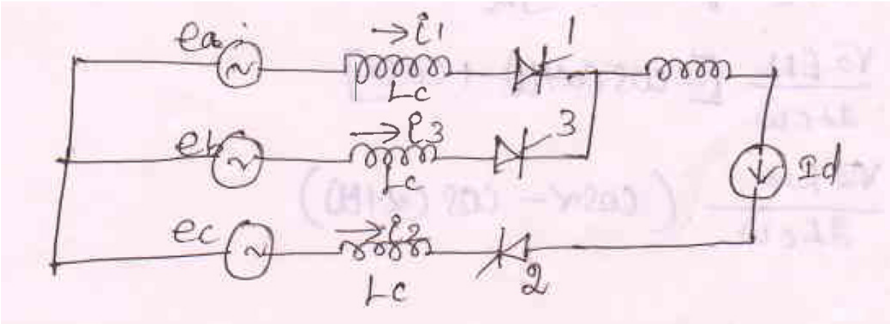
Of two three phase converters. Based on the requirement the choice of converter configuration is done.

30. Define peak inverse voltage?

The peak inverse voltage is the maximum voltage that appears across the valve when the valve is not conducting. PIV is the maximum line to line voltage across any two phases. It is given by

PIV = $\sqrt{3}V_m = \sqrt{2}V_{LL}$

31. Draw the schematic diagram of three & two valve conduction mode



32. **Write the assumptions for analysis of 6 pulse converter?**

To consider the theoretical analysis of a conventional 6-pulse bridge , the following assumptions are made:

- DC current is constant (i.e. the smoothing reactor is infinite),
- Valves are ideal switches, and
- AC system is infinitely strong (i.e. the 3 phase emfs are balanced and perfectly sinusoidal).

33. **Write the average direct voltage expression for graetz circuit?**

$$\mathbf{V_d = V_{do}[\ cos\alpha + cos(\alpha+u)\ and\ V_d = V_{do}\ cos\alpha - R_cI_d}$$

Where; $R_c = 3/\pi\omega L_c = 3/\pi X_c$ = equivalent commutation resistance

34. What is firing angle?

The angle at which thyristor is triggered it is defined as the angle between the zero crossing of the input voltage and the instant the thyristor is fired.

35. Define value rating.

The value voltage rating is specified in terms of peak inverse voltage (PIV) it has to withstand. The ratio of PIV to the average dc voltage is an Index of the value utilization. The average maximum dc voltage across the Converter is given by

$$Vdo = \frac{sq}{\pi} E_M sin \frac{\pi}{q}$$

36. What are the merits of twelve or multibridge pulse converter?

Reduced filtering requirements and Harmonics are eliminated

37. List the assumption made to develop the equivalent circuit of a converter Bridge used in dynamic simulation.

- All the values in a bridge have identical characteristics
- A value offers infinite impedance in the reverse direction
- The grading and damping circuits across the values are ignored
- The current id is assumed to be continuous and non zero.
- L/R of each phase of the converter transformer in the same.

38. Define overlap and overlap angle

Overlap is the phenomenon due to the effect of source inductance on the a.c. side. The current commutation is delayed due to the source inductance which is normally the leakage reactance of a transformer. The waveforms with commutation period, denoted by μ during which both the outgoing diode and incoming diode are conducting. This period is also known as "overlap" period.

39. Mention the various modes of operation of rectifier characteristics.

Mode I : 2 and 3 valve conduction (u< 30 deg)

Mode II : 3 valve conduction only α < 30 deg, u = 60deg

Mode III : 3 and 4 valve conduction mode α > 30 deg,(60<u<120deg)

40. Mention the various modes of characteristics of 12 pulse converter.

Mode I : 4 and 5 valve conduction 0 < 30deg

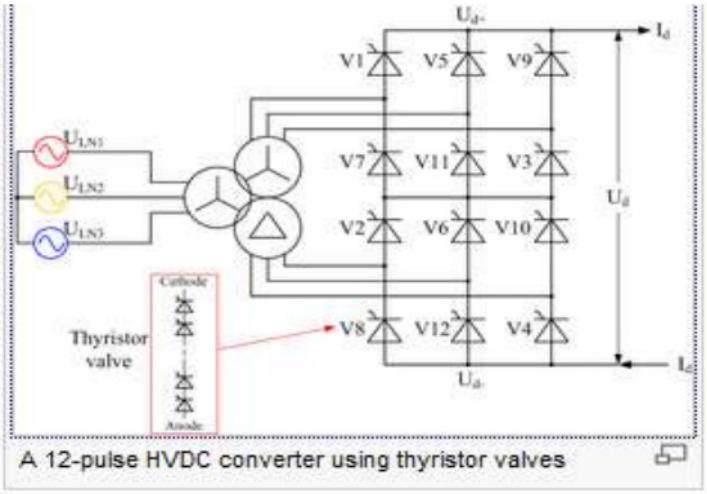
Mode 2: 5 and 6 valve conduction; 30deg < u < 60deg

Mode 3: 6 valve conduction $0 < \alpha < 30deg$, $u = 60deg$

Mode 4 : 6 and 7 valve conduction $60deg < u < u < 90deg$

Mode 5: 7 and 8 valve conduction, $90deg < u < 120deg$

41. Draw the circuit diagram of 12 pulse converter



A 12-pulse HVDC converter using thyristor valves

42. **Why series and parallel operation of thristor in HVDC TRANSMISSION?**

For higher voltage rating use series operation of thyristor

For higher current rating use parallel operation of thyristor

UNIT III CONVERTER AND HVDC SYSTEM CONTROL

43. **Why the necessity of control in a DC link?**

The expression for current through a DC link it can be observed that the denominator has only resistances, which are small when compared with the reactance of the AC system. Hence, current is sensitive to change in voltage resulting in large fluctuations which can damage the thyristors,

44. **What is the principal of control in DC link?**

The control of powerin a DC link can be achieved through the control of current of voltage. From minimization of loss considerations, it is important to maintain constant voltage in the link and adjust the current to meet the required power.

45. **State any four important reasons why the current control is desirable in the Rectifier station under normal operating conditions?**

- The increase of power in the link is achieved by reducing αr, which improves the power factor at the rectifier.
- The inverter can now be operated at minimum ע thereby minimize the reactive power consumption.
- The operation at minimum extinction angle at the inverter and current control at the rectifier results in better voltage regulation then the operation with minimum delay angle at the rectifier & current control at the inverter.
- The current during line fault are automatically limited with rectifier station in current control.

46. **How power is reversed in HVDC link?**

The power reversal in the link can take place by the reversal of the DC Voltage. This is done easily by increasing the delay angle at the station initially operating as the rectifier, while reducing the delay angle at the station initially operating as the inverter.

47. **Define firing angle control**

The current or extinction angle controller generates a control signal V_c, which is related to the firing angle required. The firing angle controller generates gate pulses in response to the control signal V_c.

48. **What are the parameters to change current and power transfer in DC link?**

i) Control angle of rectifier α

ii) Control angle of inverter β
iii) Tap changer on rectifier side
iv) Tap changer on inverter side

49. **What is equidistant pulse control?**

Equidistant Pulse Control (EPC) is one of the control scheme which is used to generate firing pulses. It does not involve direct synchronization of the control pulse to the AC voltage is applied. It is widely used in weak AC system. It uses the production of a single pulse spacing at equal intervals of (1/pf) through a ring counter, where p is the pulse number and f is the fundamental frequency.

50. **Define current margin**

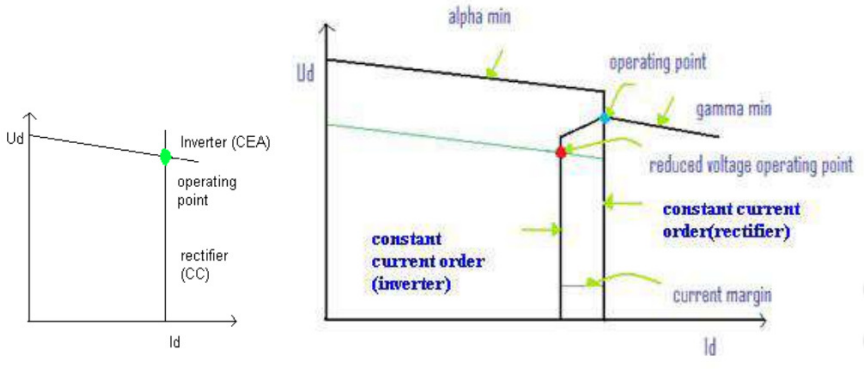
The difference between the current controller settings of the two stations is called

Current margin (I_m). In order to avoid conflict between the two current controllers at the both end, the rectifier current controller is provided with a higher current order.

$$\mathbf{I_{di} = I_{dr} - I_m}$$

Where I_{di} – current order of the inverter
I_{dr} - current order of the rectifier
I_m usually about 10% of rated value

51. Draw the characteristics curve for inverter compounding?



52. What is the need for transformer tap changer control of HVDC converter?

The tap changing transformer used to increase the power factor obtained in the ac side and maintain the operating point at point A or B in the Vd , id characteristics of rectifier and inverter use tap changing transformer.

53. What is the use of transformer tap changer control at the inverter side of an HVDC system?

The on-load tap changer control at the inverter is used mainly to maintain a constant DC voltage. The tap changer control at the rectifier is designed to maintain delay angle within the limits (say 10deg to 20deg) in order to maintain certain voltage margin for the purpose of current control.

54. What is meant by compounding a converter?

The term compounding a converter implies selection of converter characteristics in order to meet the requirements of regulation and protection

UNIT IV REACTIVE POWER AND HARMONICS CONTROL

55. What are the requirements of reactive power control in HVDC system?

- HVDC converters absorb reactive power, approximately 50% to 60% of their active power. •Harmonic filters are installed on the AC side for filtering the AC current and for generation of reactive power.
- •The reactive power absorption of a converter increases with the transmitted active power. Also the need for filtering of harmonics is increased.
- •The need for reactive power grows slowly at low power, and more pronounced at high power, whereas the filter needs behave in the opposite fashion.
- •The reactive power compensation scheme has to take care of the unbalances for the AC system requirement, by switching of filters

56. List various sources of reactive power in HVDC system.

- AC system
- AC filters
- Shunt capacitors

- synchronous condensers
- SVC or STATCOM

57. State the advantage of synchronous condenser.

It contributes to system short circuit capacity. It provides voltage sources for the line commutation at the inverter when the load is supplied by the inverter is passive.
During power swings, there is an exchange of kinetic energy between a synchronous condenser and the power system. During such power swings, it can supply a large amount of reactive power.
It provides good voltage regulation during transient due to flux linkages in the rotor windings. The effect of armature reaction is overcome by induced currents in the field during transient.

58. Write the basic concept of Thyrisor switched capacitor used in reactive power control of HVDC.

TSC is used to provide leading VARs during heavy loads. It consists of a capacitor bank, bidirectional thyristor and small inductor. Inductor is used to reduce switching transients, to dump inrush currents and also to prevent from the resonance with network. The current through the capacitor can be varied by controlling the firing angles of back to back thyristor connected in series with the capacitor.

59. **Mention the performance criteria for selection of harmonic filter**.

- Harmonic distortion
- Telephone influence factor
- Telephone Harmonic form factor
- IT product

60. How harmonics are generated?

- Magnetization nonlinearities of transformer Rotating machines and Adjustable speed drives.
- Arcing devices and Electronic and medical test equipment
- PCs and office machines , Induction Heaters
- Semiconductor based power supply system
- Inverter fed A.C. drives , Thyristor controlled reactors
- Phase controllers and A.C. regulators

61. Write the characteristics of Harmonics?

Harmonics will result in

- Resonance
- Poor Damping
- efficiency of devices reduced
- Overheating of cable
- Trip of protection
- Overheating at winding
- Increase magnetic losses.

62. **Differentiate characteristic and non-characteristic harmonics**

s.no	characteristics harmonics	Non Characteristics harmonics
1	It's always presents even under ideal operation, balanced AC voltages, equidistant pulses	Unbalance and distortion in AC voltages
2	Equal transformer leakage reactance	Unequal transformer leakage impedances
3	Order of harmonics may be h=np±1 or h=np	Order of harmonics cannot be represented

63. Define DC Filter?

Dc voltage on the converter side contains both characteristics and non characteristics harmonics. It results in production of noise in telephone circuits. DC filters are designed to only eliminate DC harmonic voltages and no need to supply reactive power as in case on AC filters. But designer should consider stresses on filters due to DC voltages in addition to harmonics during design.

64. Define total harmonics distortion?

The THD is a measure of the *effective value of the harmonic components* of a distorted waveform. That is, it is the potential heating value of the harmonics

relative to the fundamental. This index can be calculated for either voltage or current

65. **List the causes of non-characteristics harmonis**

a) Imbalance in the operation of two bridges forming 12 pulse converter
b) Firing angle errors
c) unbalance and distortion in AC voltage and
d) unequal transformer leakage impedances

66. Define Telephone influence factor.

It is an index of possible telephone interference and it is defined as

$$TIF = \left[\sum_{n=1}^{m}(I_n Z_n F_n)^2\right]^{1/2} \Big/ E$$

Where $F_n = 5nf_1p_n$ and p_n is C message weighting used by Bell telephone Systems (BTS) and Edison Electric Institute (EEI)

67. What are the types of AC filters?

- Single tuned filters
- Double tuned filters
- High pass filters – second order filters and C type filters

13. Define single tuned filter?

A tuned filter is designed to filter a single harmonic (of order h_r). if $h_r\omega = \omega_r$, then impedance offered by filter is minimum.

68. What is the function of smoothing reactor in HVDC systems?

A sufficiently large series reactor is used on DC side to smooth DC current and also for protection. The reactor is designed as a linear reactor and is connected on the line side, neutral side.

UNIT V POWER FLOW ANALYSIS IN AC/DC SYSTEMS

69. What are the basic considerations in representation of the DC systems?

The representation of the dc systems requires consideration of the following:

- Converter model
- DC transmission line/network model
- Interface between AC and DC systems
- DC system controls model

70. Define per unit system for DC quantities

A convenient per unit system for the DC quantities has the following base values.

$$V_{dc\,base} = B\,\frac{3\sqrt{2}}{\pi}V_{dc\,base} = Vdc \qquad \ldots (6.1)$$

$$I_{dc\,base} = I_{dc\,rated} \qquad \ldots (6.2)$$

$$Z_{dc\,base} = \frac{V_{dc\,base}}{I_{dc\,base}} \qquad \ldots (6.3)$$

$$P_{dc\,base} = (V_{dc\,base}) \times (I_{dc\,base}) \qquad \ldots (6.4)$$

where

B = number of bridges in series in the dc converter

$V_{ac\,base}$ = line - to - line ac base voltage referred to the LT side of the commutating transformer.

If the commutating reactance per bridge expresed in ohms is X, then the per unit total commutating reactance for the B bridges in series is

$$\bar{X}_{dc} = \frac{BX}{Z_{dc\,base}} \qquad \ldots (6.5)$$

71. What is the significance of power flow analysis?

The power flow or load flow analysis of AC systems has been thoroughly investigated in terms of numerical algorithms for obtaining the solution to the nonlinear algebraic equations.

72. What are the equations used for corrections to the bus voltage estimation in fast decoupled load flow method?

$\Delta P / V = [B'] \Delta\theta$

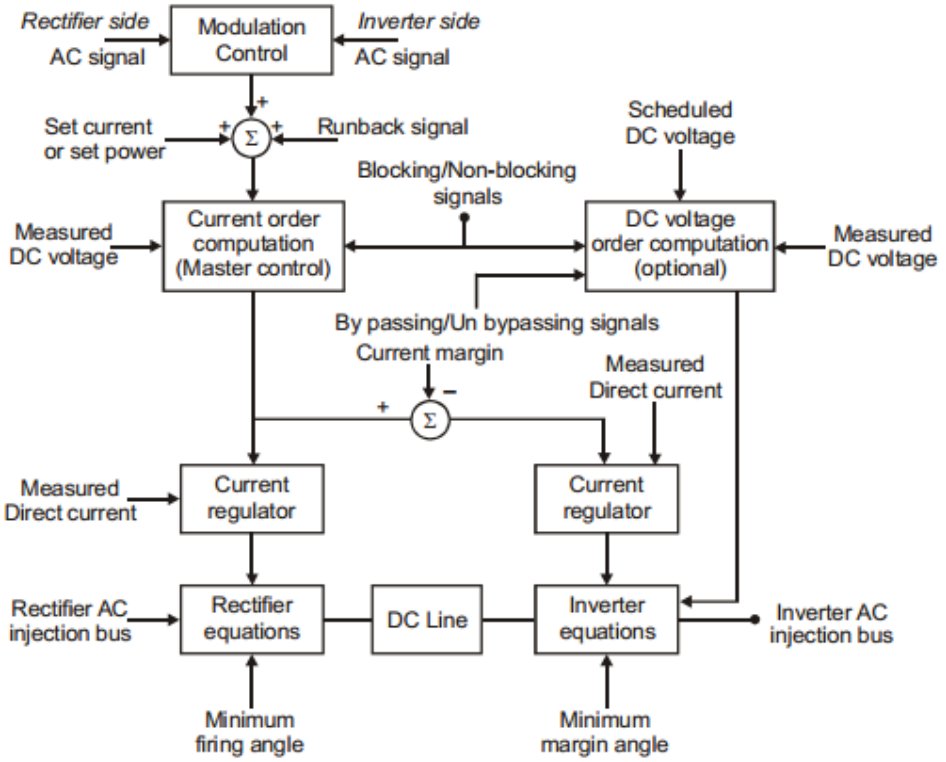
$\Delta Q / V = [B''] \Delta V$

Where ΔP, ΔQ are mismatches of real and reactive powers at bus i, Δθ and ΔV are the correction vectors to bus angles and voltage magnitudes. B' and B'' are constant matrices of appropriate sizes and consist of elements that are related to the reactances of the elements of the network.

73. Compare the simultaneous and sequential methods of AC-DC power flow.

The sequential method has the advantage of modularity in programming where the AC and DC systems are modeled separately in different program segments. Generally, the AC load flow program is written for large systems and is well tested. The AC system formulation is also well established. In contrast, the DC system controllers can be flexible and undergo changes as the technology is continuously improving. In such cases, it is much simpler to modify or update DC system models to incorporate new controllers. However, from the computational point of view and convergence of the solution algorithm under specific conditions, the unified solution method has an edge over the alternating method. It is claimed the for DC links operating from weak AC systems, the unified solution method converges much faster than the sequential method.

74. Draw the DC system model.



75. Write the different types of solution of AC/DC power flow.

The solution methodology for AC/DC power flow can be classified as

- Simultaneous or Unified Method
- Sequential or Alternating method

76. What is unified method of DC power flow?

Simultaneous or Unified Method:

The AC and DC equations are solved together. Conceptually, the simplest implementation of this approach is considered all equations combined into one set of nonlinear algebraic equations. A Jacobian matrix is then constructed and Newton's method is used to solve this set of equations. A variation of this approach is to use "fast decoupled" method of solution for the AC system equations.

77. What is sequential method of DC power flow?

Sequential or Alternating method :

The AC and DC equations are solved separately and sequentially. The AC system is solved to some degree of convergence using a simple model for the DC system on its last solution. The DC system is then solved using a simplified representation of the AC system. There are many variations of this approach as given below.

- Represent the AC system as a constant voltage, constant angle model at every converter and the DC system as a constant active and reactive power source during the AC solution.
- Represent the AC system by an uncoupled or coupled Thevenin's equivalent model during DC solution.
-

78. Write the relationship between AC and DC per unit quantities.

The base power and base impedence for the ac system are

$$P_{ac\,base} = MVA_{base} = \sqrt{3}\, V_{ac\,base}\ I_{ac\,base}$$

$$Z_{ac\,base} = \frac{V_{ac\,base}}{\sqrt{3}\, I_{ac\,base}}$$

In the ac solution, the commutating reactance is represented by the parallel combination of B individual transformer reactance. The per unit value of X_c in the ac per unit sytem is,

$$\bar{X}_{ac} = \frac{X}{B\, Z_{ac\,base}} \qquad \ldots (6.8)$$

$\therefore$ the ratio of the per unit values of X_c in the two system is

$$\frac{\bar{X}_{dc}}{\bar{X}_{ac}} = \left(\frac{BX}{Z_{dc\,base}}\right)\left(\frac{B\, Z_{ac\,base}}{X}\right)$$

$$= B^2 \left(\frac{Z_{ac\,base}}{Z_{dc\,base}}\right) = B^2 \left(\frac{V_{ac\,base}}{V_{dc\,base}}\right)^2 \left(\frac{P_{dc\,base}}{P_{ac\,base}}\right)$$

$$= \left(\frac{3\sqrt{2}}{\pi}\right)^2 \left(\frac{P_{dc\,base}}{P_{ac\,base}}\right)$$

$$\frac{\overline{X}_{dc}}{\overline{X}_{ac}} = \frac{18}{\pi^2}\left(\frac{P_{dc\,base}}{P_{ac\,base}}\right) \qquad \ldots (6.9)$$

$$\frac{\overline{I_{dc}}}{I_{ac}} = \left(\frac{I_{ac\,base}}{I_{ac}}\right)\left(\frac{I_{dc}}{I_{dc\,base}}\right) = \left(\frac{I_{dc}}{B\frac{\sqrt{6}}{\pi}}\right)\left(\frac{I_{ac\,base}}{I_{dc\,base}}\right)$$

$$= \left(\frac{\pi}{B\sqrt{6}}\right)\left(\frac{V_{dc\,base}}{\sqrt{3}\,V_{ac\,base}}\right)\left(\frac{P_{ac\,base}}{P_{dc\,base}}\right)$$

$$= \left(\frac{P_{ac\,base}}{P_{dc\,base}}\right)\left(\frac{3\sqrt{2}\pi}{\sqrt{3}\cdot\sqrt{6}\,\pi}\right)\left(\frac{B}{B}\right)$$

$$\frac{\overline{I_{dc}}}{\overline{I_{ac}}} = \frac{P_{ac\,base}}{P_{dc\,base}} \qquad \ldots (6.10)$$

Usually, $P_{dc\,base}$ is chosen to be equal to $P_{ac\,base}$. Alternatively, P_{dc} base may be chosen to be the nominal rating of the dc line. It is obvious that the use of the per unit system for hte dc quantities offers no particular advantage. The dc quantities may in fact be handled in terms of their natural units, and many computer programs do so.

79. Draw the norton's equivalent circuit for a converter.

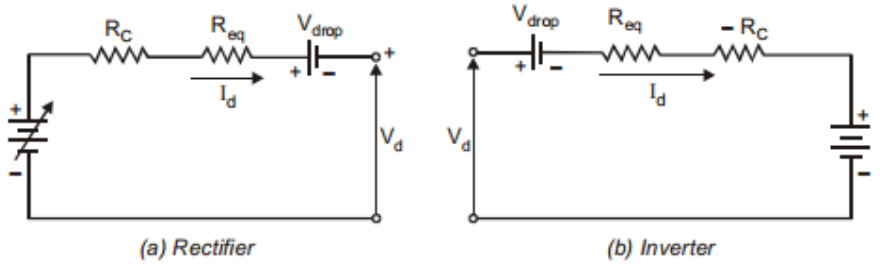


Fig. 6.11 converter equivalent circuits