Chapter-5 combined compensators unified Power Flow controller (UPFC) and interline Power Flow controller (IPFC)

* The unified Power Flow controller

The unified power flow controller (UPFC) concept was proposed by Gyugyi in 1991. The UPFC was devised for the real time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility required to solve many of the problems facing the power delivery industry within the frame work of traditional power transmission concepts. the UPFC is able to control simultaneously or selectively all the parameters affecting power flow in the transmission line (i.e voltage, impedance and phase angle) and this unique capability is signified by the adjective "unified" in its name. It can independently control both the real & reactive power flow in the line.

* Basic operating principles:

From the conceptual view point, the UPFC is a generalized synchronous voltage source (SVS)

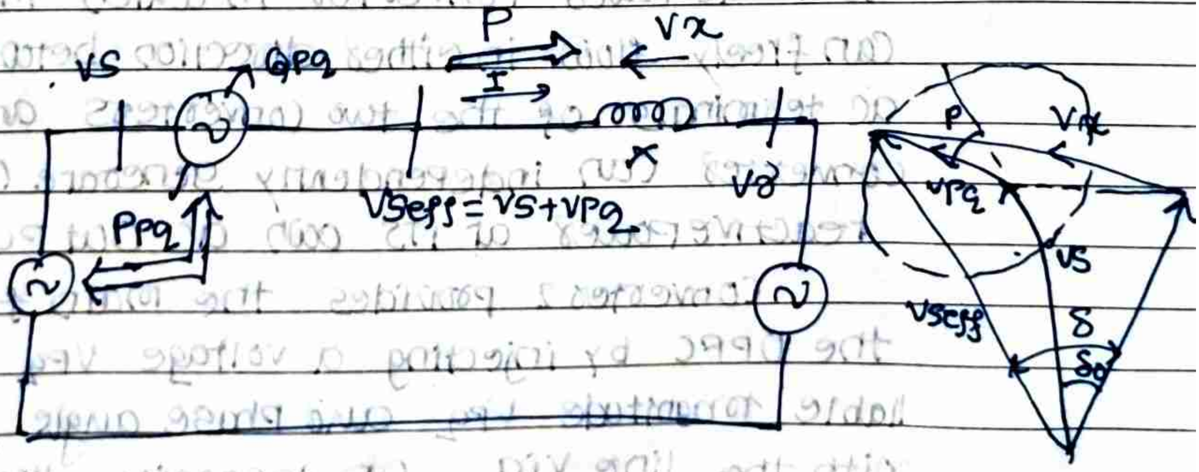

Fig conceptual representation of the UPFC in a two machine power system

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represented at the fundamental (power sys frequency by voltage phasor V_{pq} with contro-ble magnitude V_{pq} $(0 \leq V_{pq} \leq V_{pqmax})$ and ρ $(0 \leq \rho \leq 2\pi)$ in series with the transmission line as illustrated for the usual elementary two machine system (or for two independent systems with a transmission link intertie) in fig 8.3
the SVS generally exchanges both reactive and real power with the transmission system. SVS is able to generate only the reactive power exchanged. the real power must be supplied to it or absorbed from it by a suitable power supply or sink. In the UPFC arrangement the real power exchanged is provided by one of the end buses

In the presently used practical implementation the UPFC consists of two voltages sourced converters as illustrated fig 8.4. These back-to back converters labeled "converter 1" and "converter 2" in the figure are operated from a common dc link provided by a dc storage capacitor. As indicated before this arrangement functions as an ideal ac to ac-power converter in which the real power can freely flow in either direction between the ac terminals of the two converters and each converter can independently generate (or absorb) reactive power at its own ac output terminal

Converter 2 provides the main function of the UPFC by injecting a voltage V_{pq} with contro-llable magnitude V_{pq} and phase angle ρ in series with the line via an insertion transformer This injected voltage acts essentially as synchronous ac voltage source.

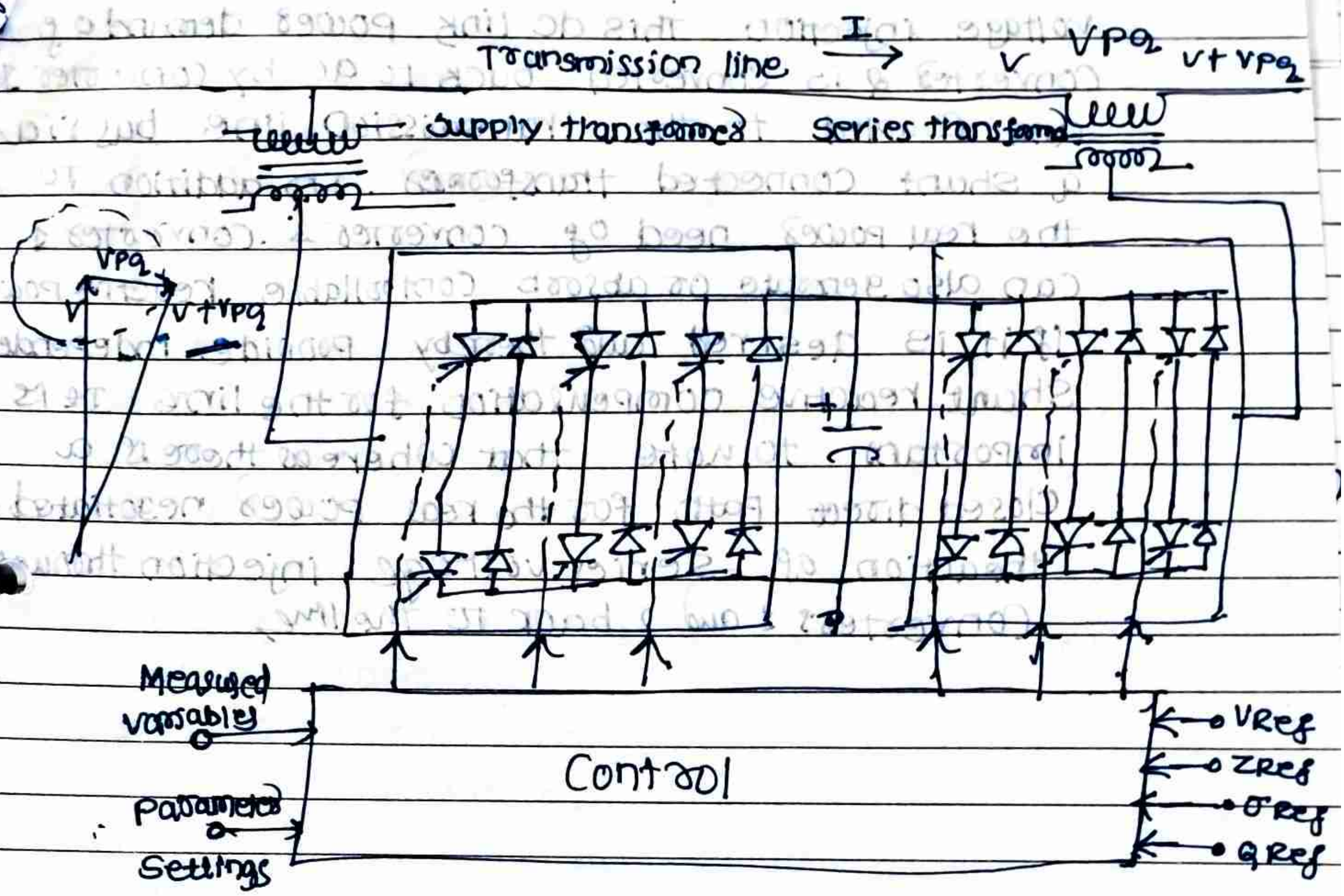

fig Implementation of the UPFC by two back-to back voltage-sourced converters

The transmission line current flows through this voltage source resulting in reactive and real power exchange between it and the ac system. the reactive power exchanged at the ac terminal (i.e at the terminal of the series insertion transformer) is generated internally by the converter the real power exchanged at the ac terminal is converted in to dc power which appears at the dc link as a positive or negative real power demand

The basic function of converter 1 is to supply or absorb the real power demanded by converter 2 at the common dc link to support the real power exchange resulting from the series voltage injection. This dc link power demand of converter 2 is converted back to ac by converter 1 and coupled to the transmission line bus via a shunt connected transformer. In addition to the real power need of converter 2, converter 1 can also generate or absorb controllable reactive power if it is desired and thereby provide independent shunt reactive compensation for the line. It is important to note that whereas there is a closed direct path for the real power negotiated by the action of series voltage injection through converters 1 and 2 back to the line

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* Control Structure of UPFC :

- With suitable controls the UPFC can cause the series - injected voltage vector to vary rapidly and continously in magnitude and or angles as desired.
- It is not only able to establish an operating point within a wide range of possible. P.Q conditions on the line. but also has the inherent capability to transition rapidly from one such achievable. operating point to any other.
- The control of the UPFC is based upon the vector control approach
- The term vector. instead of phasor is used in this section to represent a set of three instantaneous phase variables voltages or currents that sum to zero
- The symbol $\bar{V}$ and $\bar{I}$ are used for voltage and current vectors
- These vectors are not stationary, but move around a fixed point in the plane as the values of the phase variables change. describing various trajectories which become circles identical to those obtained with phasor. when the phase variable represent a balanced steady -state condition.
- These vectors in an orthogonal co-ordinate system with p and q axes with such that the p-axis is always coincident with the instantaneous voltage vector $\bar{V}$ and the q axis is in quadrature with it
- In this co-ordinate system the p-axis current component i_p accounts for the instantaneous real power and the q-axis current component. i_q for the reactive power

under balanced steady-state conditions the d-axis and q-axis components of the voltage and current vector are constant quantities.

- This characteristic of the described vector representation makes it highly suitable for the control of the UPFC by faciliating the decoupled control of the real and reactive current components.
- The UPFC control system may be divided fuctionally in to internal (or converter) control and fuctional operation control.
- The internal controls operate the two converters so as to produce the commanded series injected voltage and simultaneously draw the desired shunt reactive current.
- The internal control provide gating signals to the converter valves so that the converter output voltages will properly respond to the internal reference variables I_{pRef}, I_{qRef} and V_{pqref},
- The series converter responds directly and independently to the demand for series voltage vector injection.
- The shunt converter operates under a closed loop current control structure whereby the shunt real and reactive power components are independently controlled.
- The shunt real power is dictated by another control loop that acts to maintain a preset voltage level on the dc link thereby providing the real power supply or sink needed for the support of the series voltage injection.
- i.e the control loop for the shunt real power ensures

control structure of UPFC

* with suitable control the UPFC can cause the series-injected voltage vector to vary rapidly and continously in magnitude and lor angle as desired

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* The internal control operate the two converters so as to produce the commanded series injected voltage and simultaneously draw the desired shunt reactive current
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* The series converter responds directly and independently to the demand for series voltage vector injection.
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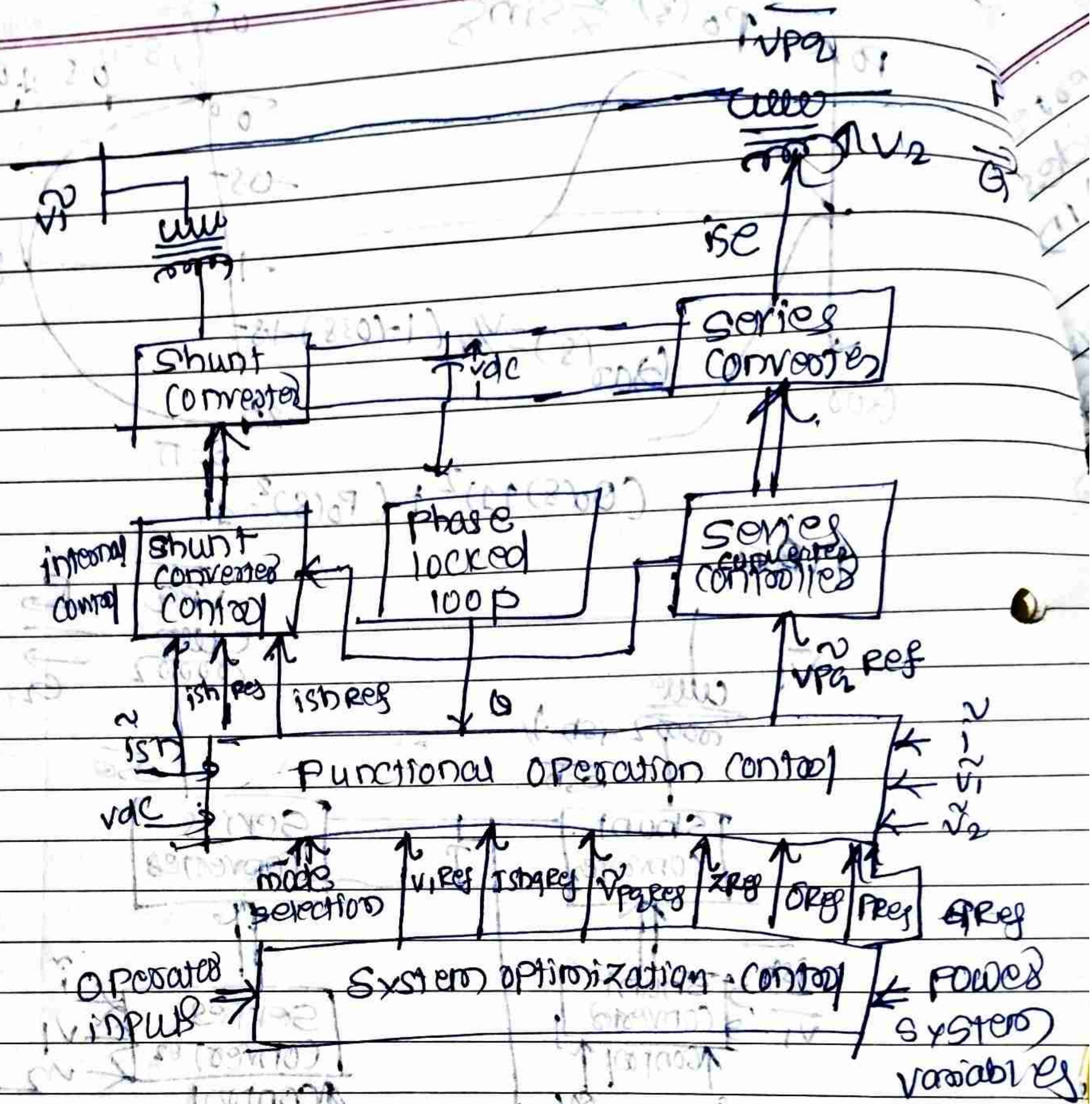

Over all UPFC control structure

1. S.C draws a controlled current ish from the line
2. ish is automatically determined by the
3. one component of ishp is automatically determined by the requirement to balance the real power of the series converter
4. ishq is reactive and can be set to any desired reference level (inductive or capacitive) within the capability of the converter
5. The reactive compensation control modes of the shunt converter are very similar to those commonly employed for the STATCOM and conventional static var compensator

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Reactive power control mode

* In this mode the Reference input is an inductive or capacitive var request

* The shunt converter control translates the var referance into a corresponding shunt current request and adjusts the gating of the converter to establish the desired current
* The control in closed-loop arrangement uses current feedback signals obtained from the output current of the shunt converter to enforce the current reference.
* A feed back signal representing the dc bus voltage Vdc is also used to ensure the necessary dc link voltage.
*

Voltage control mode
* In voltage control mode (which is normally used in practical applications)
* The shunt converter reactive current is automatically regulated to maintain the transmission line voltage to a reference value at the point of connection with a defined droop characteristic.
* the droop factor defines the per unit voltage error per unit of converter reactive current within the current range of the converter
* the voltage control uses voltage feedback signals usually representing the magnitude of the positive sequence component of bus voltage V_1

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* Functional control of the series converter

1) The series converter controls the magnitude & angle of the voltage vector V_{pq} injected in series with the line.

2) This voltage injection is directly or indirectly always intended to influence the flow of power on the line

3) V_{pq} is dependent on the operating mode selected for the UPFC to control power flow

Direct voltage control mode.

- The series converter simply generates the voltage vector V_{pq} with the magnitude & phase angle requested by the reference input
- This operating mode may be advantageous when a separate system optimization control co-ordinates the operation of the UPFC and other FACTS controllers employed in the transmission system.
- Special functional case of direct voltage injection include those having dedicated control objectives.

* E.g when the injected voltage vector V_{pq} is kept in phase with the system voltage for voltage magnitude control or
* In quadrature with it for controlled "quadrature boosting" or
* In quadrature with the line current vector to provide controllable reactive series compensation.

* IPFC (Interline power flow controller (IPFC)

* This capability of the UPFC is facilitated by its power circuit which is basically an ac to ac power converter, implemented by two back-to back converters with a common dc voltage link.

* The output of one converter is coupled in series while the output of the other in shunt with the transmission line.

* UPFC concept provides a powerful tool for the cost effective utilization of individual transmission lines by facilitating the independent control of both the real and reactive power flow, and thus the maximization of real power transfer at minimum losses in the line.

* The IPFC is operated for compensating a number of transmission lines at a given substation.

* Conventionally series capacitive compensation is employed to increase the transmittable real power over a given line and also to balance the loading of a normally encountered multiline transmission system.

* However independent of their means of implementation, series reactive compensators are unable to control the reactive power flow in and thus the proper load balancing of the lines.

* This problem becomes particularly evident in those cases where the ratio of reactive to resistive line impedance (X/R) is relatively low.

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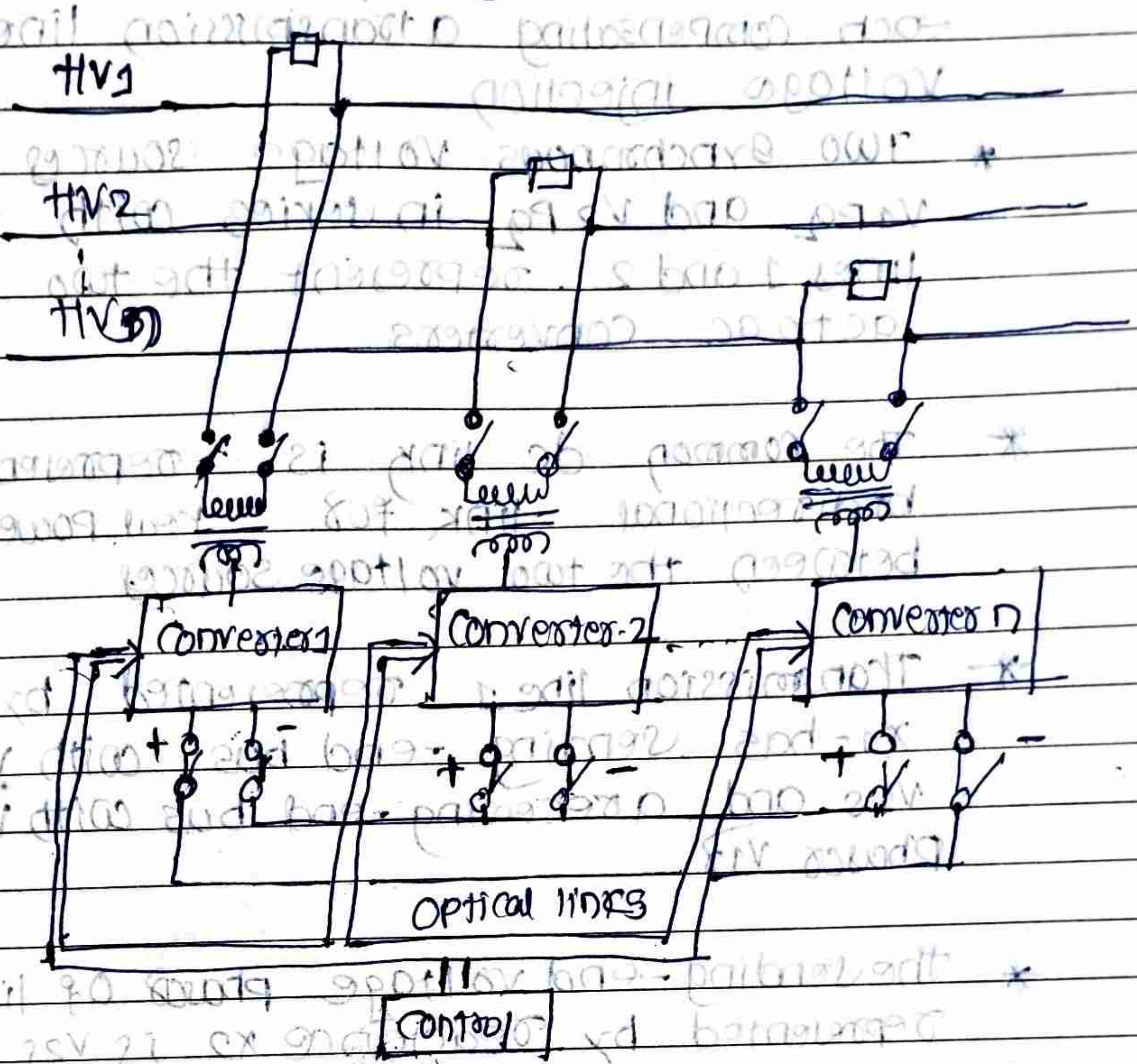
* series reactive compensation reduces only the effective reactive impedance X and thus significantly decreases the effective X/R ratio and thereby increases the reactive power flow and losses in the line
* The IPFC scheme together with independently controllable reactive series compensation of each individual line provides a capability to directly transfer real power between the compensated lines
* Equalize both real and reactive power flow between the lines reduce the burden of overload lines by real power transfer
* Compensate against resistive line voltage drops and the corresponding reactive power demand
* Increase the effectiveness of the overall compensating system for dynamic disturbances

* Basic operating principles of IPFC

1) in general form the interline power flow controller employs a number of dc-to ac converters each providing series compensation for a different line
2) The concept of the IPFC. the compensating converters are linked together at their dc terminal
3) with this scheme in addition to providing series reactive compensation any converter can be controlled to supply real power to the common dc link from its own transmission line
4) Thus an overall surplus power can be made available from the under utilized line which then can be used by other lines for real power compensation

* Basic Operating principles of IPFC (cont...)



Interline power flow controller comprising n converters

1) some of the converters. compensating overloaded lines or lines with a heavy burden of reactive power flow
2) can be equipped with full, two-dimensional reactive and real power control capability similar to that offered by the UPFC
3) This arrangement mandates the rigorous maintenance of the overall power balance
4) at the common dc terminals by appropriate control action
4) consider an elementary IPFC scheme consi...

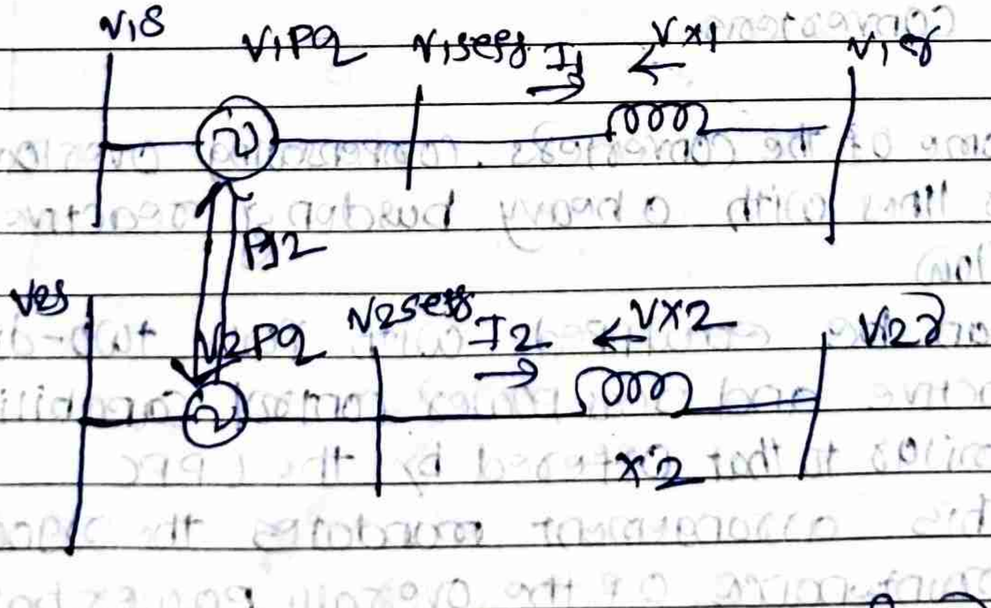
of two back-to-back dc-to-ac converters each compensating a transmission line by series voltage injection

* Two synchronous voltage sources with phasors V_{1pq} and V_{2pq} in series with transmission lines 1 and 2 represent the two back-to-back dc-to-ac converters.

* The common dc link is represented by a bidirectional link for real power exchange between the two voltage sources

* Transmission line 1 represented by reactance X_1 has sending-end bus with voltage phasor V_{1s} and a receiving-end bus with voltage phasor V_{1r}

* The sending-end voltage phasor of line 2, represented by reactance X_2 is V_{2s} and the receiving-end voltage phasor is V_{2r}



* For clarity all the sending end and receiving-end voltages are assumed to be constant with fixed amplitudes: $V_{1s} = V_{1r} = V_{2s} = V_{2r} = 1.0$ P.U.

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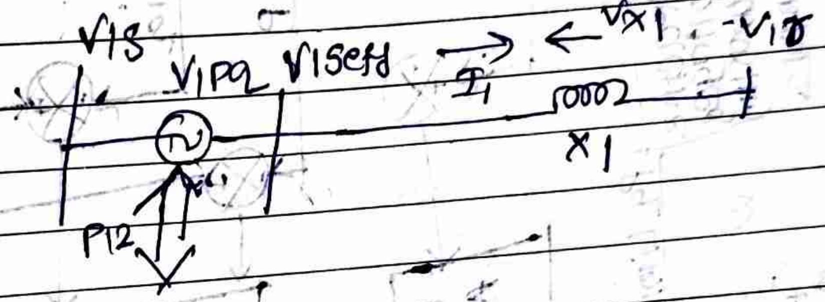
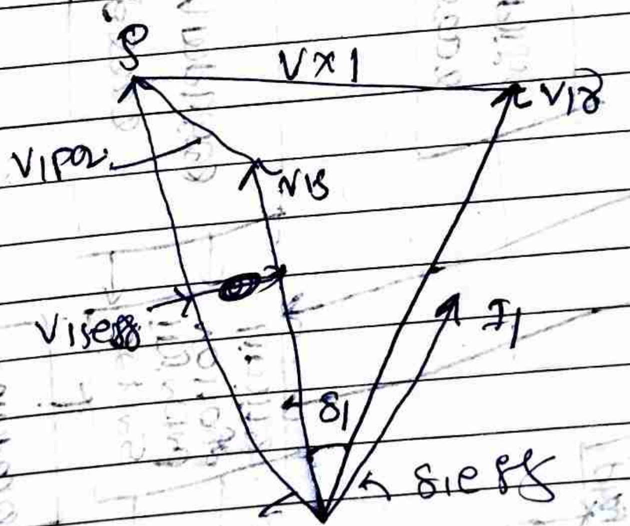
and with fixed angle resulting in identical transmission angle $\delta_1 = \delta_2 (=30°)$ for the two systems

* The two line impedances.

= $V_{1pq\,max} = V_{2pq\,max}$.

and $X_1 = X_2 = 0.5$





$P = \frac{V_1^2}{x} \sin\delta$

Control structure