UNIT-5

POWER QUALITY ENHANCEMENT USING CUSTOM POWER DEVICES

Basic terms and definitions

Custom Power (CP)	The technology of application of power electronics to power distribution system for the benefit of a customer or a group of customers is called Custom Power (CP). Through this technology the utilities can supply value- added power to specific customers.
Types of custom power devices	1. Network Reconfiguring type 2. Compensating type

Concepts

Network Reconfiguring type devices:
1. Solid State Current Limiter (SSCL)
2. Solid Stare Circuit Breaker (SSCB)
3. Solid State Transfer Switch (SSTS)

Compensating devices are
a) Distribution STATCOM (D- STATCOM)
b) Dynamic Voltage Restorer (DVR)
c) Unified Power Quality Conditioner (UPQC)

Solid State Current Limiter (SSCL):

Topology of a current limiter is shown in Fig.5.1. It contains anti parallel(back to back) gate-turn off thyristor (GTO) switch , a current limiting inductor and a Zinc oxide arrester (ZnO). All these are connected in parallel.
Current limiter is connected in series with a distribution feeder that must be protected.
The schematic diagram of Anti parallel GTO switch is shown in Fig.5.2.
It includes a series of opposite poled GTO pairs. Each GTO has a RC snubber circuit in parallel. The number of GTOs depends on the rated peak voltage level across current limiter. ZnO arrester is used to limit this voltage level. GTOs can be switched off at any time by applying a negative gate pulse. Therefore it has the capability to interrupt current at any time.

Operating Principle:

- Under normal conditions (unfaulted) conditions, GTOs are gated, that is GTOs in forward path are gated positively and GTOs in reverse path are gated negatively.
- When a fault occurs, GTOs are turned off as soon as the fault is detected. When GTOS are turned off, fault current is diverted to snubber capacitor and it charges.
- The voltage across anti-parallel GTO switch rises and it is clamped to by ZnO arrester. This voltage also appears inductor Lm. The current acroos inductor also rises linearly.
- This linear rise will continue till it becomes equal to the fault current flowing in the line. Thus fault current is limited by series impedance (combination of limiting reactor and feeder impedance).

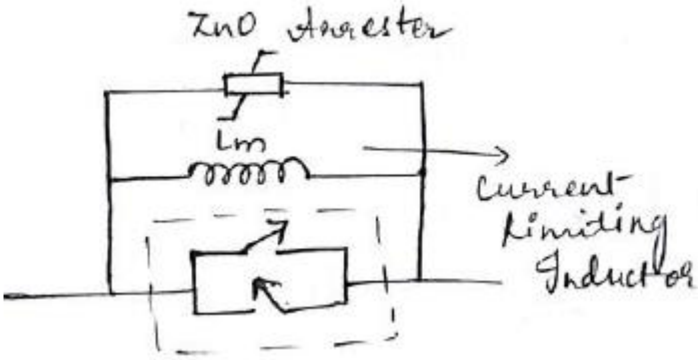

Fig 5.1 A GTO based fault current limiter

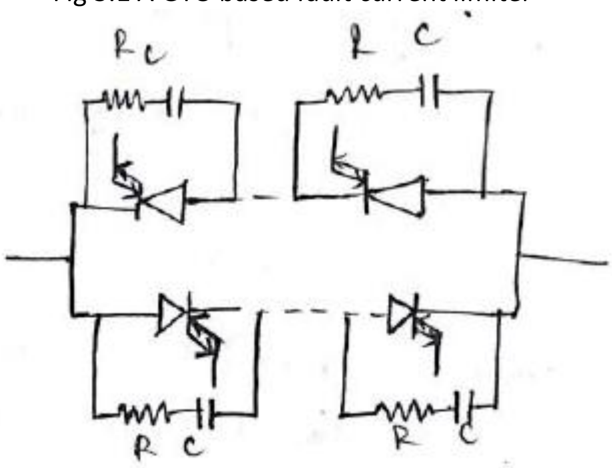

Fig 5.2 Schematic diagram of anti parallel GTO switch

- To restore normal operation, when current drops to normal level, the line current is sensed and turn on command is given to GTOs. The anti parallel GTO switch will get turned on and thus the system is restored.

Solid State Breaker (SSB) or Solid State Circuit Breaker (SSCB):

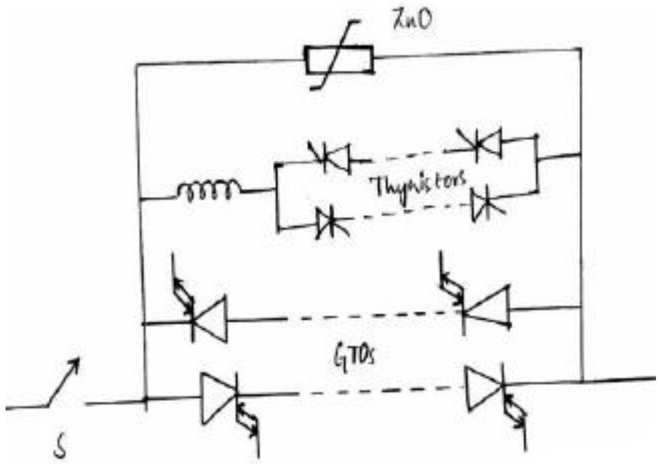

Fig 5.3 Schematic diagram of Solid State Breaker

- The circuit of SSB is almost similar to SSCL, except that the anti parallel thyristor switch is added in series with current limiting inductor.
- Under normal conditions, GTOs are 'ON' and carry current.
- When fault occurs; the device goes through a number of sub- cycle auto reclose operations.
- If the fault does not clear, then GTOs are turned off and thyristors are turned on,

such that the fault current now starts flowing through current limiting inductor.

- ZnO arrester is used to protect the device against lightning and switching surges.
- A switch is also placed in series with the circuit.

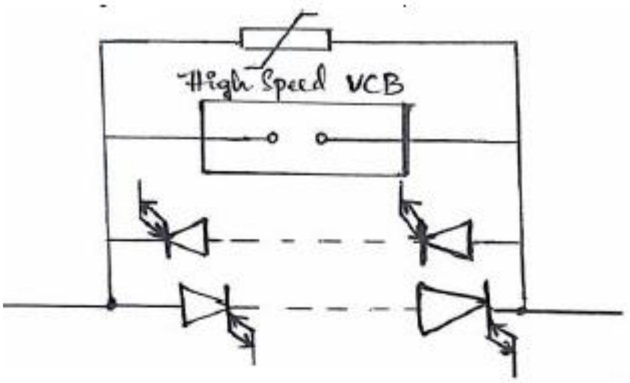

Fig 5.4 An alternate SSB topology

Fig.5.4 shows alternate SSB topology.

- It consists of anti parallel GTO switch and ZnO arrester connected in parallel with high speed Vacuum Circuit Breaker (VCB).
- Current limiting inductor is not present in this circuit.
- During normal conditions (unfaulted), current flows through VCB.
- When a fault is detected, GTOs are turned on and VCB is opened simultaneously.
- VCB uses electromagnetic repulsion forces to open the breaker at a high speed. Thus an arc is produced with a voltage, that acts as counter electromotive force.
- The fault current flowing through VCB is reduced by this electromotive force and it is commutated to GTO switch. When fault current is completely commutated to GTO switch, it is interrupted by switching off GTO.
- ZnO arrester is used to suppress any over voltage that may occur in the circuit.

Solid State Transfer Switch (SSTS):

- Solid State Transfer Switch (SSTS) is also known as Static Transfer Switch (STS).
- It is used to transfer power from preferred feeder to an alternate feeder when a voltage sag/swell or fault occurs on preferred feeder.
- Transfer switch is used to protect sensitive loads.
- SSTS circuit has two pairs of opposite poled switches. The switches are usually made up of thyristors. These switches are denoted as SW1 and SW2.
- Suppose the preferred feeder supplies power to the load;
- In this case, power is supplied through with SW1 and SW2 remains open.
- If a sudden voltage sag occurs in preferred feeder, SSTS closes switch SW2 such that current starts flowing through alternate feeder to the load.
- During this period, SW1 is switched off.
- This switching scheme is known as Make Before Break (MBB), in which the switch SW1 is disconnected only after switch SW2 is connected.
- It is not always possible to operate the device in MBB fashion, when there is a fault on preferred feeder. Depending on the direction of current, the device may operate in Break Before Make (BBM) scheme. Otherwise, the alternate feeder may start feeding the fault.

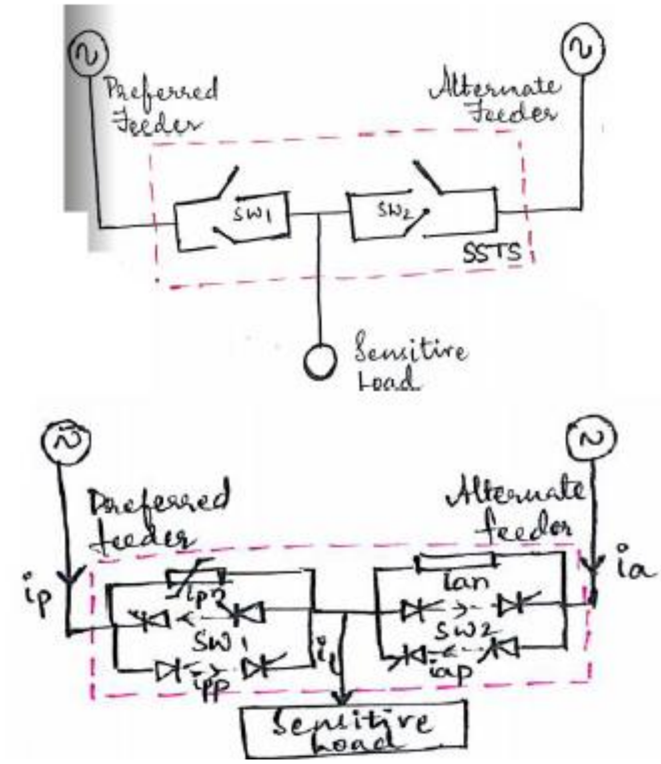

Fig 5.5 Schematic diagram of SSTS

Unified Power Quality Conditioner (UPQC)

- The schematic diagram of UPQC is shown in Fig.5.6 (a).

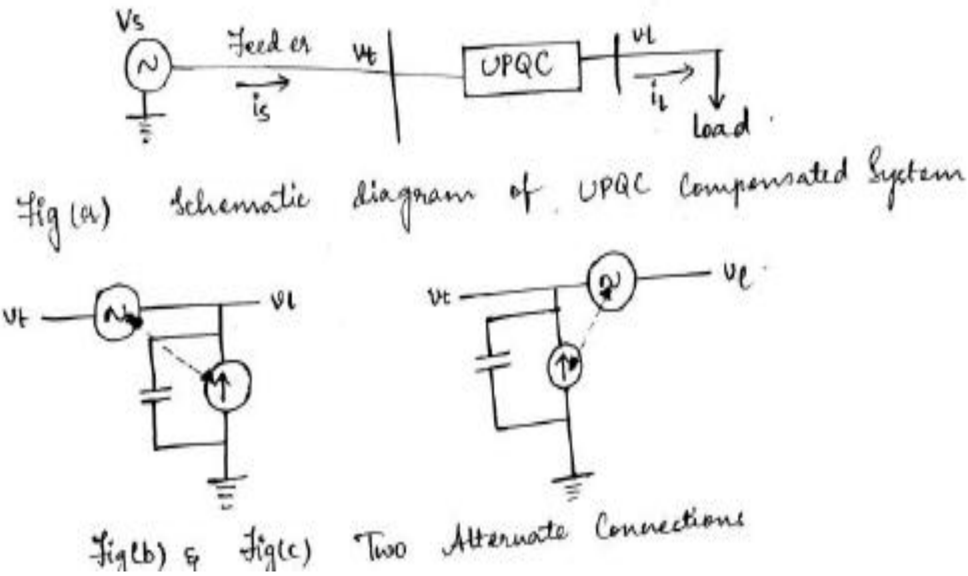

Fig 5. 6 Schematic diagram of UPQC

- This is useful when both source and load are distorted. For example, assume that source voltage V_s is both unbalanced and distorted. The load current i_L is also unbalanced and distorted.

As a result terminal voltage V_t , load voltage V_L and source current i_s will also be unbalanced and distorted.

- If other customers are connected to load bus that draw purely balanced sinusoidal currents, then unbalanced and distorted source and load will affect them. A UPQC can eliminate this problem.

- UPQC is a combination of both series and shunt compensators. Thus it has benefits of both devices. Thus it can regulate the load bus voltage as shown in Fig.5.6 (a). Therefore all loads including unbalanced and non-linear load will have a supply voltage that is balanced and sinusoidal.
- UPQC can also make the current drawn from the supply (i_s) to be balanced, sinusoidal and in phase with the terminal voltage (V_t). Therefore, the voltage of any bus upstream from PCC will not be affected due to non-linear and unbalanced load. Therefore upstream bus voltages will remain unbalanced and distorted.
- There are two ways of connecting UPQC as shown in fig 5.6(b) and 5.6 fig(c). As shown in fig 5.6(b), the series device is placed before the shunt device. As shown in fig 5.6(c), series device is placed after the shunt device.
- The energy exchange between series and shunt device takes place through common dc capacitor.

UPQC combines both shunt active power filter and series active power filter. The series active power filter compensates voltage harmonics, voltage unbalance, voltage sag/ swell, voltage flicker etc., Shunt active filter compensates current harmonics, current unbalances etc. Then UPQC operates in both voltage control mode and current control mode.

  - UPQC combines operations of both Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Restorer (DVR).
  - In voltage control mode, UPQC makes the bus voltage at load terminals to be sinusoidal and free from any unbalances, flicker and distortions.
  - In current control mode, UPQC draws a sinusoidal current from utility bus, irrespective of unbalances and harmonics from source voltages and load currents.

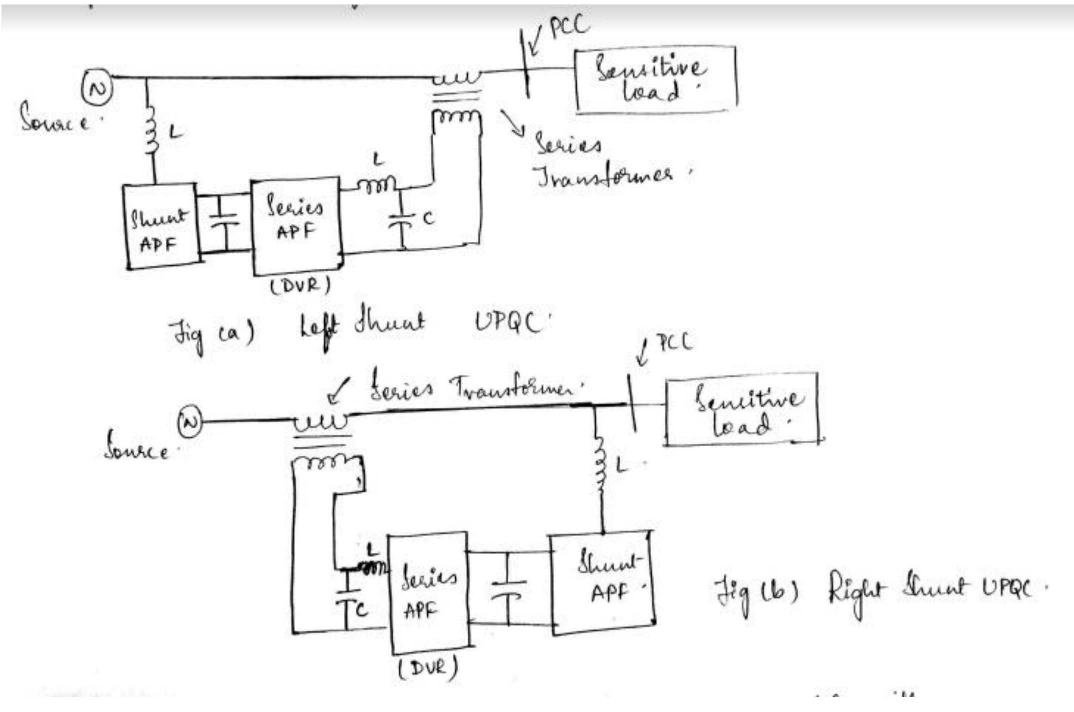

Fig 5. 7 Types of UPQC

Depending on the location of shunt compensator with respect to series compensator, UPQC can be classified as

(a) Left Shunt UPQC
(a) Right Shunt UPQC

- DC link (energy storage) unit supplies the required power for compensation during sag/ swell conditions.
- Series APF and Shunt APF employ IGBTs and GTOs.
- Harmonics generated by the compensators are minimized using LC filtering.

The overall UPQC system can be divided into two sections.
(i) Control Unit
(ii) Power Unit

Control unit includes disturbance detection, measurement of voltages/ currents and gate signal generation.
Power circuit includes two voltage source converters (series APF and shunt APF), filters and injection transformers.

Right Shunt UPQC:

- Shunt APF will be placed in the right of series APF.
- At PCC, the load voltage will be balanced and sinusoidal.
- The compensation is carried out by series APF and compensates the power quality issues (current harmonics unbalance) on load side.

Left Shunt UPQC:

- Shunt APF will be placed to the left of series APF.
- This type of UPQC compensates for power quality issues on both sides like sags, swells, harmonics, flicker etc.
- Thus unbalanced sinusoidal currents are drawn by UPQC irrespective of source side disturbances.

Dynamic Voltage Restorer (DVR)

- A DVR is used to protect sensitive loads from sags, swells or disturbances in the supply voltage. It is a series compensation device.

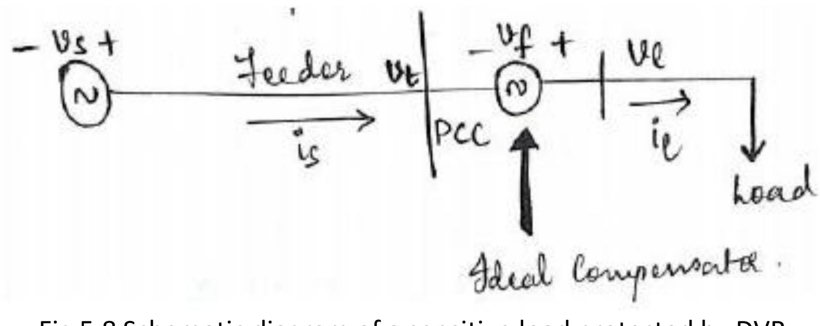

Fig 5.8 Schematic diagram of a sensitive load protected by DVR

As shown in the Fig 5.8, DVR is represented as ideal voltage source that injects voltage Vf in the direction as shown.

Two ways of constructing DVR are:
(i) Capable of supplying real power
(ii) Capable of absorbing real power.

DVR voltage control is simple, if it is capable of supplying or absorbing real power.

From the fig., $V_L = V_t + V_f$ ----------------------Eq.1

where V_L is load bus voltage.

DVR can regulate the bus voltage by measuring terminal voltage V_t and supplying the balance through V_f.

It is assumed that :

- Current through the line I_s is same as current through the load I_L
- The phase difference between the load current I_L and load voltage V_L depends on the power factor of the load.
- The positive sequence fundamental frequency component of voltage V_t, must be in Quadrature with positive sequence fundamental component with the load current I_L.

The basic principle of Dynamic Voltage Restorer is to inject voltage of required magnitude and frequency, such that load side voltage can be restored to desired amplitude and frequency, even when the source voltage is distorted.

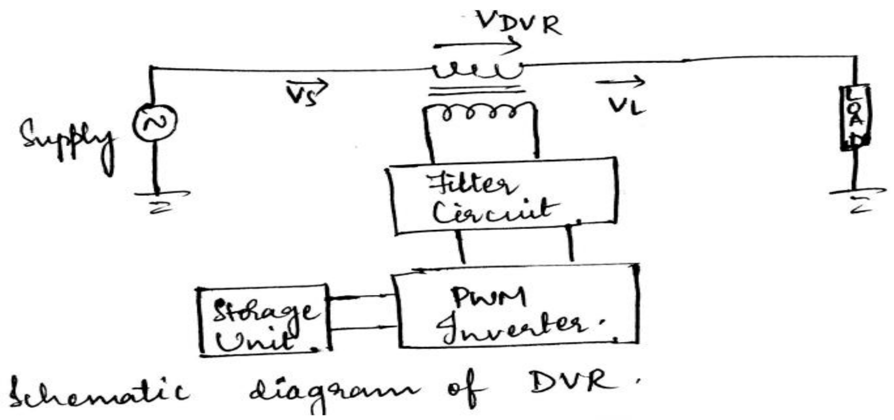

Fig 5.9 Schematic diagram of DVR

- The device employs GTOs in the inverter structure.
- DVR can generate or absorb real and reactive power at load side independently.
- Thus it injects AC voltages in series and synchronism with distribution and transmission line voltages.
- The storage unit can be DC capacitors or batteries. Under normal conditions, DVR operates in Standby mode.

During disturbances, the nominal system voltage is compared to the voltage variation. Thus the differential voltage is computed which is to be injected by DVR.

- The amplitude and phase angle of injected voltages are variable, thus allowing control of real and reactive power exchange between DVR and distribution system.
- The DC input terminal of a DVR is connected to an energy storage device of appropriate capacity.
- A DVR can inject a voltage of 50% of nominal voltage. Thus DVR provides protection

against sags of 50% up to 0.1 seconds.

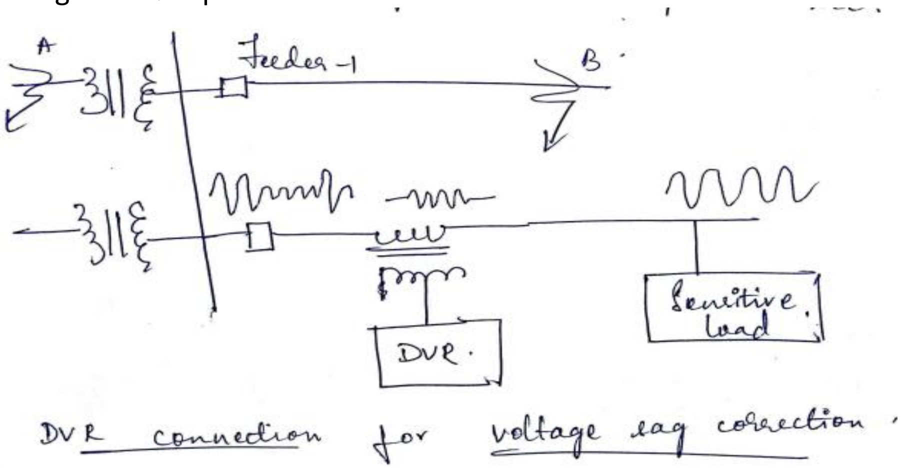

Fig 5.10 DVR for voltage sag correction

As shown in the Fig 5.10., DVR is connected in series with the distribution feeder.

- For a fault at point A on feeder 1, feeder-2 will experience voltage sag.
- Without the presence of DVR, sensitive load will be tripped and causes loss of production.
- DVR will protect sensitive load by inserting voltages of sufficient amplitude, phase angle and frequency into the feeder through series transformer.

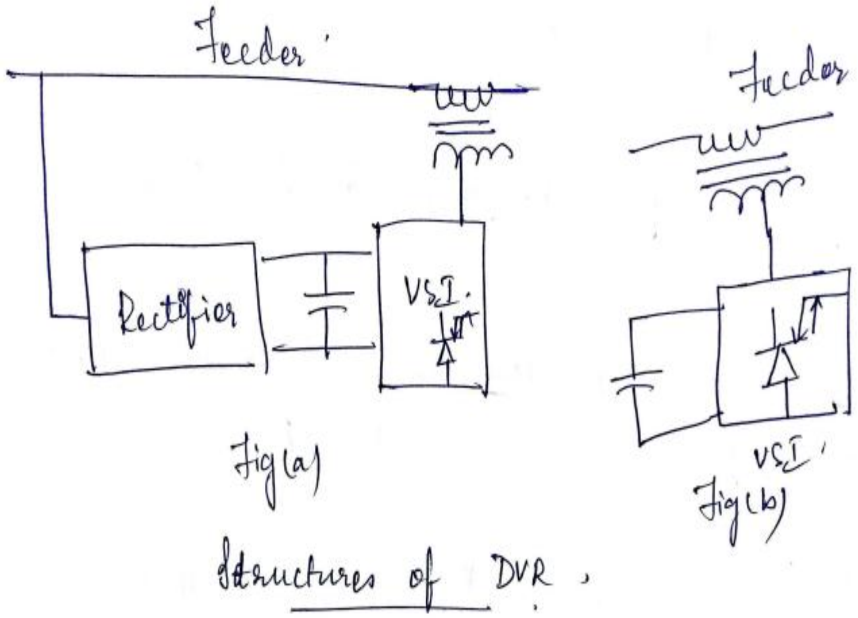

Fig 5.11 Structures of DVR

DVR has two structures.

In Fig.5.11(a), DC bus of VSI is fed through a rectifier. Therefore DVR can absorb real power from feeder through the DC bus.

In Fig. 5.11.(b), DVR is supplied by dc storage capacitor. In this structure, no real power exchange takes place with the supply system in steady state.

Important Questions:

1. Explain the significance of solid state current limiter for limiting high currents.
2. Explain the principle of operation of solid state breaker.
3. Sketch the circuit of solid state transfer switch and explain its operation.
4. Discuss the role of dynamic voltage restorer in power quality enhancement.
5. Explain how unified power quality conditioner improves quality of power at load end.
6. Briefly discuss about the significance of custom power devices the enhancement of power quality.