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Improvement Test

Sub:	REACTIVE POWER MANAGEMENT							Code:	10EE831
Date:	21/05/2018	Duration:	90 mins	Max Marks:	50	Sem:	8th	Branch:	EEE

Answer Any FIVE FULL Questions

		Marks	OBE	
			CO	RBT
1	Explain with the help of necessary diagrams, the principle of operation of TSC. Sketch the relationship between current and number of capacitors conducting.	[10]	CO4	L4
2	Explain series capacitor protection using varistor protective gear.	[10]	CO4	L4
3	With the help of diagram & waveform explain working of TCR.	[10]	CO4	L4
4	Discuss the application of synchronous condenser in i) Power System Voltage Control ii) Emergency reactive power supply	[10]	CO5	L2
5	With neat sketches explain various starting methods of synchronous condenser.	[10]	CO5	L4
6	Explain the effects of harmonics on electrical equipment.	[10]	CO6	L4

******All the Best******

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******All the Best*****

ANSWER KEY

1ANS:

THYRISTOR SWITCHED CAPACITOR

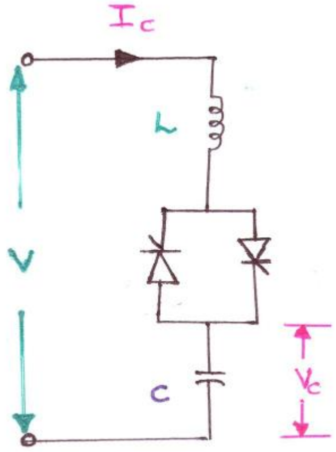

Fig 4: Single phase unit

* A thyristor Switched capacitor scheme consist of capacitor bank split up into approximately sized units each of which is Switched ON & OFF by using thyristor Switches.

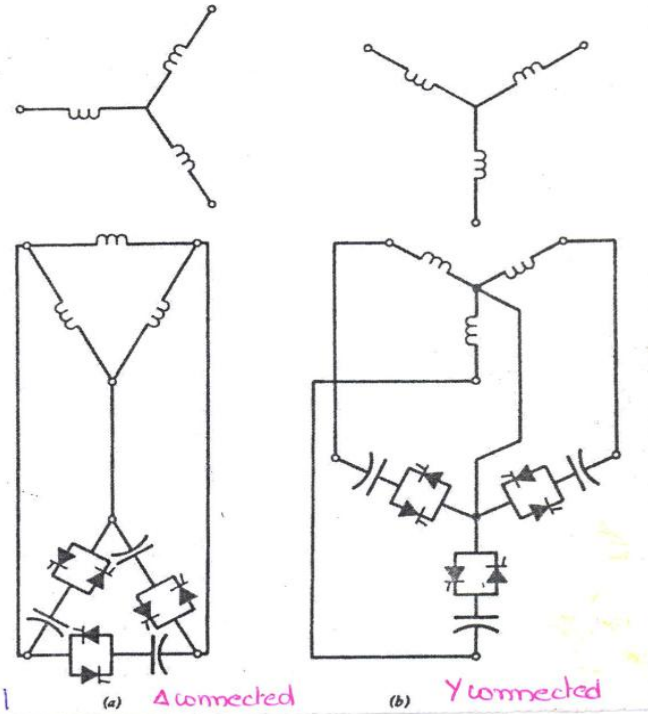

Fig 5: 3 Ph TSC

* Each 1Ph unit consist of a capacitor (C) in series with a bidirectional thyristor switch and a small inductor L.
* The purpose of L is to limit switching transients, to damp inrush current & to prevent resonance with the network.
* In 3Ph, units are connected in Δ or Y.
* The susceptance is adjusted by controlling the no: of parallel paths.
* Each capacitor always conducts for an integral no: of half cycles.
* There are K no: of capacitors in parallel each controlled by switch as in figure 6.

* Total susceptance will be equal to any combination of K no: of individual susceptances.

* Total susceptance varies in a stepwise manner.
* With the no: of capacitors, the step also varies.
* The maximum no: of steps is obtained when no combinations are equal.
* So all the individual susceptance should be different.
* But in Power system it is more economical to make susceptance equal.
* So usually one compromise is made such that there is K-1 equal susceptance B and one susceptance B/2.
* The half susceptance increases the no: of combinations from K to 2K.

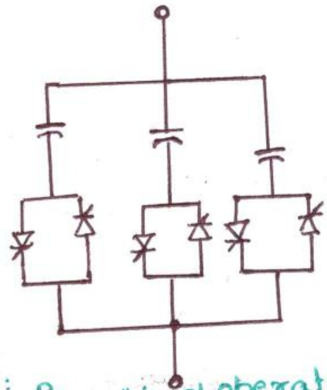

Fig 5: Principle of operation of TSC

* The relation between the compensator current & no: of capacitors conducting is shown in fig 6.

* ignoring switching transients, the current is sinusoidal ie it contains no harmonics.

*

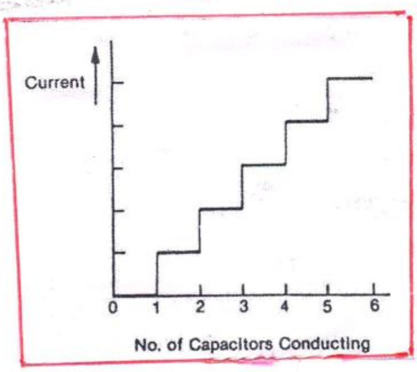

Fig 6: Rel ship b/w current and no: of capacitors conducting

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3ans:

THYRISTOR CONTROLLED REACTOR (TCR)

* The basic elements of a TCR are a reactor in series with a bidirectional thyristor switch.

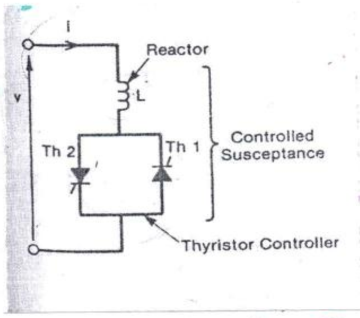

Fig1: Reactor (TCR)

* The controlling element is the thyristor controller, a oppositely poled thyristors which conduct on alternate half cycles of supply frequency.
* Firing angle α is measured from a zero crossing of voltage
* Full conduction is obtained at a firing angle of 90° i.e precisely we can say at the peak of supply voltage.
* The current is essentially reactive and lagging the voltage by nearly 90°.
* The current contains a small in-phase component due to power loss in the reactor. (0.5 - 2% of Q_P)
* If gating is delayed by equal amounts on both thyristors it is as shown in fig (a) to (d).
* Full conduction is obtained for gating of 90° & partial conduction for gating between 90° & 180°.
* If we increase the gating angle, the fundamental harmonic content of I will reduce.

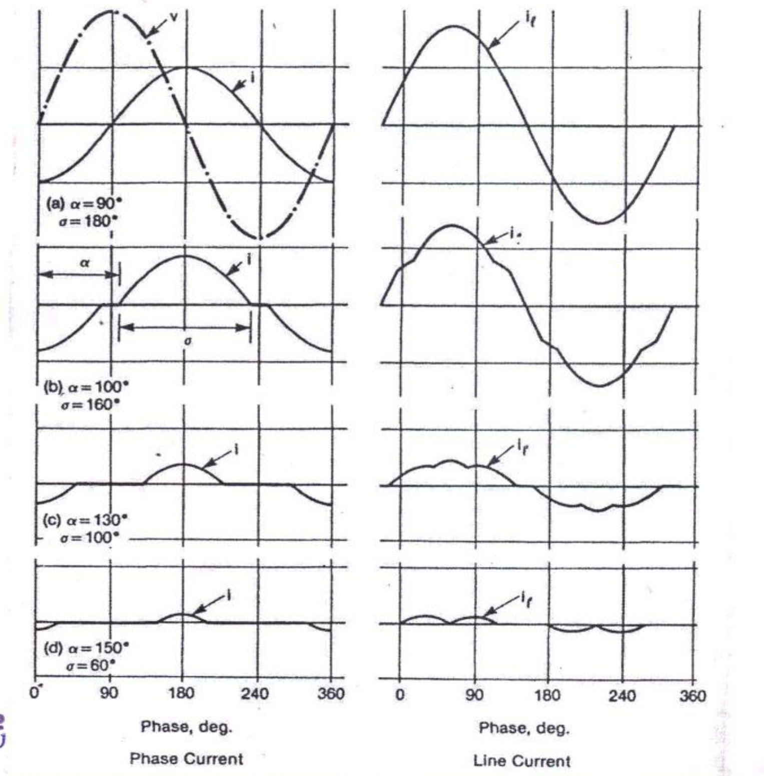

Fig2. Phase & line current waveforms of TCR

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* It is equivalent to increasing the reactor inductance, so the reactive power reduces.

* TCR is same as a controllable susceptance and can be applied as a static compensator.

* Let σ be the conduction angle related to α by

$$\sigma = 2(\pi - \alpha) \longrightarrow (1)$$

* The instantaneous current is given by

$$i = \begin{cases} \frac{\sqrt{2}V}{X_L}(\cos\alpha - \cos\omega t) & \text{for } \alpha < \omega t < \alpha+\sigma \\ 0 & \text{for } \alpha+\sigma < \omega t < \alpha + \pi \end{cases} \longrightarrow (2)$$

where $V \rightarrow$ rms voltage

$X_L = \omega L$ fundamental frequency reactance of the reactor (in Ω)

$\omega = 2\pi f$

$\alpha \rightarrow$ gating delay angle

* Fourier Analysis of current waveform gives the fundamental component

$$I_1 = \frac{\sigma - \sin\sigma}{\pi} \frac{V}{X_L} \longrightarrow (3)$$

where I_1 & $V \rightarrow$ are the RMS values

* Now we can rewrite eqn ③ as

$$I_1 = B_L(\sigma) V \longrightarrow ④$$

where $B_L(\sigma)$ is an adjustable fundamental freq susceptance controlled by the conduction angle σ

$$\text{where } B_L(\sigma) = \frac{\sigma - \sin\sigma}{\pi X_L} = \frac{I_1}{V} \longrightarrow ⑤$$

* The maximum value of B_L is $\frac{1}{X_L}$ which is obtained with $\sigma = \pi$ or 180° ie full conduction in thyristor controller & $\alpha = 90^\circ$.

* The minimum value of B_L is zero, obtained with $\sigma = 0$ & $\alpha = 180^\circ$.

* This control principle is known as phase control.

* The variation of susceptance as well as TCR current is smooth or continuous.

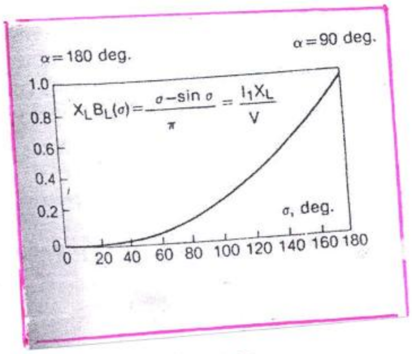

Fig 3. control of TCR.

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2ans:

VARISTOR PROTECTIVE GEAR

* A new development in protective gear uses zinc-oxide varistors, a form of non-linear resistors, to limit the voltage across the capacitor.

* It offers all the advantagous of practical re-insertion while eliminating the need for high speed switching.

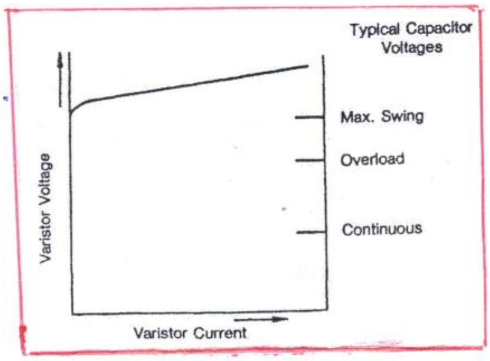

Fig 10: voltage / current charac of varistor.

* Fig 10 shows a typical varistor voltage and current profile.

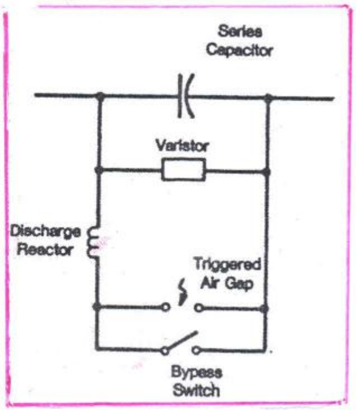

Fig 11: Series capacitor protection using varistor

* Basic circuit for this type of protective gear is shown in fig 11.

* varistor is connected directly in parallel with the capacitor.

* The stability of zinc oxide allows the varistor to withstand continuous energization, without any kind of deterioration.

* A triggered air gap is shown in fig 11. But here the gap is not used to limit the capacitor voltage. Instead this function is performed by varistor.

* The firing of the gap is now initiated by the control logic which monitors the energy absorbed by varistor.

* Therefore, for extreme system faults where varistor current magnitude or duration is excessive, the gap is triggered to short circuit the varistor and protect it from further delay.

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* A bypass switch is still necessary in this protective system to allow manual control of insertion as well as bypass the capacitor for abnormal system or equipment conditions.

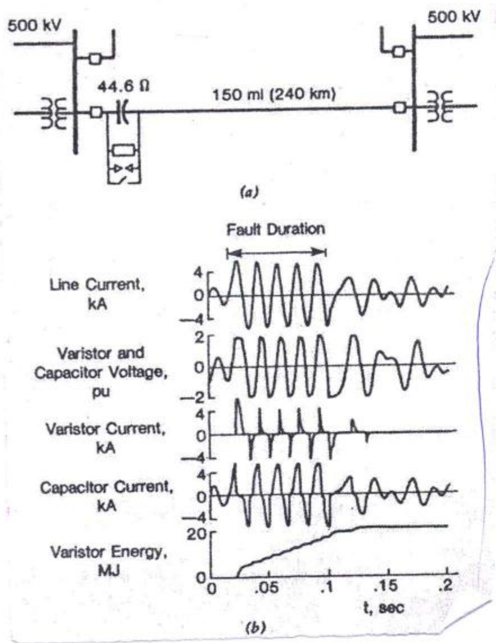
* Here again Discharge reactor is still needed to limit the magnitude & frequency of capacitor current when gap or bypass switch closes.

* The varistor characteristics in figure 10 is determined by the no: of Zinc - oxide discs and their series parallel connection.

* A 500kV, 60 Hz idealized system as in fig below is simulated to describe the essential feature of Zinc oxide Varistor.

→ Each phase has a protective level of 2 p.u of [illegible] rated capacitor voltage for a fault current of 25 kA.

→ The capacitor rated current was assumed to be 1600 A RMS.



→ Under normal case, line current flows through the series capacitor and negligible current flows in the varistor.

→ The bypass switch is open and gap is not conducting, it is shown in 1st cycle of waveform.

→ A fault on the system increases the capacitor current & voltage.

* If capacitor voltage rises enough, varistor conducts and limits further voltage increase.

* The capacitor - varistor shared conduction continues until fault is cleared in the system.

* The line-current then drops to post-fault level, reducing the capacitor voltage.

Thus line current flow is restored to series capacitor.

4ans:

POWER SYSTEM VOLTAGE CONTROL

* In distribution and subtransmission areas, the changing reactive power requirements are generally satisfied by switched capacitor banks supplemented with load tap-changing transformers and feeder voltage regulators for voltage control.

* On transmission network wide variations in reactive power requirements exist.
  - → light loading —X mission line→ behave like Q sources
  - → heavy loading —X mission line→ appear as Q loads

* So proper reactive power interchange with neighbouring utilities is needed.

* TCR & TSC's are commonly used in transmission voltage control.

Some technical advantages of synchronous condensers are:

① provide continuously adjustable (stepless) reactive Power which enables close control of transmission line voltage.

② have the capability to provide both capacitive & inductive reactive power.

EMERGENCY REACTIVE POWER SUPPLY

* Ability to provide emergency voltage control during major system disturbances is probably the prime incentive for condenser applications.

* Such emergencies occur due to contigencies such as → the occurance of fault, sudden loss of transmission, or major generation.

* In extreame cases it can result in system breakup, or islanding at least initially.

* Mostly system upsets are characterized by abnormal voltages in the initial conditions.

* Voltage extreams can occur in either direction.

* This occurs mostly when areas are islanded.

* Fig 3 shows short-time emergency reactive power output with reduced voltage available at one insta-llation

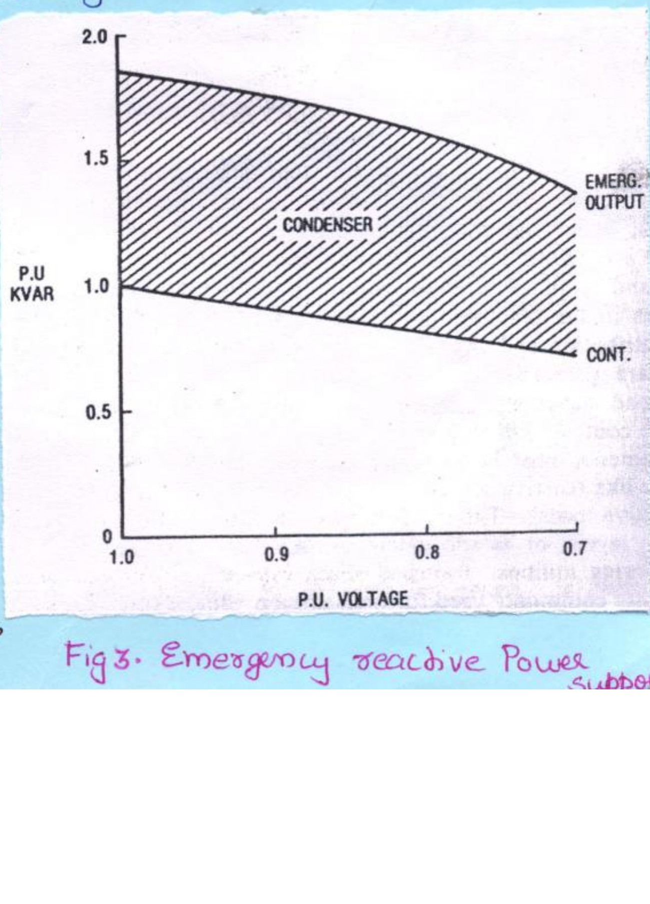


Fig 3. Emergency reactive Power support

5ans:

STARTING METHODS

* The Practical starting methods of a synchronous condenser includes reduced voltage, starting motor & static starter.
* Generally starting will be infrequent, as units will be shutdown only when it is required for maintenance.
* Starting time is generally not critical, 15-20 mins is acceptable.

1. STARTING MOTOR :

* This method uses a wound-rotor motor with one less pair of poles than the main condenser. to accelerate the unit to rated speed & synchronize to the line,

* It has the advantage of eliminating any voltage dip on the system, as well as stator or amortisseur winding stress during the startup.

amortisseur winding :* A squirrel cage winding placed near the surface of the pole faces of a synchronous motor.

* Main purpose is to damp speed fluctuations or oscillations that may occur as a result of sudden load changes.
* Also used to accelerate motor during starting

This starting method have been extensively used for starting up of both synchronous condensers & pumped hydro units.

A motor rating of 0.5% of condenser rating is used.

Torque control of motor during starting is by means of a liquid rheostat control.

At 98% speed, the control responds to the pulsed output of speed matching Relays to bring the slip to very small value.

It will allow automatic synchronizing relay to initiate breaker closing.

* condenenser has a direct - connected dc exciter, this may be used as a driving motor to bring the condenser up to speed & synchronize to line.

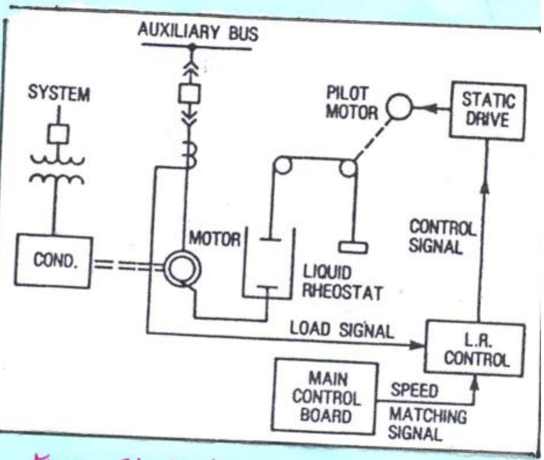


Fig 5. Starting motor control

* Two 250 MVAr condensers presently in service use dc exciter starting, in an automated system.

* Torque control during starting in this case is through a controlled DC voltage to the exciter/motor.

2. REDUCED VOLTAGE STARTING:

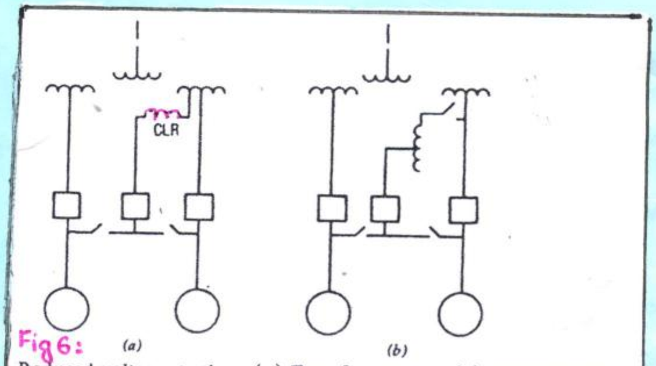


Fig 6: Reduced voltage starting. (a) Transformer tap. (b) Autotransformer

- Two arrangements of reduced voltage starting are shown in figure 6.

- As in fig 6 (b) various switching arrangements, particularly with respect to autotransformer, are also used.

- There is no much difference in performance. The choice merely depends on the matter of economics.

- Autotransformer connections utilize tripping of neutral breaker with the series winding. It serves a a reactor during start - run transition.

- There is no practical differences in the performances of 6 (a) & 6 (b).

* The reduced voltage tap of transformer delta winding of 6(a) may be a symmetrical center tap for half voltage or corner delta connection.

* Due to corner delta tap, unbalanced currents flow during starting.
* These flows are of very small values. Sensitive ground relay settings are designed accordingly.

* Transformer should be designed such that any excessive unbalance is avoided.

* Short - circuit current on tap tends to be higher in amperes than of full winding. So a CLR (current limiting reactor) as shown in 6(a) is connected.

* This unit is started as an induction motor on reduced voltage tap.
* Excitation is applied when full speed is reached. and unit pulls into step.

Because of reluctant torque, the unit may pull in on wrong pole, initially.

A reactive power relay is used to check whether condenser has correct pole orientation.

After this check, the transfer to full voltage is made by tripping the start breaker. and closing the running breaker.

* The starting tap voltage is 35-50%.

* Fig 7 shows a case where a slight delay in closing the running breaker, reduced the 2nd voltage dip to a small value.

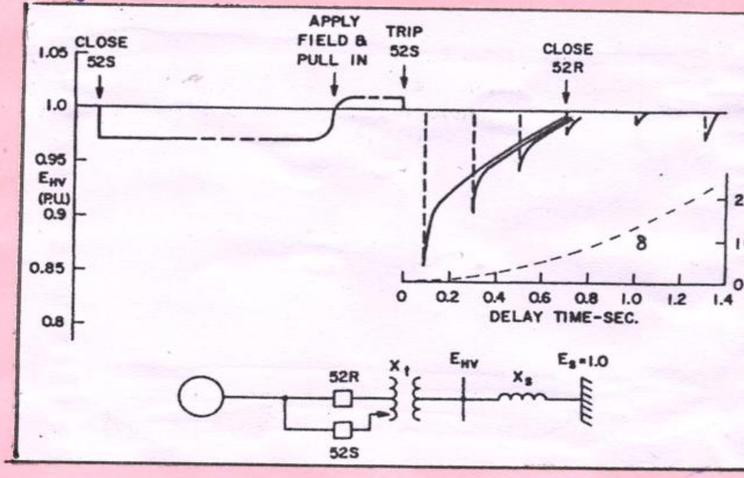


Fig7 Delay start-run transfer

3. STATIC STARTING :

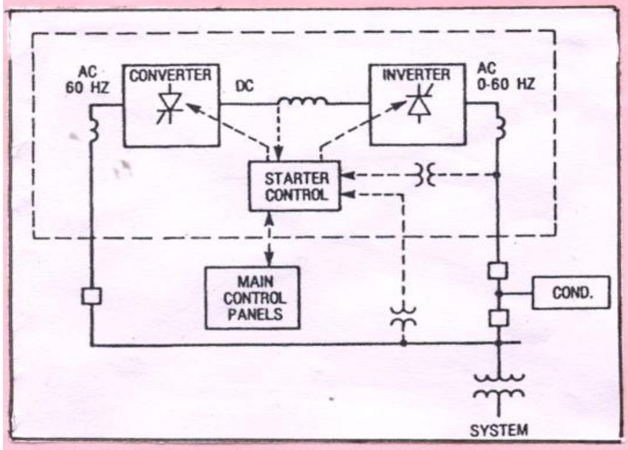


Fig 8. Schematic arrangement of Static starting system.

→ Static starting is a synchronous or "back to back" type of start.

→ Here condenser is accelerated to rated speed in synchronism with static equivalent of a starting generator.

→ The static-starting equipment is a self-contained static equivalent of synchronizing controls, excitation, governer, valves of starting generator.

→ Major elements of static starting system are the following :

1. Static Starter Cubicles : It contain power thyristor elements & associated control.
2. Commutating reactor and smoothing reactor located adjascent to the starter cubicles.

3. Power Switchgear for supply to the starter and for connection to the unit to be started.

* The starter is like the converter equipment of a HVDC terminal except that the receiving system into which the power is sent is at changing frequency.

* During acceleration the line - side converter operates as an ~~inverter~~ rectifier while the machine side converter operates as an inverter.

* Above certain speed the condenser can supply the reactive commutation required for operation of the inverter.

* Below this speed, it is necessary to establish the rotating stator flux by successively switching the inverter O/P from phase to phase.

6ans:

10.3. EFFECT OF HARMONICS ON ELECTRICAL EQUIPMENT

Blown capacitor fuses or failed capacitors in power capacitor banks are often the first evidence of excessive ac harmonic levels. ANSI Standard C55.1-1980 and NEMA CP1-1973 cover the characteristics of shunt power capacitors. In these standards, considerable attention is given to harmonics, and allowances are made for increases in both the effective voltage and current due to harmonics. Continuous operation with excessive harmonic current can lead to increased voltage stress and overtemperature, and can shorten the life of capacitors. Typically, a 10% increase in voltage stress will result in a 7% increase in temperature, reducing the life expectancy to 30%. This "life" analysis does not allow for capacitor failure initiated by dielectric corona. The damage done by corona produced by excessive peak voltages depends on both the intensity and duration of the corona. There have been numerous cases of premature failure — in the order of months rather than years — as a result of inadequate provision for harmonic voltages.

Harmonic currents can cause overheating of rotating machinery, particularly solid-rotor (nonsalient-pole) synchronous generators. Harmonic currents produce a magnetomotive force that causes currents to flow in the solid rotor surface, adding to the heating. Positive-sequence rectifier harmonics [following the equation $n = kq + 1$ (7th, 13th, etc.)] rotate forwards and cause harmonic orders 6, 12, and so on, in the rotor. Those harmonics following the equation $n = kq - 1$ (5th, 11th, etc.) are negative sequence, rotate against the rotation of the rotor, and again produce harmonic orders 6, 12, and so on, in the rotor. The resulting pulsating magnetic field caused by the oppositely rotating pairs of magnetomotive forces sets up localized heating in the rotor which may require a derating of the machine. The derating for 6-pulse operation, where the 5th and 7th harmonics dominate, can be considerable, depending on the particular machine design. Derating for balanced 12-pulse rectifier operation is generally minimal. The presence of rotor amortisseur windings greatly alleviates the rotor heating problem.

Induction motors are much less affected by harmonics than are solid-rotor synchronous generators. However, excessive harmonic currents can overheat induction motors, especially when they are connected into systems where capacitors in resonance with the system are aggravating one or more harmonics.

Harmonic currents carried by transformers will increase the load (I^2R) loss by a factor greater than the mere increase in rms current. The amount of the increase depends on the proportion of I^2R loss proportional to frequency squared (eddy current loss), and the amount proportional to the first power of frequency (stray load loss). The same is true of current-limiting or tuning reactors. As a result, designers of reactors need to know the amount and order of each significant harmonic so that they can apply the proper factor for I^2R loss contributed by the fundamental and each contributing harmonic.