EE5210 - LECTURE 26

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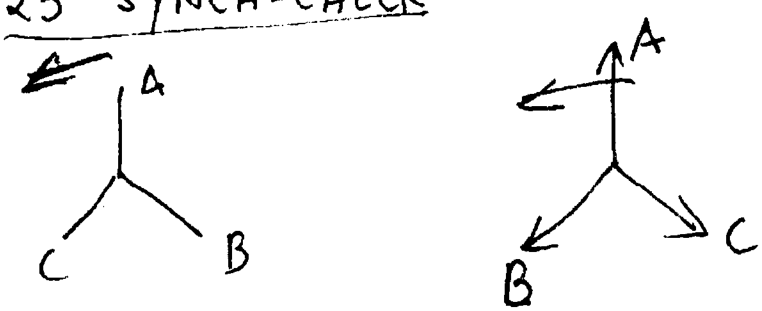
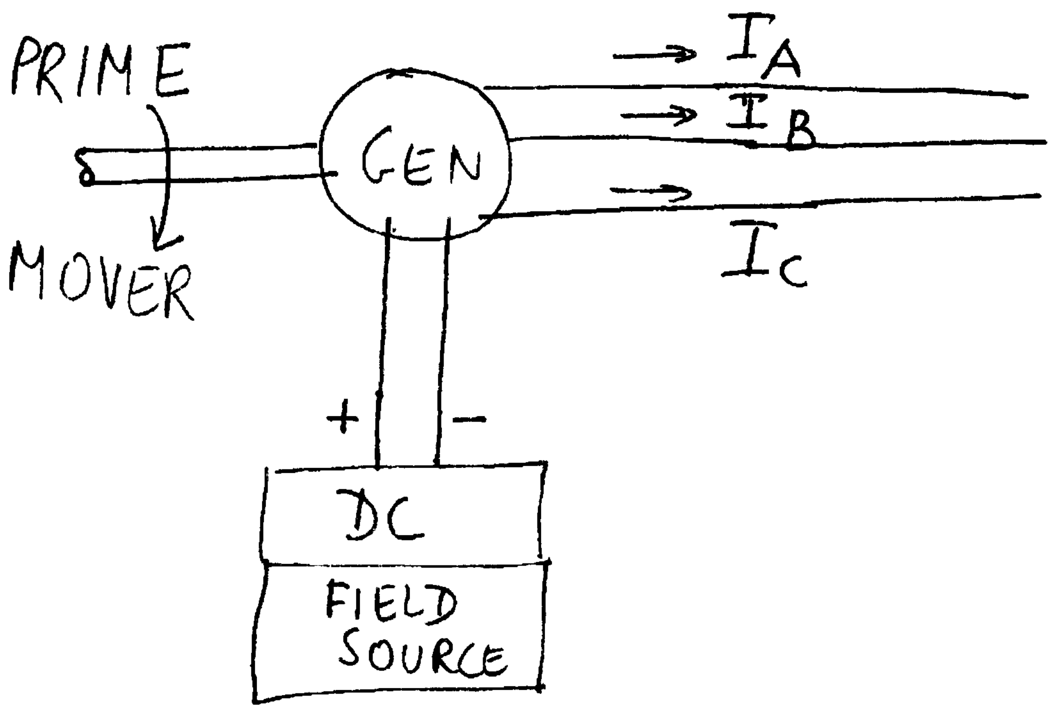
Outline

1. Generation sources – coal, gas, hydro, renewables, energy policy
2. Synchronous machines
3. Types of Grounding - Fault example
4. Types of faults and protection
5. Differential protection (87)
6. Backup protection, (21, 51V, 50/51, 32, Underpower (37), 40, 46.
7. Protection from system faults – Out-of-Step, surges, islanding, 81UF, 81OF, df/dt., 25 SYNCH-CHECK



SYNCHRONOUS GENERATORS :-

CONVERTS MECHANICAL POWER TO ELECTRICAL →

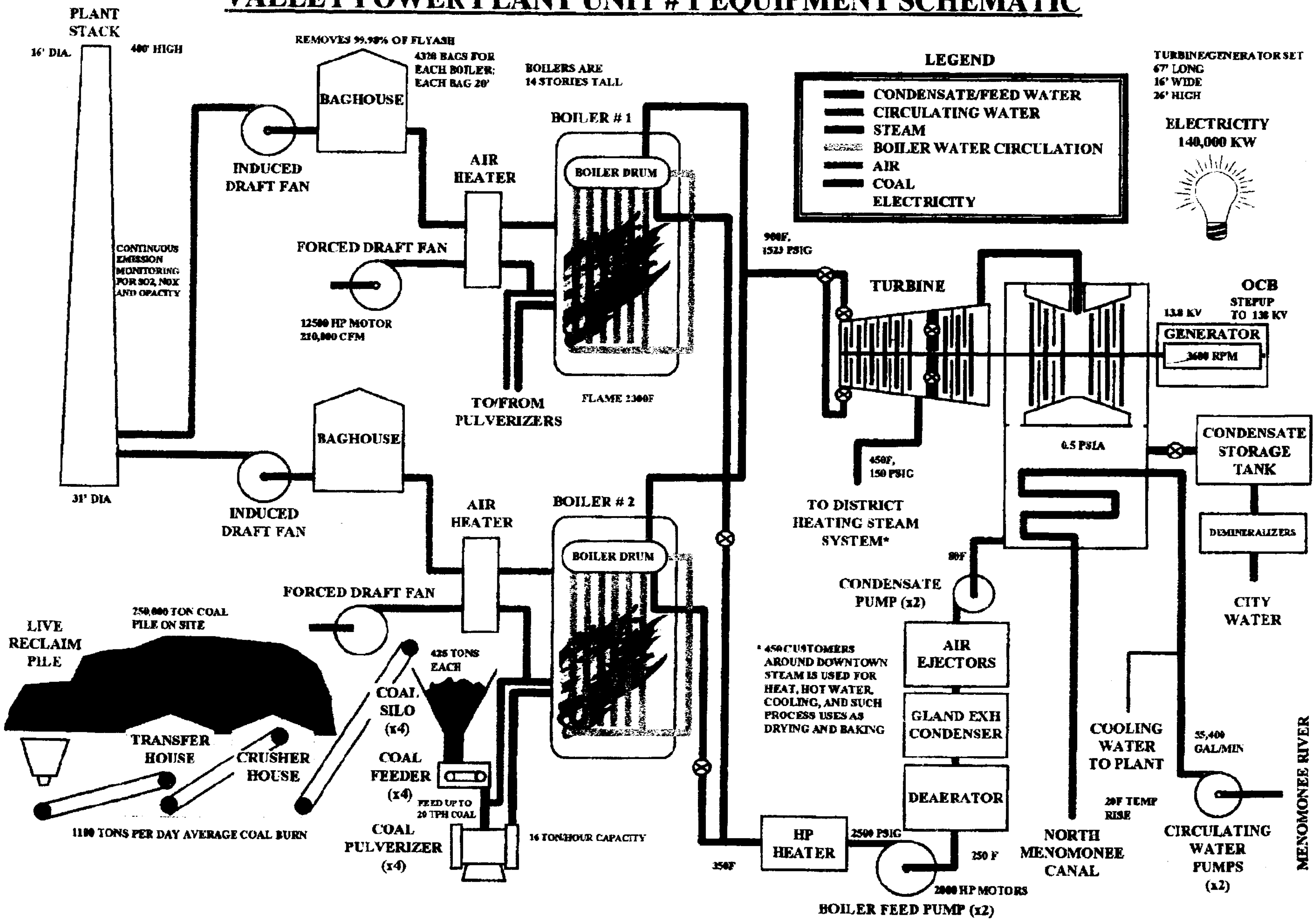


COAL, OIL, NATURAL GAS NUCLEAR, WATER (DROP IN DAM), DIESEL ENGINE.

REMEMBER THE PRIME MOVER!

[E.G. GEN AS MOTOR]

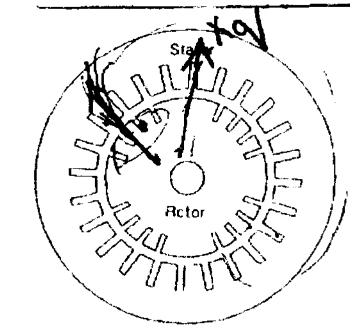
VALLEY POWER PLANT UNIT # 1 EQUIPMENT SCHEMATIC



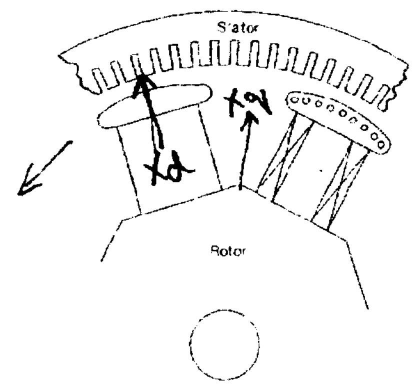
2

(2A)

WHY LAMINATIONS (?)



Round Rotor



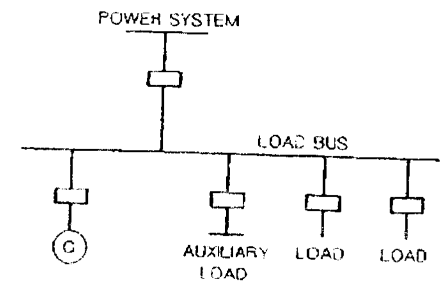
Salient-Pole

Figure 2 Synchronous Generator Types

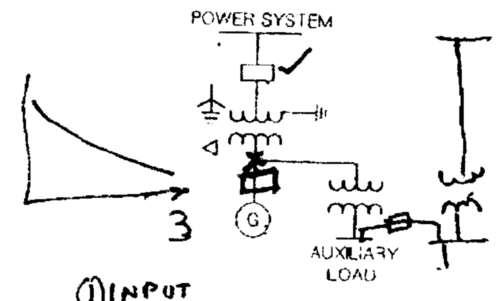
Synchronous machines are classified into two principal designs— round-rotor machines and salient-pole machines. Figure 2 provides a cross-sectional view of both types of construction. Generators driven by steam turbines have cylindrical (round) rotors with slots into which distributed field windings are placed. Most cylindrical rotors are made of solid steel forgings. The number of poles is typically two or four. Generators driven by water wheels (hydraulic turbines) have laminated salient-pole rotors with concentrated field windings and a large number of poles. Whatever type of prime mover or machine design, the energy source used to turn the shaft is maintained at a constant

CONNECTION OF GENERATORS TO THE POWER SYSTEM

There are two major basic methods used within the indus try to connect generators to the power system. They are direct and unit connections.



3a) Direct Connected



3b) Unit Connected

Figure 3

Direct Connected: Figure 3A shows the one-line diagram for a direct connection of a generator to the power system. The generator is connected to its load bus without going through a voltage transformation. The generator supplies power directly to the load. This type of connection is an earlier method used within the industry for the connection of generators when generators were small in size. It is still used today to connect smaller machines.

ALTERNATIVE SOURCES OF ENERGY

1) PHOTOVOLTAICS / SOLAR
2) WIND
3) FUEL CELLS
4) MICRO TURBINES
5) GEOTHERMAL
6) BIOMASS
7) TIDAL

OUR DISCUSSION DOES NOT INCLUDE THESE TODAY. MAYBE TOMORROW?

TYPES OF FAULTS

(1) STATOR
- PHASE - PHASE
- PHASE - GROUND
- TURN-TO-TURN
- LOSS OF COOLANT

(2) ROTOR
- GROUND FAULT IN FIELD/ROTOR (64)
- LOSS OF FIELD (40)

(3) SYSTEM DISTURBANCES (& BACKUP)
- V/Hz (24)
- REVERSE POWER (32)
- UNDER POWER (37)
- UNDER/OVER FREQUENCY (81)
- UNDER/OVER VOLTAGE (27/59)
- df/dt
- NEGATIVE SEQUENCE (46)
- IMPEDANCE (21)

- SURGES FROM SYSTEM
- ISLANDING DETECTION
- SYNCH CHECK (25)

(4) MECHANICAL MONITORING

- VIBRATION [ROTOR BALANCING]
- BEARING TEMP
- LIMIT SWITCHES,
- CONTROL OIL PRESSURE
- TURBINE DIFFERENTIAL PRESSURE

EX. 1

(1) Calculate the 3-ϕ fault currents & the 1-ϕ fault current (to ground) for the foll. generator (solidly grounded)

13.8 kV, 100 MVA,

$X_d'' = 0.13 = X_2$ (p.u.)

$X_0 = 0.013$ (p.u.)

[VALUES FROM TABLE A.4 of W.D. STEVENSON]

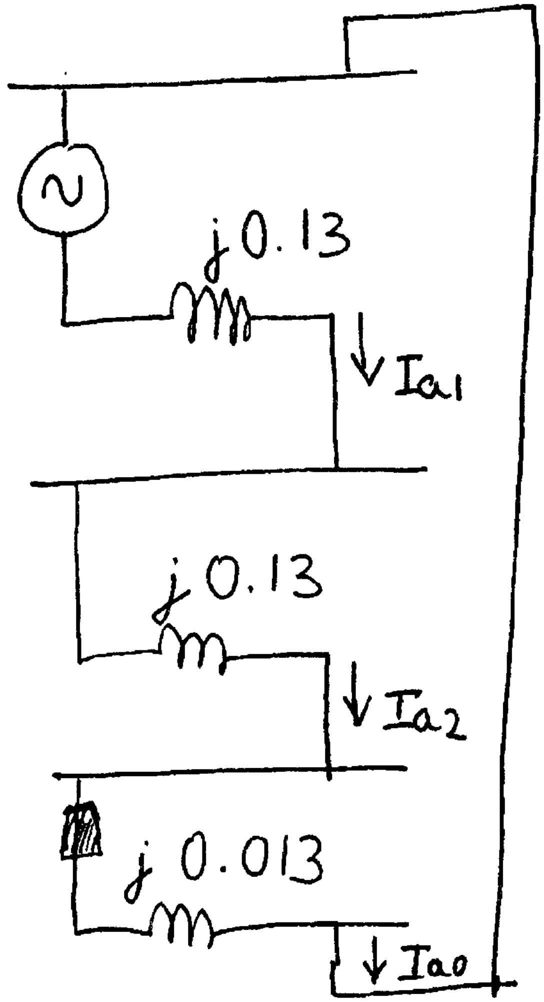
NOTE :- $X_0 \simeq 0.1\, X_d''$

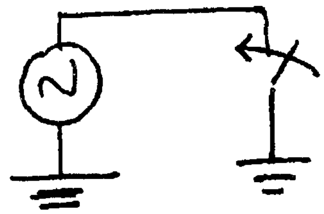
$X_0 = 2.5 - 3.0\ X_1$ [for TRANSMISSIO LINES]

$X_0 \cong X_1$ [TRANSFORMERS 3-LIMBED CORE]

$< X_1 \longrightarrow$ 5-LIMBED CORE]

EX. 2





$$I_{a1} = I_{a2} = I_{a0}$$

$$= \frac{1.0}{j0.13 + j0.13 + j0.013}$$

$$= \frac{1}{j0.273} = 3.66 pu$$

I_A = SINGLE PHASE-GND = $3 * 3.66$ pu
$= 10.98$ pu.

$$I_{3\phi} = \frac{1}{j0.13} = 7.69 \text{ pu}$$

$I_{pu} \simeq 4$ kA.

FORCES $\propto (I^2)$

EX. 3.

ADD RESISTANCE OR REACTANCE IN ZERO SEQUENCE NETWORK.

<u>HOW</u> <u>MUCH</u> <u>RESISTANCE</u> ?

① HIGH (VERY) = ∞ = UNGROUNDED

② HIGH – LIMIT FAULT CURRENT TO 1-10 A

③ LOW RESITANCE – LIMIT FAULT CURRENT TO (50-600A

④ SOLIDLY GROUNDED

<u>SIZE OF GENERATOR DETERMINES TYPE OF GROUNDING.</u>

EX. 4.

NOTE $X_d = 1.76$ pu

$I_{3\phi\text{-fault}}$ in STEADY STATE

ASSUMING NO VOLTAGE

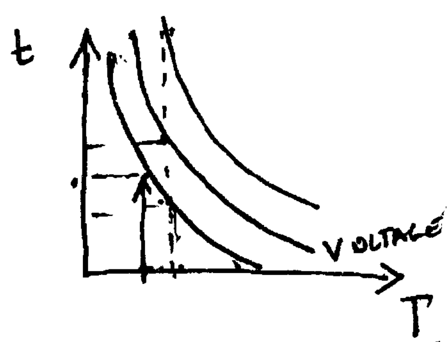
REGULATOR CONTROL < LOAD

CURRENT.

[NEED 51V] – VOLTAGE RESTRAINED

OVERCURRENT RELAY

(81 OF) ALSO.



EX. 5

Table A.4 Typical reactances of three-phase synchronous machines.†

Values are per unit. For each reactance a range of values is listed below the typical value.‡

	Turbine-generators				Salient-pole generators	
	2-pole		4-pole			
	Conventional cooled	Conductor cooled	Conventional cooled	Conductor cooled	With dampers	Without dampers
X_d	1.76 1.7–1.82	1.95 1.72–2.17	1.38 1.71–1.55	1.87 1.6–2.13	1 0.6–1.5	1 0.6–1.5
X_q	1.66 1.63–1.69	1.93 1.71–2.14	1.35 1.17–1.52	1.82 1.56–2.07	0.6 0.4–0.8	0.6 0.4–0.8
X'_d	0.21 0.18–0.23	0.33 0.264–0.387	0.26 0.25–0.27	0.41 0.35–0.467	0.32 0.25–0.5	0.32 0.25–0.5
X''_d	0.13 0.11–0.14	0.28 0.23–0.323	0.19 0.184–0.197	0.29 0.269–0.32	0.2 0.13–0.32	0.30 0.2–0.5
X_2	$= X''_d$	$= X''_d$	$= X''_d$	$= X''_d$	0.2 0.13–0.32	0.40 0.30–0.45
X_0§						

† Data furnished by Westinghouse Electric Corporation.
‡ Reactances of older machines will generally be close to minimum values.
§ X_0 varies so critically with armature winding pitch that an average value can hardly be given. Variation is from 0.1 to 0.7 of X''_d.

Table A.5 Typical range of transformer reactances†

Power transformers 25,000 kVA and larger

Nominal system voltage, kV	Forced-air-cooled, %	Forced-oil-cooled, %
34.5	5–8	9–14
69	6–10	10–16
115	6–11	10–20
138	6–13	10–22
161	6–14	11–25
230	7–16	12–27
345	8–17	13–28
500	10–20	16–34
700	11–21	19–35

† Percent on rated kilovoltampere base. Typical transformers are now designed for the minimum reactance value shown. Distribution …