Welcome to

Energy Production Systems Engineering

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Session 2: Electrical Safety & Steam Plant Fundamentals

Spring 2012

Session 2: Electrical Safety & Steam Plant Fundamentals

- **Electrical Installation Safety Requirements**
- **Electrical Safe Work Practices**
- **Steam Plant Fundamentals**

Electrical Safety

Installation Safety Requirements

Engineering Methods of Reducing Hazard Risk

Specifying Current Limiting Fuses on Low Voltage Switchgear Breakers
IR detectors / IOC relays / Pressure relays in switchgear
Dual Setting relays
Specifying ARC Resistant Switchgear
Remote Control of Switchgear Breakers
Remote Racking of Switchgear Breakers
High Resistance Grounding on Low Voltage and Medium Voltage (15kV and below) Systems
Differential & Zone protection
Others???

Arc Flash

Aftermath of arc flash event.

Common Electrical Task

IEEE Arc Flash Test

Slow Motion Text

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Safer Engineering Design

Current Limiting Fuses = faster clearing time.

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Its not just the front of the switchgear!

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Flash Boundary

Dc = [2.65 * MVAbf * t] $^{1/2}$

Dc = 2nd degree burn distance
MVAbf = bolted fault at point of arc
t = clearing time

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Flash Boundary

Dc = [53 * MVA * t] $^{1/2}$

D_c = 2nd degree burn distance (ft)
MVA = Transformer MVA rating
t = clearing time (sec)
(alternate formula)
Dc = [2.65 * MVAbf * t]^0.5
MVAbf = bolted fault MVA at point of fault.

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Personal Protective Equipment

PPE for Shock Protection
PPE for Thermal Protection from Arc

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PPE

PPE shall be provided and used
Shall be inspected prior to each use

Art Wise in protective clothing and gear as he inserts a starter bucket into a Motor Control Center.

Hazard Risk Category Table 130.7(C)(9)(a)

Table defines HRC (arc flash protection) and Gloves/Tools (shock protection) required. Task specific

Table 130.7(C)(9)(a) Hazard/Risk Category Classifications

Task (Assumes Equipment Is Energized, and Work Is Done Within the Flash Protection Boundary)	Hazard/ Risk Category	V-rated Gloves	V-rated Tools
Panelboards Rated 240 V and Below — Notes 1 and 3			
Circuit breaker (CB) or fused switch operation with covers on	0	N	N
CB or fused switch operation with covers off	0	N	N
Work on energized parts, including voltage testing	1	Y	Y
Remove/install CBs or fused switches	1	Y	Y
Removal of bolted covers (to expose bare, energized parts)	1	N	N
Opening hinged covers (to expose bare, energized parts)	0	N	N

Table Notes

- 1. Maximum of 25 kA short circuit current available, 0.03 second (2 cycle) fault clearing time.
- 2. Maximum of 65 kA short circuit current available, 0.03 second (2 cycle) fault clearing time.
- 4. Maximum of 42 kA short circuit current available, 0.33 second (20 cycle) fault clearing time.
- 5. Maximum of 35 kA short circuit current available, 0.5 second (30 cycle) fault clearing time.

Ancillary Protective Equipment

Tools
Temporary grounds
Rubber insulating equipment
Barriers
Inspection and maintenance

PPE matrix

NFPA70E defines what PPE required for what HRC

Table 130.7(C)(10) Protective Clothing and Personal Protective Equipment (PPE) Matrix

Protective Clothing and Equipment	Protective Systems for Hazard/Risk Category					
Hazard/Risk Category Number	−1 (Note 3)	0	1	2	3	4
Non-melting (according to ASTM F 1506-00) or Untreated Natural Fiber						
a. T-shirt (short-sleeve)	X			X	X	X
b. Shirt (long-sleeve)		X				
c. Pants (long)	X	X	X (Note 4)	X (Note 6)	X	X
FR Clothing (Note 1)						
a. Long-sleeve shirt			X	X	X (Note 9)	X
b. Pants			X (Note 4)	X (Note 6)	X (Note 9)	X
c. Coverall			(Note 5)	(Note 7)	X (Note 9)	(Note 5)
d. Jacket, parka, or rainwear			AN	AN	AN	AN

Protective Clothing Characteristics

From NFPA70E

Hazard risk category	Description	Min arc rating Cal/cm²
0	Non-melting flammable	N/A
1	FR shirt/pant or FR coverall	4
2	Cotton underwear + FR shirt/pant	8
3	Cotton underwear + FR shirt & pants + FR coveralls	25
4	Cotton underwear + FR shirt & pants + FR coverall	40

PPE examples

Troubleshooting live equipment, such as testing a contactor (left), requires hazard/risk level 2 PPE, suitable for protection from an arc flash of 8 cal/cm2, but racking of a circuit breaker (right) demands hazard/risk level 3 PPE, suitable for protection from an arc flash of 25 cal/cm2.

Alerting Techniques

Safety signs and tags
Barricades outside Limited Approach Boundary
How about if arc boundary > limited approach boundary?
Attendants

Electrical Safety – Safe work practices

End of Electrical Safety

Steam Plant Fundamentals

Steam Plant Fundamentals

Download Steam table &/or software
Homework review –Question two out
How was homework easy or hard?
Syllabus Update – No session next week
Tour Optional
Homework 2 guidance
- Nuclear SG = Saturated Steam
- If substance subcooled, used T-s plot or software, table will not work
Questions?

Steam Plant Fundamentals

Temperature – Average Molecular KE
Steam cycle (Thermodynamics)
Temperature (hot to cold)

TR = TF + 460

TK = TC + 273

Use R (or K) for engineering calculations

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Steam Plant Fundamentals

Pressure – force per unit area
Pisa – Psig – "hg – Pa – Torr - % Vacuum

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Steam Plant Fundamentals

% Vacuum	Torr (mm Mercury)	Micron	psia, (lb/in^2) abs	Inches Mercury Absolute	Inches Mercury Gauge	kPa abs
0	760	760,000	14.7	29.92	0	101.4
1.3	750	750,000	15.5	29.5	0.42	99.9
1.9	735.6	735,600	14.2	28.9	1.02	97.7
7.9	700	700,000	13.5	27.6	2.32	93.5
21	600	600,000	11.6	23.6	6.32	79.9
34	500	500,000	9.7	19.7	10.22	66.7
47	400	400,000	7.7	15.7	14.22	53.2
50	380	380,000	7.3	15	14.92	50.8
61	300	300,000	5.8	11.8	18.12	40
74	200	200,000	3.9	7.85	22.07	26.6
87	100	100,000	1.93	3.94	25.98	13.3
89.5	80	80,000	1.55	3.15	26.77	10.7
93	51.7	51,700	1	2.03	27.89	6.9
96.1	30	30,000	0.58	1.18	28.74	4
97.4	20	20,000	0.39	0.785	29.14	2.7
98.7	10	10,000	0.193	0.394	29.53	1.3
99	7.6	7,600	0.147	0.299	29.62	1
100	0	0	0	0	29.92	0

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Steam Plant Fundamentals

Density – mass per unit volume
(lbm/ft3)
Specific Volume is 1/D

Specific Heat – Heat transferred / temperature change (per unit mass)

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Sensible Heat – Heat added (or removed) that changes temperature

Latent Heat – Heat added (or removed) that changes phase

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Steam Plant Fundamentals

Three modes of heat transfer –
Conduction
Convection
Radiation

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Conduction is the transfer of energy through matter from particle to particle. It is the transfer and distribution of heat energy from atom to atom within a substance. Conduction is most effective in solids-but it can happen in fluids.

Steam Plant Fundamentals

Convection is the transfer of heat by the actual movement of the warmed matter. Convection is the transfer of heat energy in a gas or liquid by movement of currents. (It can also happen is some solids.) The heat moves with the fluid.

Steam Plant Fundamentals

Radiation: Electromagnetic waves that directly transport ENERGY through space (no medium needed for heat transfer).

Steam Plant Fundamentals

Enthalpy – total useful energy in substance (BTU/lbm)

Includes internal & flow energy

h = (u + p*v)/J

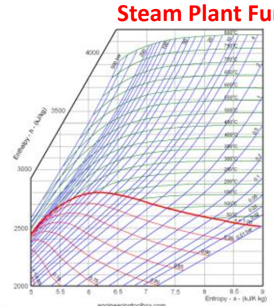
Entropy – energy not available for work (BTU/lbm*R)

Steam Plant Fundamentals

States – solid – liquid – gas

Value of h defined by properties of material.

Steam Plant Fundamentals



Mollier Diagram

Blue = Pressure

Green = Temperature

Red = Quality

Steam Plant Fundamentals

T-S Diagram

Lines of constant P

4 regions
B = 0% quality
A = 50% quality
C = 100% quality

Critical point

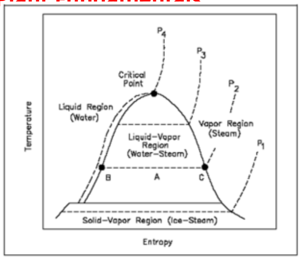


Figure 13 T-s Diagram for Water

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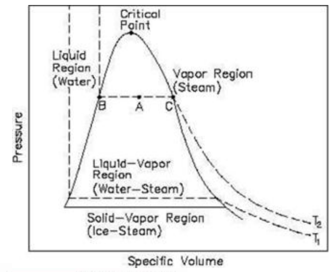
Steam Plant Fundamentals



P-v Diagram

Lines of constant T

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Steam Plant Fundamentals

Steam Tables – Download Available at
Class website
thomasblairpe.com/ppe.html

Steam Property Software – Link to software available at class website
thomasblairpe.com/ppe.html

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Steam Plant Fundamentals

Steam Tables – Saturated & Superheated Steam sections

First for Saturated section – How to use:

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Steam Plant Fundamentals

Table 1. Saturated Steam: Temperature Table

Temp Fahr t	Abs Press. Lb per Sq In. p	Specific Volume Sat. Liquid v_f	Evap v_{fg}	Sat. Vapor v_g
32.0*	0.08859	0.016022	3304.7	3304.7
34.0	0.09600	0.016021	3061.9	3061.9
36.0	0.10395	0.016020	2839.0	2839.0
38.0	0.11249	0.016019	2634.1	2634.2

Temperature (°F)
Abs Press (psia)
Vf = 0% quality Specific Volume
Vg = 100% quality Specific Volume
Vfg = Specific Volume difference between Vg and Vf

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Steam Plant Fundamentals

Table 1. Saturated Steam: Temperature Table

Enthalpy Sat. Liquid h_f	Evap h_{fg}	Sat. Vapor h_g	Entropy Sat. Liquid s_f	Evap s_{fg}	Sat. Vapor s_g	Temp Fahr t
-0.0179	1075.5	1075.5	0.0000	2.1873	2.1873	**32.0***
1.996	1074.4	1076.4	0.0041	2.1762	2.1802	**34.0**
4.008	1073.2	1077.2	0.0081	2.1651	2.1732	**36.0**
6.018	1072.1	1078.1	0.0122	2.1541	2.1663	**38.0**

Entropy (BTU/(lbm * °F)
sf = 0% quality Enthalpy
sg = 100% quality Enthalpy
sfg = Enthalpy difference between sg and sf

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Steam Plant Fundamentals

Table 1. Saturated Steam: Temperature Table

Enthalpy Sat. Liquid h_f	Enthalpy Evap h_{fg}	Enthalpy Sat. Vapor h_g	Entropy Sat. Liquid s_f	Entropy Evap s_{fg}	Entropy Sat. Vapor s_g	Temp Fahr t
-0.0179	1075.5	1075.5	0.0000	2.1873	2.1873	32.0 *
1.996	1074.4	1076.4	0.0041	2.1762	2.1802	34.0
4.008	1073.2	1077.2	0.0081	2.1651	2.1732	36.0
6.018	1072.1	1078.1	0.0122	2.1541	2.1663	38.0

Enthalpy (BTU/lbm)
hf = 0% quality Enthalpy
hg = 100% quality Enthalpy
hfg = Enthalpy difference between hg and hf
This is used to determine available energy in fluid

Steam Plant Fundamentals

Table 1. Saturated Steam: Temperature Table

Enthalpy Sat. Liquid h_f	Enthalpy Evap h_{fg}	Enthalpy Sat. Vapor h_g	Entropy Sat. Liquid s_f	Entropy Evap s_{fg}	Entropy Sat. Vapor s_g	Temp Fahr t
-0.0179	1075.5	1075.5	0.0000	2.1873	2.1873	32.0 *
1.996	1074.4	1076.4	0.0041	2.1762	2.1802	34.0
4.008	1073.2	1077.2	0.0081	2.1651	2.1732	36.0
6.018	1072.1	1078.1	0.0122	2.1541	2.1663	38.0

Enthalpy (BTU/lbm) for percent quality is:

H = hf + hfg * (%Quality/100%)

Steam Plant Fundamentals

Table 1. Saturated Steam: Temperature Table

Enthalpy Sat. Liquid h_f	Enthalpy Evap h_{fg}	Enthalpy Sat. Vapor h_g	Entropy Sat. Liquid s_f	Entropy Evap s_{fg}	Entropy Sat. Vapor s_g	Temp Fahr t
-0.0179	1075.5	1075.5	0.0000	2.1873	2.1873	32.0 *
1.996	1074.4	1076.4	0.0041	2.1762	2.1802	34.0
4.008	1073.2	1077.2	0.0081	2.1651	2.1732	36.0
6.018	1072.1	1078.1	0.0122	2.1541	2.1663	38.0

Example above, for fluid at 38 ^{O}F,
hf = 6.018 (BTU/lbm)
hg = 1072.1 (BTU/lbm)
h(50% Quality) =
6.018 + 1072.1 * (50/100) =
542 (BTU/lbm)

Steam Plant Fundamentals

Example 1: For **saturated** water at temperature of (212 ^{O}F);

A. What is the enthalpy for a sample with 0% steam quality?
B. What is enthalpy for sample with 100% steam quality?
C. What is enthalpy for sample with 50% steam quality?
D. What is pressure for above?

Steam Plant Fundamentals

Temp Fahr t	Abs Press. Lb per Sq In. p	Enthalpy Sat. Liquid h_f	Enthalpy Evap h_{fg}	Enthalpy Sat. Vapor h_g
180.0	7.5110	148.00	990.2	1138.2
182.0	7.850	150.01	989.0	1139.0
184.0	8.203	152.01	987.8	1139.8
186.0	8.568	154.02	986.5	1140.5
188.0	8.947	156.03	985.3	1141.3
190.0	9.340	158.04	984.1	1142.1
192.0	9.747	160.05	982.8	1142.9
194.0	10.168	162.05	981.6	1143.7
196.0	10.605	164.06	980.4	1144.4
198.0	11.058	166.08	979.1	1145.2
200.0	11.526	168.09	977.9	1146.0
204.0	12.512	172.11	975.4	1147.5
208.0	13.568	176.14	972.8	1149.0
→ 212.0	14.696	180.17	970.3	1150.5
216.0	15.901	184.20	967.8	1152.0

Steam Plant Fundamentals

Answer:

A. From table, hf = 180.7 (BTU/lbm)
B. From table, hg = 1150.5
C. Using equation;

h(50%) = 180.17 + 970.3 * (50/100) =
665 (BTU/lbm)

D. Pressure is Psat = 14.7 psia

Steam Plant Fundamentals

Saturated steam also given with pressure instead of temperature
SAME INFO

Abs Press. Lb/Sq In. p	Temp Fahr t	Specific Volume Sat. Liquid v_f	Evap v_{fg}	Sat. Vapor v_g
0.08865	32.018	0.016022	3302.4	3302.4
0.25	59.323	0.016032	1235.5	1235.5
0.50	79.586	0.016071	641.5	641.5
1.0	101.74	0.016136	333.59	333.60
5.0	162.24	0.016407	73.515	73.532
10.0	193.21	0.016592	38.404	38.420
14.696	212.00	0.016719	26.782	26.799
15.0	213.03	0.016726	26.274	26.290

Steam Plant Fundamentals

Steam Tables – Superheated Steam sections - How to use:

Steam Plant Fundamentals

Table 3. Superheated Steam

Abs Press. Lb/Sq In. (Sat. Temp)		Sat. Water	Sat. Steam	Temperature – Degrees Fahrenheit 200	250	300	350	400
1 (101.74)	Sh			98.26	148.26	198.26	248.26	298.26
	v	0.01614	333.6	392.5	422.4	452.3	482.1	511.9
	h	69.73	1105.8	1150.2	1172.9	1195.7	1218.7	1241.8
	s	0.1326	1.9781	2.0509	2.0841	2.1152	2.1445	2.1722

Abs Press (psia) / Tsat also
Sh = Superheat, F
v = Specific Volume, (F^3/lbm)
h = enthalpy, (BTU/lbm)
s = entropy, (BTU/(lbm * F)

Steam Plant Fundamentals

Table 3. Superheated Steam

Abs Press. Lb/Sq In. (Sat. Temp)		Sat. Water	Sat. Steam	Temperature – Degrees Fahrenheit 200	250	300	350	400
1 (101.74)	Sh			98.26	148.26	198.26	248.26	298.26
	v	0.01614	333.6	392.5	422.4	452.3	482.1	511.9
	h	69.73	1105.8	1150.2	1172.9	1195.7	1218.7	1241.8
	s	0.1326	1.9781	2.0509	2.0841	2.1152	2.1445	2.1722

Sh, v, h, and s values given for
- saturation conditions
- various higher temps

Steam Plant Fundamentals

Example 2: For **superheated steam** at 400 ^{O}F at atmospheric pressure (14.7 psia);

A. What is the enthalpy?
B. What is amount of "Superheat"

Steam Plant Fundamentals

Table 3. Superheated Steam

Abs Press. Lb/Sq In. (Sat. Temp)		Sat. Water	Sat. Steam	Temperature – Degrees Fahrenheit 200	250	300	350	400
14.696 (212.00)	Sh				38.00	88.00	138.00	188.00
	v	.0167	26.799		28.42	30.52	32.60	34.67
	h	180.17	1150.5		1168.8	1192.6	1216.3	1239.9
	s	.3121	1.7568		1.7833	1.8158	1.8459	1.8743

A.Enthalpy is 1239.9 (BTU/lbm)
B.Amount of "super heat" is 188 ^{O}F
(note: this is given in table, but also can
Calculate as 400 ^{o}F – 212 ^{O}F)

Steam Plant Fundamentals

Example 3: For **superheated steam** at 350 ^{O}F at atmospheric pressure (14.7 psia);

A. What amount of energy is required to raise 2 lbm of steam from 350 ^{O}F to 400 ^{O}F?

B. What is change in volume of that 2 lbm sample when it changes from 350 ^{O}F to 400 ^{O}F?

Steam Plant Fundamentals

Table 3. Superheated Steam

Abs Press. Lb/Sq In. (Sat. Temp)		Sat. Water	Sat. Steam	Temperature – Degrees Fahrenheit 200	250	300	350	400
14.696 (212.00)	Sh				38.00	88.00	138.00	188.00
	v	.0167	26.799		28.42	30.52	32.60	34.67
	h	180.17	1150.5		1168.8	1192.6	1216.3	1239.9
	s	.3121	1.7568		1.7833	1.8158	1.8459	1.8743

A.Energy = h * m

= (1239.9 – 1216.3)(BTU/lbm) * 2(lbm)

= 47.2 BTU

B. (34.67 – 32.5)(F^3/lbm) * 2(lbm)

= 4.34 F^3

Steam Plant Fundamentals

Why Enthalpy is important value!!!

Example 4: For **superheated steam** at 400 ^{O}F at atmospheric pressure (14.7 psia) that is flowing into a turbine at a rate of 100,000 lbs/hr

A. What is the ideal rate of energy delivery (POWER) into the turbine (excluding energy of exhaust)?

Energy/Time = Power = h * flow rate

Steam Plant Fundamentals

Table 3. Superheated Steam

Abs Press. Lb/Sq In. (Sat. Temp)		Sat. Water	Sat. Steam	Temperature – Degrees Fahrenheit 200	250	300	350	400
14.696 (212.00)	Sh				38.00	88.00	138.00	188.00
	v	.0167	26.799		28.42	30.52	32.60	34.67
	h	180.17	1150.5		1168.8	1192.6	1216.3	1239.9
	s	.3121	1.7568		1.7833	1.8158	1.8459	1.8743

A.Power = h * (m/t)

= (1239.9)(BTU/lbm) * 100,000(lbm/hr)

= 123.99 MBTU/hr

Steam Plant Fundamentals

Why Enthalpy is important value!!!

Example 5: For the system described in example 4, if the turbine exhaust steam is at 1 psia, saturated steam conditions, steam quality of 90%, what is net power delivered to the turbine by the steam?

From example 4, enthalpy into turbine was (1239.9)(BTU/lbm)

Steam Plant Fundamentals

Abs Press. Lb/Sq In. p	Temp Fahr t	Enthalpy Sat. Liquid h_f	Evap h_{fg}	Sat. Vapor h_g
0.08865	32.018	0.0003	1075.5	1075.5
0.25	59.323	27.382	1060.1	1087.4
0.50	79.586	47.623	1048.6	1096.3
1.0	101.74	69.73	1036.1	1105.8
5.0	162.24	130.20	1000.9	1131.1
10.0	193.21	161.26	982.1	1143.3
14.696	212.00	180.17	970.3	1150.5
15.0	213.03	181.21	969.7	1150.9

A. hf = 69.73 & hfg = 1036.1

h = hf + hfg * (%quality/100%)

= 69.73 + 1036.1 * (90/100)

= 1002.22 (BTU/lbm) = enthalpy out of turbine.

Steam Plant Fundamentals

Net enthalpy drop is 1239.9 – 1002.22

= 237.68 (BTU/lbm)

Given that mass flow is 100,000 lbm/hr

Net power delivered to turbine is

237.68 BTU/lbm * 100,000 lbm/hr =

23.768 MBTU/hr

Steam Plant Fundamentals

If we define efficiency (ignoring pump work) as;

P(turb)out / P(turb)in * 100%, efficiency of this turbine is;

(23.768/123.99) * 100% =

19.2% efficient

Perhaps this is why we do not run turbines at atmospheric pressure

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Steam Plant Fundamentals

Previous steam fundamentals critical to understand –

Practice using steam tables.

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Steam Plant Fundamentals

Ideal Gas Law – approximation for steam

PV = nRT or

PV/T = constant

Therefore

$P_1V_1/T_1 = P_2V_2/T_2$

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Steam Plant Fundamentals

Ideal Gas Law Continued – PV/T = const

With V constant, if you raise T, you raise P.

With P constant, if you raise T, you raise V.

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Steam Plant Fundamentals

To be continued …

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End of Session 2: Electrical Safety & Steam Plant Fundamentals

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