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Module II – Circuit Analysis

Circuit Analysis Basics

Joint EPRI/NRC-RES Fire PRA Workshop
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A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

CIRCUIT ANALYSIS BASICS

Objectives

- Provide the minimum level of information needed to understand the functionality of common circuits analyzed in the remainder of the course
- Focus on three common circuits
  - Air operated valve / Solenoid operated pilot valve (AOV / SOV)
  - Motor operated valve (MOV)
  - Circuit Breaker (PCB – MVPCB & LVPCB)
- Present overviews of typical nuclear power plant electrical power distribution system

CIRCUIT ANALYSIS BASICS

Circuit Design Basics

- Concepts
  - Typical circuit devices and symbols
  - ANSI/IEEE standard device numbers
  - Types of drawings and their purpose
  - Equipment of Interest
  - Operation of common equipment

CIRCUIT ANALYSIS BASICS

Typical Circuit Devices

- Circuit breakers and fuses
- Motor starters and contactors
- Relays and contacts
- Terminal blocks
- Control power transformers (CPTs)
- Actuating coils
- Indicating lamps and alarms
- Switches
  - Control/hand (maintained, momentary, spring-return to normal)
  - Limit and torque
  - Sensors
  - Transfer and isolation
  - Position

CIRCUIT ANALYSIS BASICS

Typical Device Symbols – Refer to Handout

TYPICAL ELECTRICAL DRAWING SYMBOLS AND CONVENTIONS

ELECTRICAL SYMBOLS

◆ Denotes common symbols we will encounter in the sample problems

CONTACTS, SWITCHES, CONTACTORS AND RELAYS

SYMBOL	DESCRIPTION
X1 N.O. X1 N.C.	Relay contact - Shown with relay in de-energized or in reset position. (Show relay coil designation near contact.)
T1 TDC T1 TDO	Timing Relay Contact - TDC indicates contact closes at end of timing period. TDO contact opens at end of timing period.
X1	Coil - Relay, contactors, circuit breaker, solenoid etc. (Show device designation, X1)
T1 TDPU (TDDO)	Coil - Timing Relay - TDPU indicates timing period starts when coil is energized. TDDO indicates timing period starts when coil is de-energized.
R1 O R	Latching Relay or Mechanically-Held Contactor O=operate; R=reset; TC=trip coil; CC=closing coil. (Coils may be separated on diagram)
	Knife Switch, general. (If shown closed, terminals must be added.)
	Switch - General, single pole, single throw.
	Switch - One pole of multi-pole switch shown. Other poles shown elsewhere.
	Pushbutton - Momentary or spring return. Single Circuit (make)
	Pushbutton - Momentary or spring return. Single Circuit (break)
	Pushbutton - Momentary or spring return. Two Circuit
	Pushbutton - Maintained, two circuit
	Pushbutton - Maintained, single circuit
H A	Selector Switch - Two position, maintained (designate position shown; i.e. A=Auto; H=Hand)
T C SR SR	Selector Switch - Three position, SR indicates spring return from position so labeled. ("TRIP-(NORMAL)-CLOSE" position shown)
	Limit Switch - Normally oper - Not applicable for Motor Operated Valves and Solenoid Valves.
	Limit Switch - Normally closed - Not applicable for Motor Operated Valves and Solenoid Valves.

CIRCUIT ANALYSIS BASICS

IEEE Standard Devices Numbers – Refer to Handout

ANSI/IEEE Standard Device Numbers

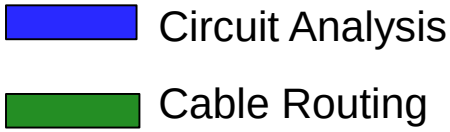
1 – Master Element
2 – Time delay Starting or Closing Relay
3 – Checking or Interlocking Relay
4 – Master Contactor
5 – Stopping
6 – Starting Circuit Breaker
7 – Rate of Change Relay
8 – Control Power Disconnecting Device
9 – Reversing Device
10 – Unit Sequence Switch
11 – Multi-function Device
12 – Overspeed Device
13 – Synchronous-speed Device
14 – Underspeed Device
15 – Speed – or Frequency, Matching Device
16 – Data Communications Device
17 – Shunting or Discharge Switch
18 – Accelerating or Decelerating Device
19 – Starting to Running Transition Contractor
20 – Electrically Operated Valve
21 – Distance Relay
22 – Equalizer Circuit Breaker
23 – Temperature Control Device
24 – Volts per Hertz Relay
25 – Synchronizing or Synchronize-Check Device
26 – Apparatus Thermal Device
27 – Undervoltage Relay
27s - DC under voltage Relay
28 – Flame detector
29 – Isolating Contactor or Switch
30 – Annunciator Relay
31 – Separate Excitation
32 – Directional Power Relay or Reverse Power Relay
33 – Position Switch
34 – Master Sequence Device
35 – Brush-Operating or Slip-Ring Short-Circuiting Dev
36 – Polarity or Polarizing Voltage Devices
37 – Undercurrent or Underpower Relay
38 – Bearing Protective Device
39 – Mechanical Condition Monitor
40 – Field (over/under excitation) Relay
41 – Field Circuit Breaker
42 – Running Circuit Breaker
43 – Manual Transfer or Selector Device
44 – Unit Sequence Starting Relay
45 – DC over voltage Relay
46 – Reverse-phase or Phase-Balance Current Relay
47 – Phase-Sequence or Phase-Balance Voltage Relay
48 – Incomplete Sequence Relay
49 – Machine or Transformer, Thermal Relay - OLR
50 – Instantaneous Overcurrent Relay
50G - Instantaneous Earth Overcurrent Relay (Neutral CT Method)
50N - Instantaneous Earth Overcurrent Relay (Residual Method)
50BF - Breaker failure
51 – AC Inverse Time Overcurrent Relay
51G - AC Inverse Time Earth Overcurrent Relay (Neutral CT Method)
51N - AC Inverse Time Earth Overcurrent Relay (Residual Method)
52 – AC Circuit Breaker
52a - AC Circuit Breaker Position (Contact Open when Breaker Open)
52b - AC Circuit Breaker Position (Contact Closed when Breaker Open)
53 – Exciter or DC Generator Relay
54 – Turning Gear Engaging Device
55 – Power Factor Relay
56 – Field Application Relay
57 – Short-Circuiting or Grounding Device
58 – Rectification Failure Relay
59 – Overvoltage Relay
60 – Voltage or Current Balance Relay.
61 – Density Switch or Sensor
62 – Time-Delay Stopping or Opening Relay
63 – Pressure Switch
64 – Ground Detector Relay
64R - Restricted earth fault
64S - Stator earth fault
65 – Governor
66 – Notching or Jogging Device
67 – AC Directional Overcurrent Relay
68 – Blocking Relay

Page 1

CIRCUIT ANALYSIS BASICS

Types of Drawings and Their Purpose

- Single-line drawings
- Three-line drawings
- Elementary or schematic diagrams
- Block diagrams
- Cable raceway schedules
- Wiring or connection drawings
- Instrument loop diagrams
- Vendor shop drawings
- Equipment arrangement or location drawings
- Tray and conduit layout drawings
- Underground and duct-bank layout drawings
- Specialty drawings (electrical penetration, logic, load lists, coordination diagrams, short circuit calculations)
- Piping and instrument diagrams



CIRCUIT ANALYSIS BASICS

Drawing Types – Refer to Electrical Basic Drawing Index

Index - Electrical Basics Drawing Samples	
Basics 1	Overall Plant 1-Line
Basics 2	7.2 kV Bus 1-Line
Basics 3	4.16 kV Bus 1-Line
Basics 4	600 V 1-Line
Basics 5	480 V MCC 1-Line
Basics 6	7.2 kV 3-Line Diagram
Basics 7	4.16 kV 3-Line Diagram
Basics 8	AOV Elementary & Block Diagram
Basics 9	4.16 kV Pump Schematic
Basics 10	480 V Pump Schematic
Basics 11	MOV Schematic (with Block included)
Basics 12	12-/208 VAC Panel Diagram
Basics 13	Valve Limit Switch Legend
Basics 14	AOV Schematic (with Block included)
Basics 15	Wiring (or Connection) Diagram
Basics 16	Wiring (or Connection) Diagram
Basics 17	Tray & Conduit Layout Drawing
Basics 18	Embedded Conduit Drawing
Basics 19	Instrument Loop Diagram

CIRCUIT ANALYSIS BASICS

Equipment of Interest

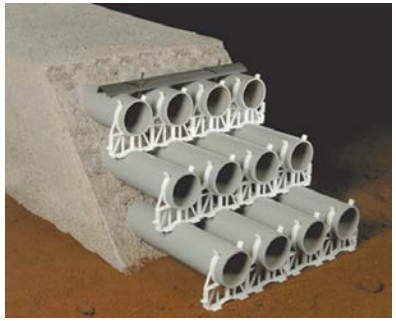
- Cables and panel wiring
- Raceways
- Valves
- Transformers – big to small
- High, medium, and low voltage switchgear
- Protective relays
- Circuit breakers
- Instrumentation

CIRCUIT ANALYSIS BASICS

Equipment of Interest – Cables & Raceways

- Cables and Panel Wiring
  - Single-conductor cable
  - Multi-conductor cable
  - Triplex cable
  - Size conventions and ampacity
  - Shielded, unshielded, & armored
  - Materials – conductor, insulation, & jacket

- Raceway Types
  - Conduit
  - Tray – ladder and solid
  - Wireways
  - Pull boxes
  - Junction boxes
  - Terminal boxes
  - Duct-banks
  - Embedded conduit
  - Air drops



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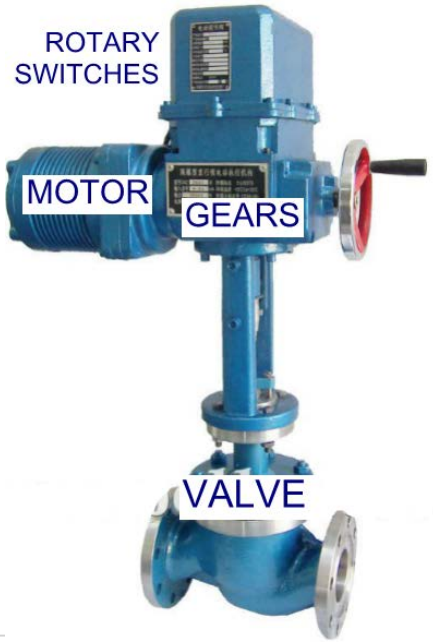
CIRCUIT ANALYSIS BASICS

Equipment of Interest – Valves

- Air Operated Valves (AOV)
  - Pilot solenoid operated
  - Bi-modal function
  - Modulate function
- Solenoid Valves (SOV)
  - AC & DC operated
- Motor Operated Valve (MOV)
  - Typical design
  - Inverted design



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CIRCUIT ANALYSIS BASICS

Equipment of Interest – Transformers

- Power Transformers
  - Main transformers
  - Unit auxiliary transformers (UAT)
  - Startup or reserve auxiliary transformer (SUT, RAT)
  - Station service transformer (SST)

- Control Power Transformers (CPT)
- Instrument Transformers
  - Potential transformer (PT)
  - Current transformer (CT)
  - Zero sequence current transformer

- Specialty Transformers

CIRCUIT ANALYSIS BASICS

Equipment of Interest – Switchgear & Relays

- Switchgear
  - Medium Voltage
    - 1,000 V – 15,000 V
    - 13.8 kV, 12.47 kV, 7.2 kV, 6.9 kV, 4.16 kV, 2.4 kV
  - Low Voltage
    - Up to 1,000 V
    - 120 V, 208 V, 240 V, 277 V, 480 V, 600 V
  - Typically metal-clad, indoor, draw-out design
  - Separate control power circuit and protective devices
- Protective Relays
  - Overcurrent relays (50, 51, 50N, 51N, 50G)
  - Differential relays (87, 87T, 87B)
  - Undervoltage relays (27)
  - Frequency relays (81)
  - Reverse power relays (32, 67)
  - Lockout relays (86)

CIRCUIT ANALYSIS BASICS

Equipment of Interest – Circuit Breakers

- Medium Voltage Power Circuit Breakers
  - Power Circuit Breakers (PCB)
    - Vacuum Circuit Breakers (VCB)
    - Air Circuit Breakers (ACB)
    - Gas Circuit Breaker (GCB)
  - 1,000 V – 15 kV

- Low Voltage Power Circuit Breakers (LVPCB)
  - Below 1,000 V
  - Same basic features as medium voltage power breakers
  - Internal or external trip devices
- Molded Case Circuit Breakers
  - Internal trip devices
    - Thermal and/or magnetic
  - Generally manually operated

CIRCUIT ANALYSIS BASICS

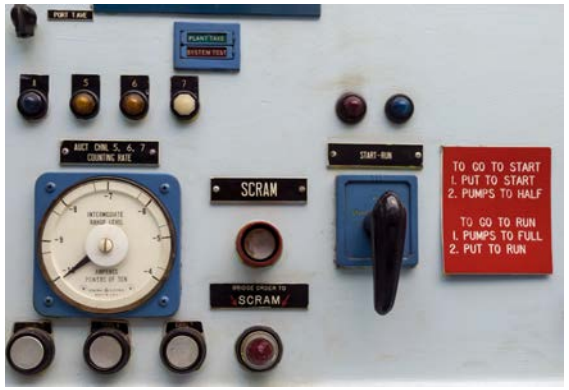
Equipment of Interest – Motors

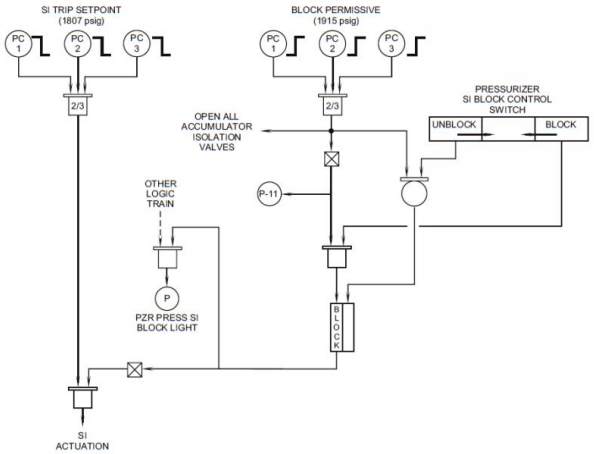
- AC, DC, 1-phase, 3-phase
- Synchronous vs. induction design
- Large motors controlled by circuit breaker
- Smaller motors often controlled by a “motor starter”
- Continuous duty (pump) vs. intermittent duty (MOV)
- MOVs and DC motors are most often reversing design
- High temp is usually an alarm or time-delay trip
- Locked rotor current must be considered

CIRCUIT ANALYSIS BASICS

Equipment of Interest – Process Inst & Rx Protection

- Process Instrumentation
  - Temperature
  - Level
  - Flow
  - Pressure
- Reactor Trip
  - Trip signals
  - Actuation circuitry
- Engineered Safety Features Actuation System
  - Input signals
  - Actuation logic
  - Solid-state protection system (SSPS)
- Digital Control Systems (DCS)





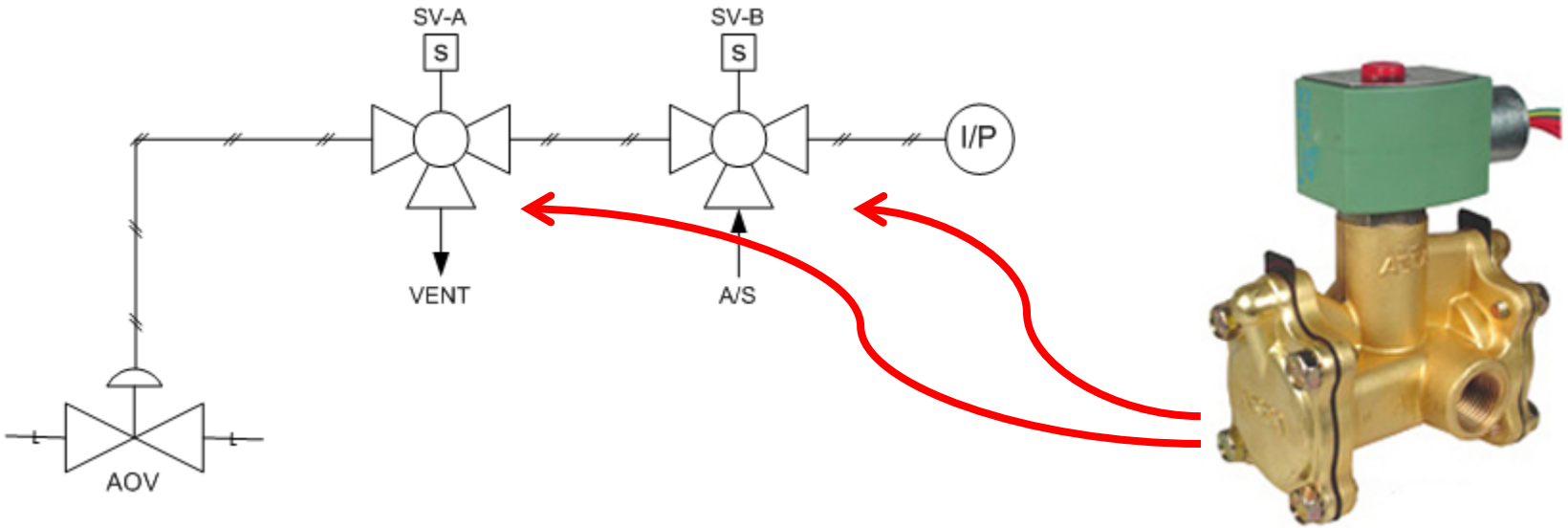
CIRCUIT ANALYSIS BASICS

Electrical Circuit Operation – Common Circuits

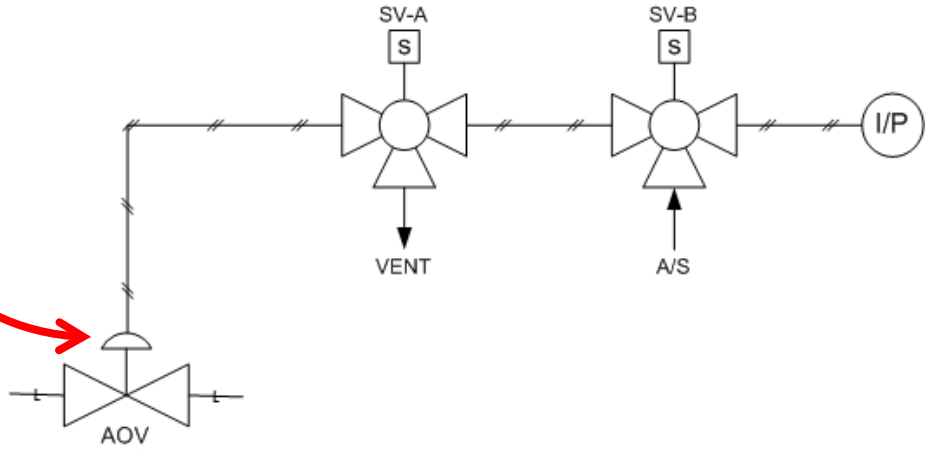
- Air Operated Valve (AOV)
  - Main air valve
  - Pilot solenoid valve
- Direct acting solenoid valve
- Motor Operated Valve (MOV)
- Power Circuit Breakers (PCB)
  - Medium Voltage Power Circuit Breaker
  - Low Voltage Power Circuit Breaker

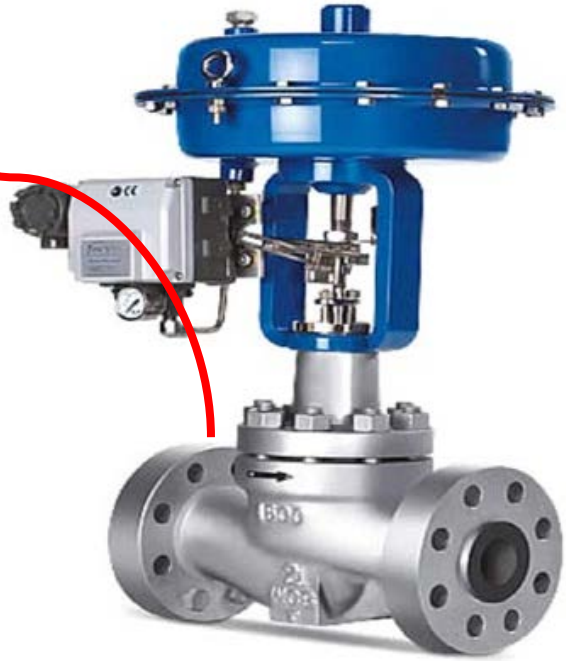
Solenoid Operated Valve (SOV)

- An SOV is an electromechanically operated device
  - Valve is controlled by electric current
  - Commonly used to control air operated valves (AOVs)
  - When used for AOV, called a pilot valve

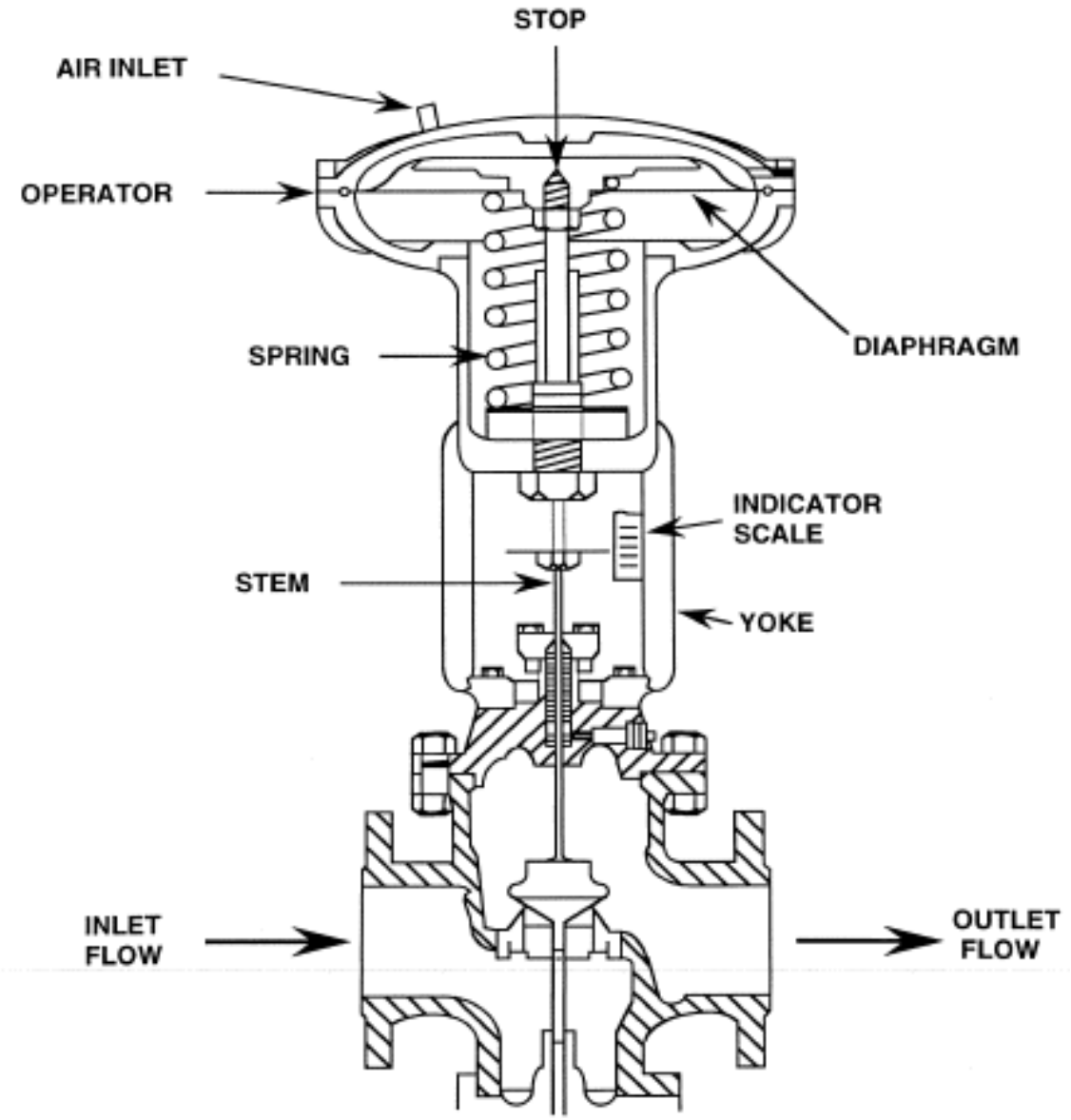


Air Operated Valve (AOV)

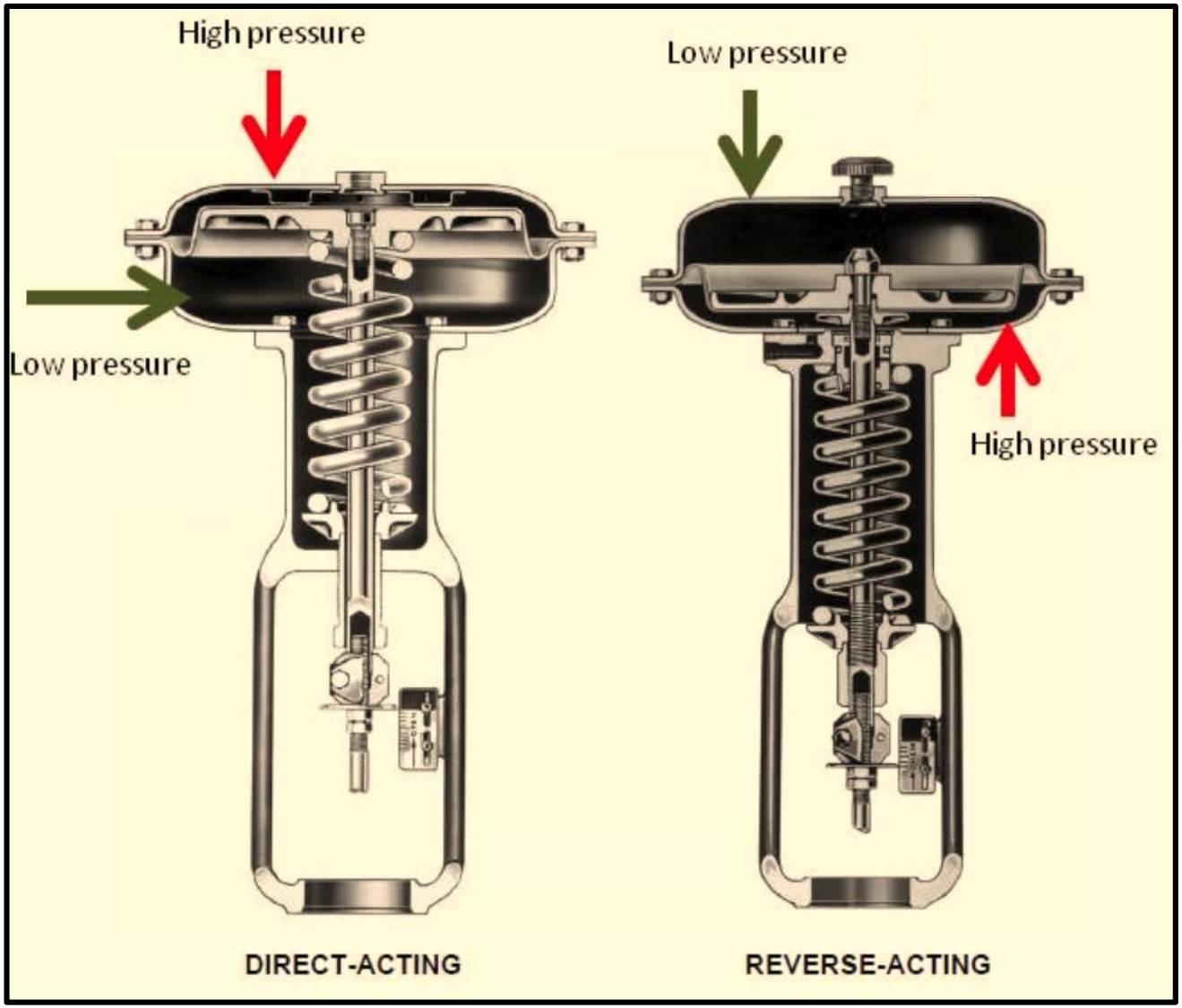




Air Operated Valve (AOV)



Air Operated Valve (AOV)



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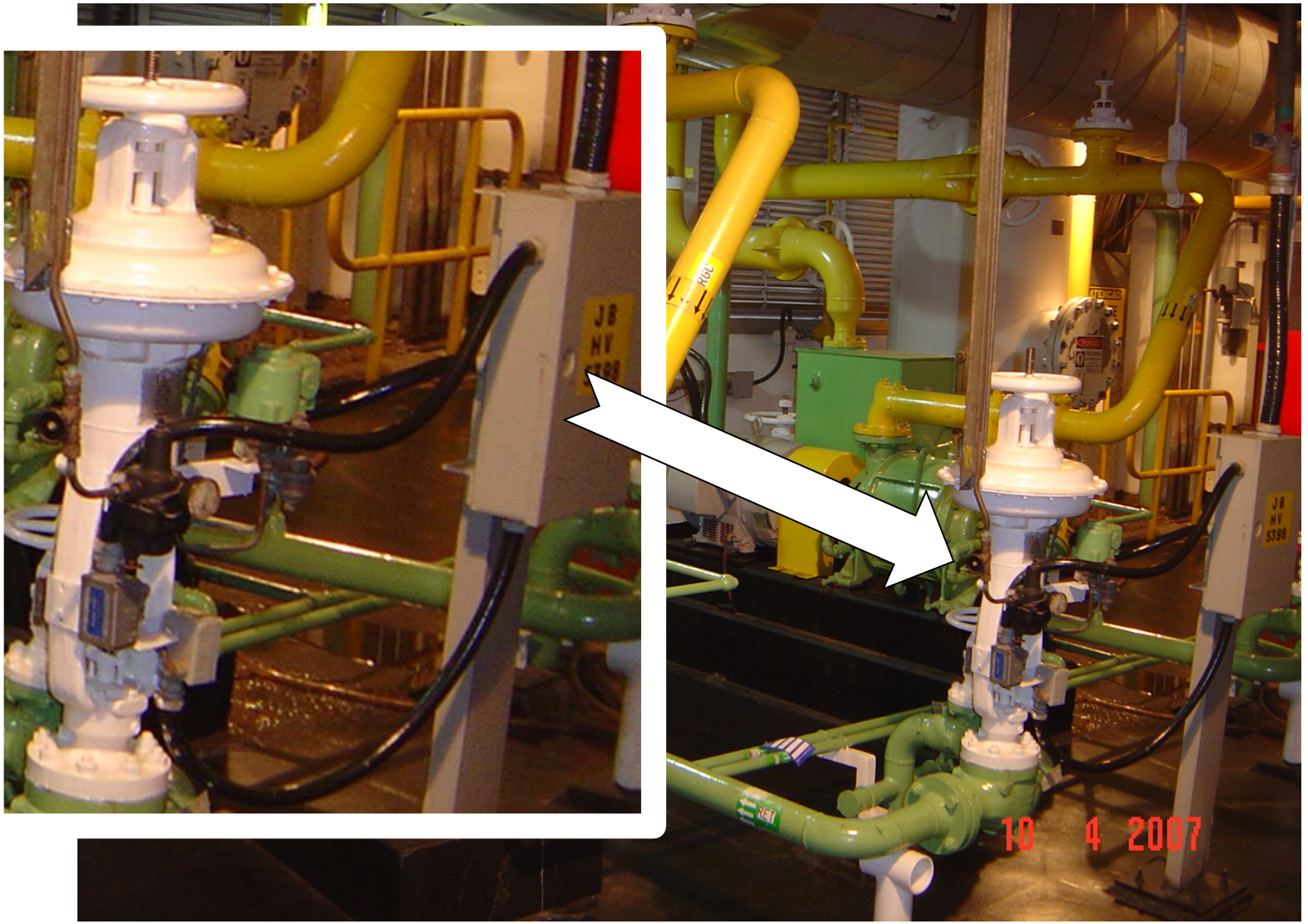
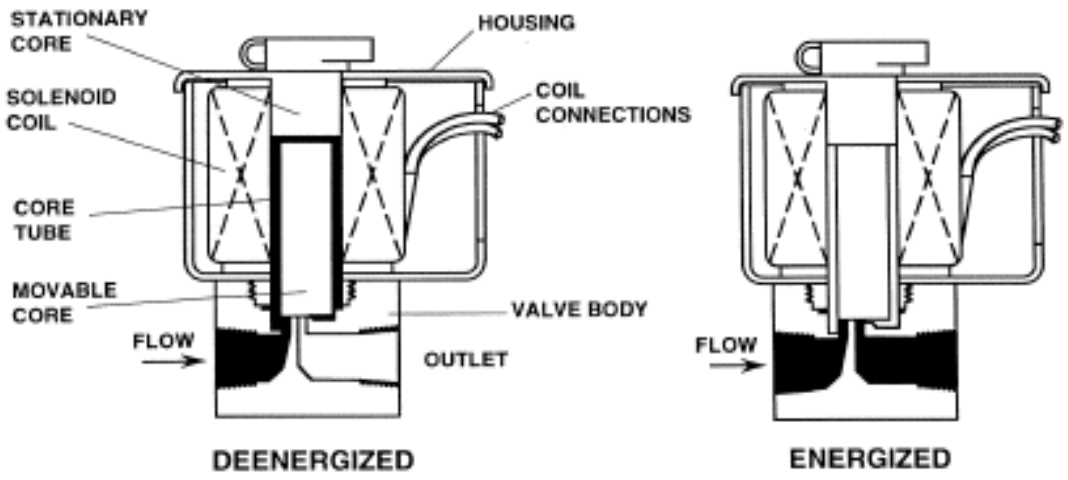
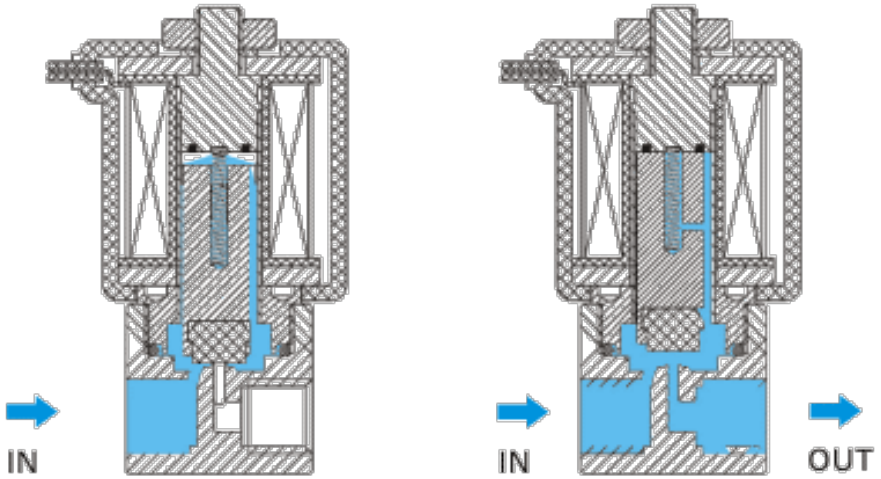
Where is the AOV in this picture?



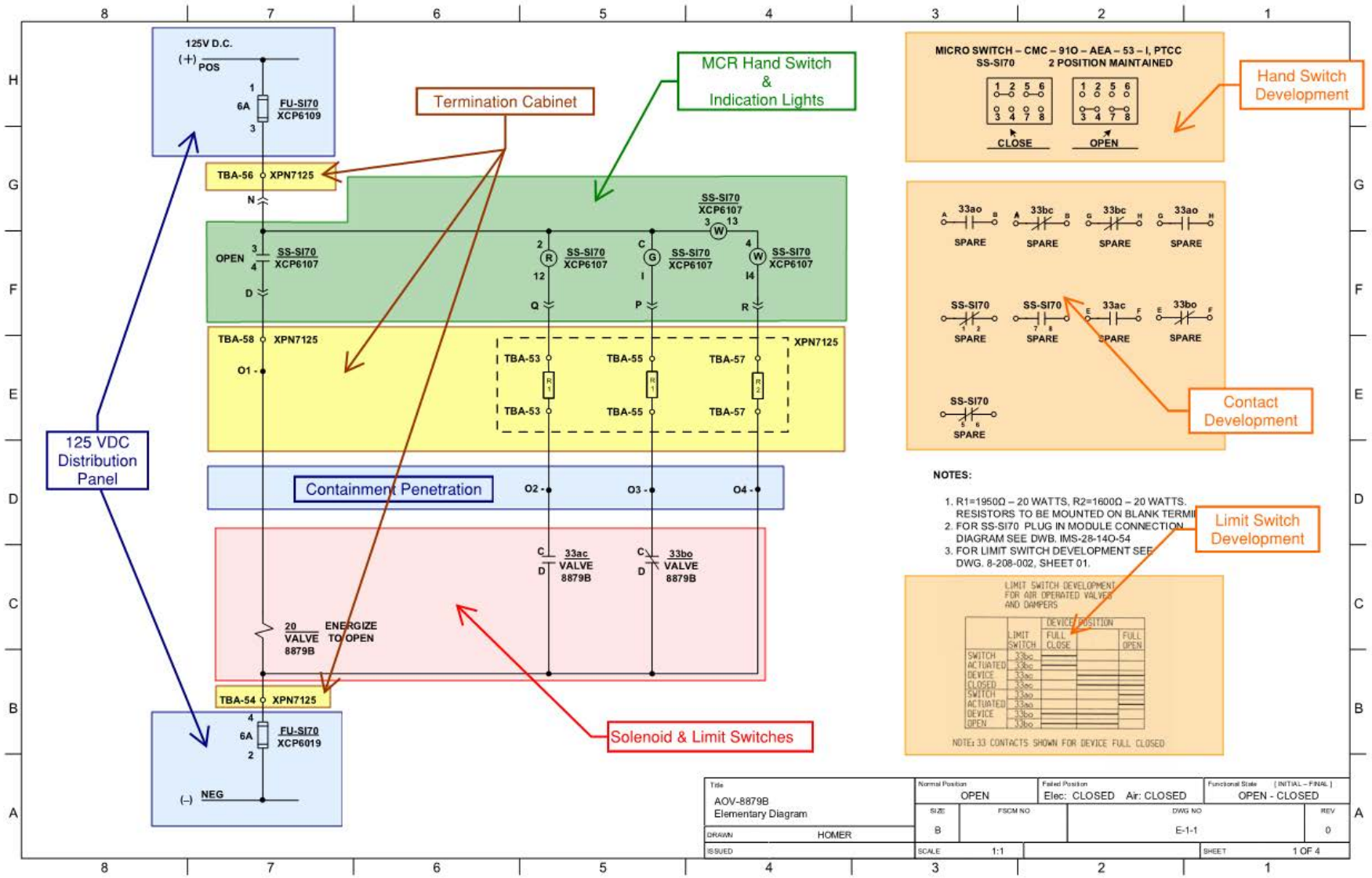
Direct Acting SOV



A. Direct-Acting Solenoid Valve



SOV Elementary Diagram



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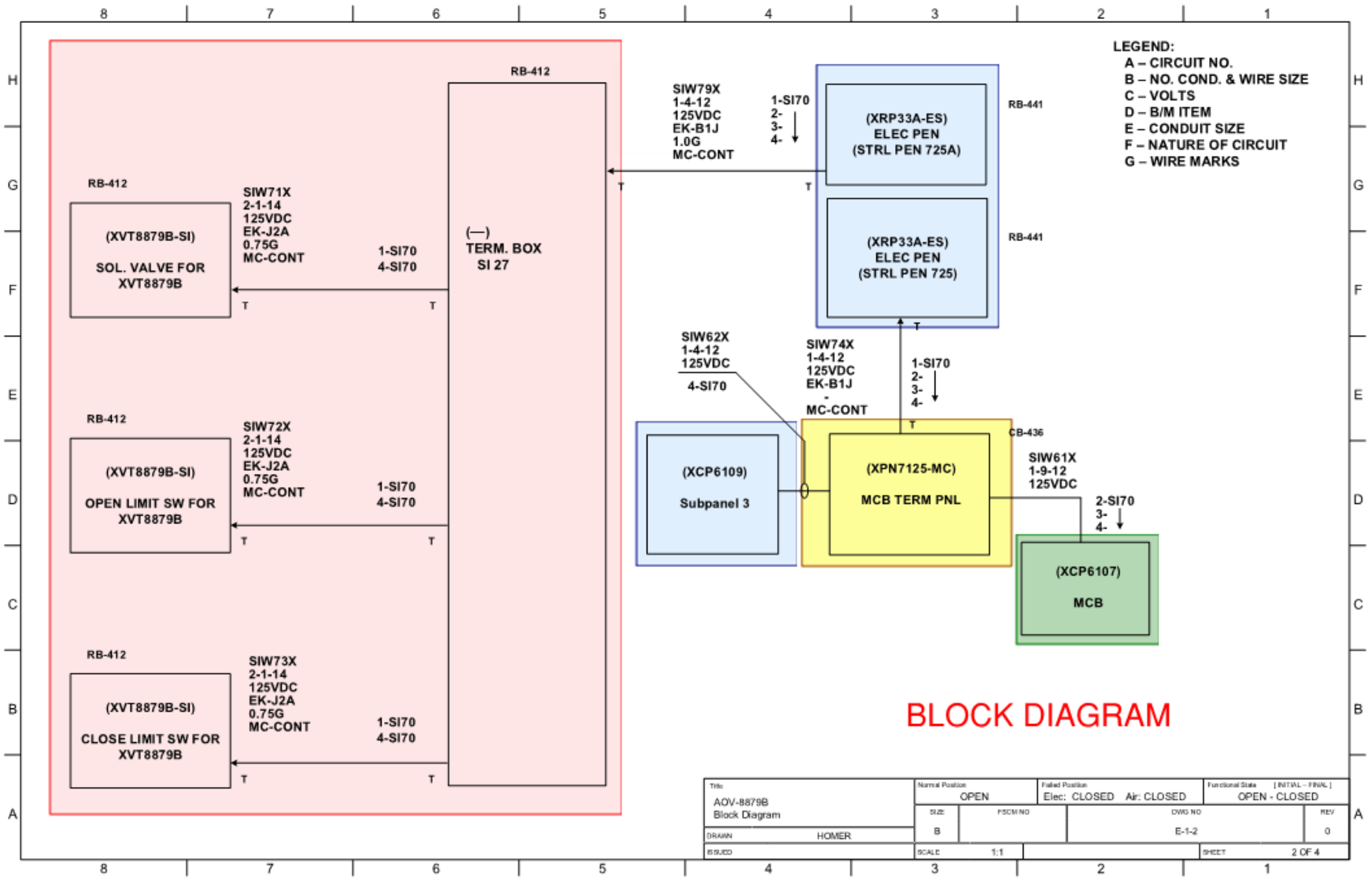
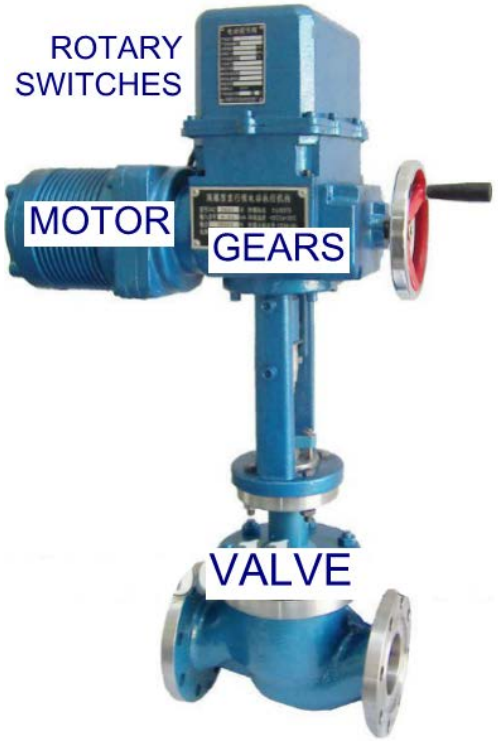
SOV Block Diagram



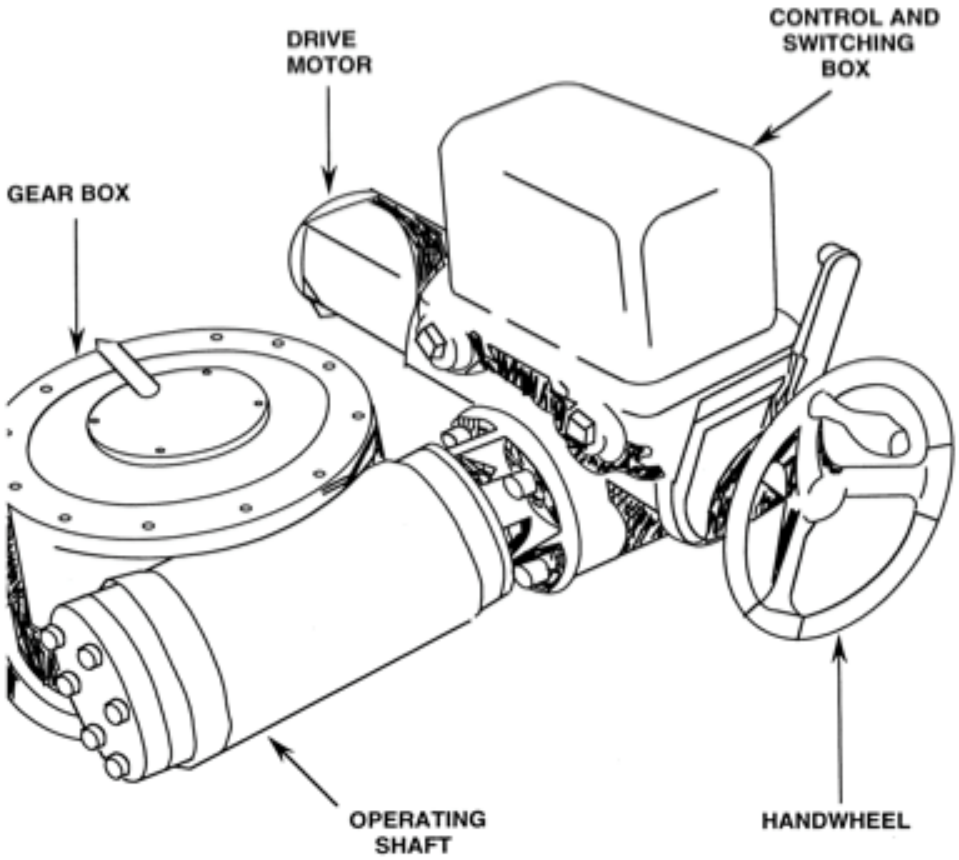
Lets Walk Through SOV Operation

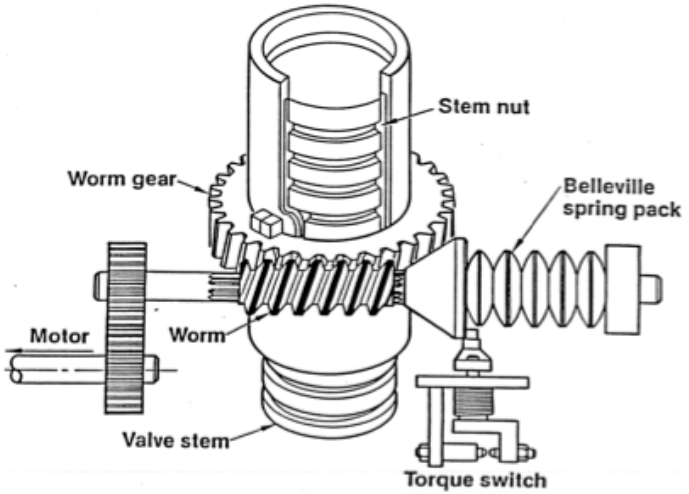
Motor Operated Valve

- A Motor Operated Valve (MOV) is a valve with an actuator driven by an electric motor
- MOVs typically serve an “On-Off” or “Open-Close” purpose
- MOVs are not typically used for throttling
- Valve types can include
  - Gate
  - Ball
  - Butterfly

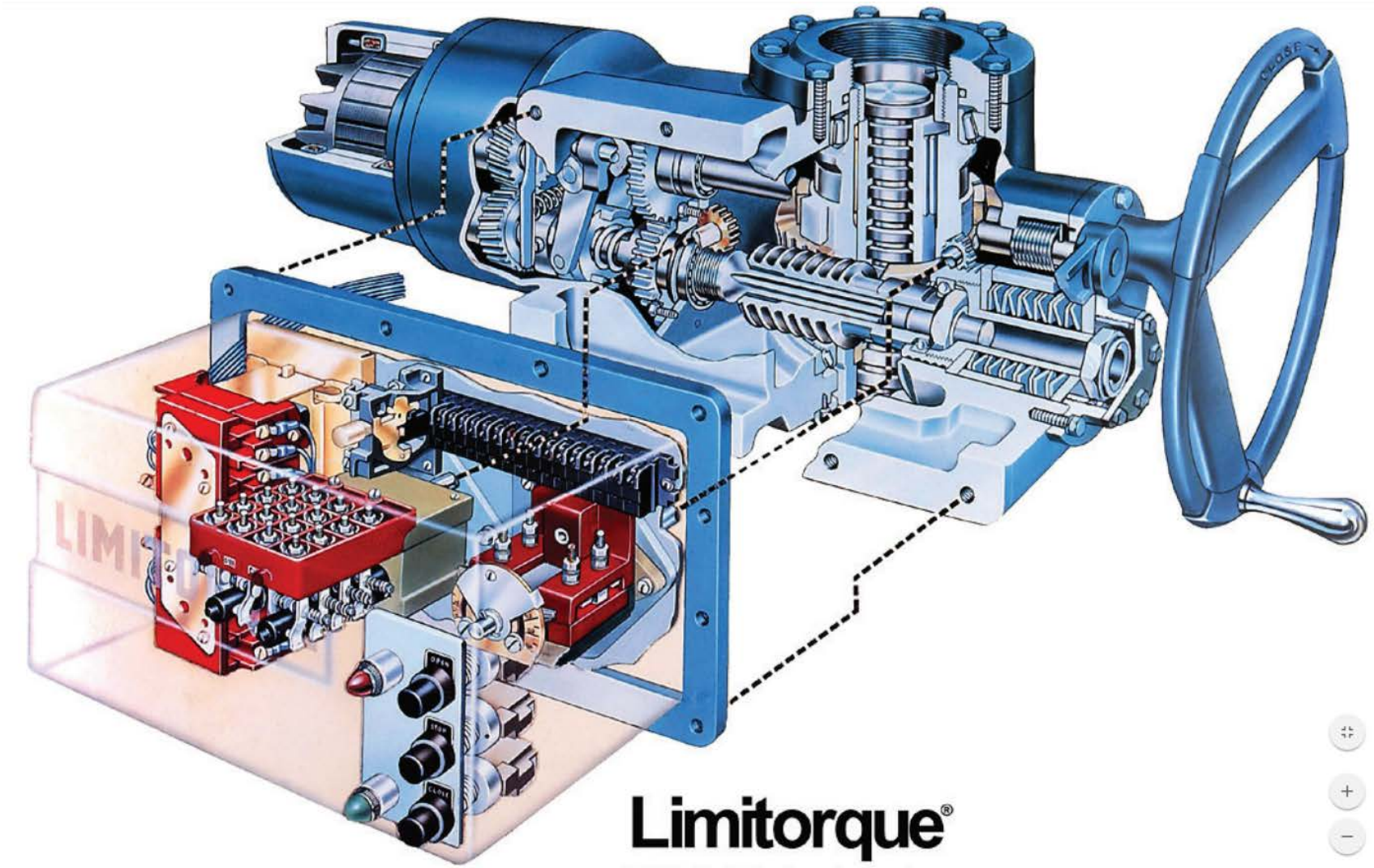


MOV Actuator

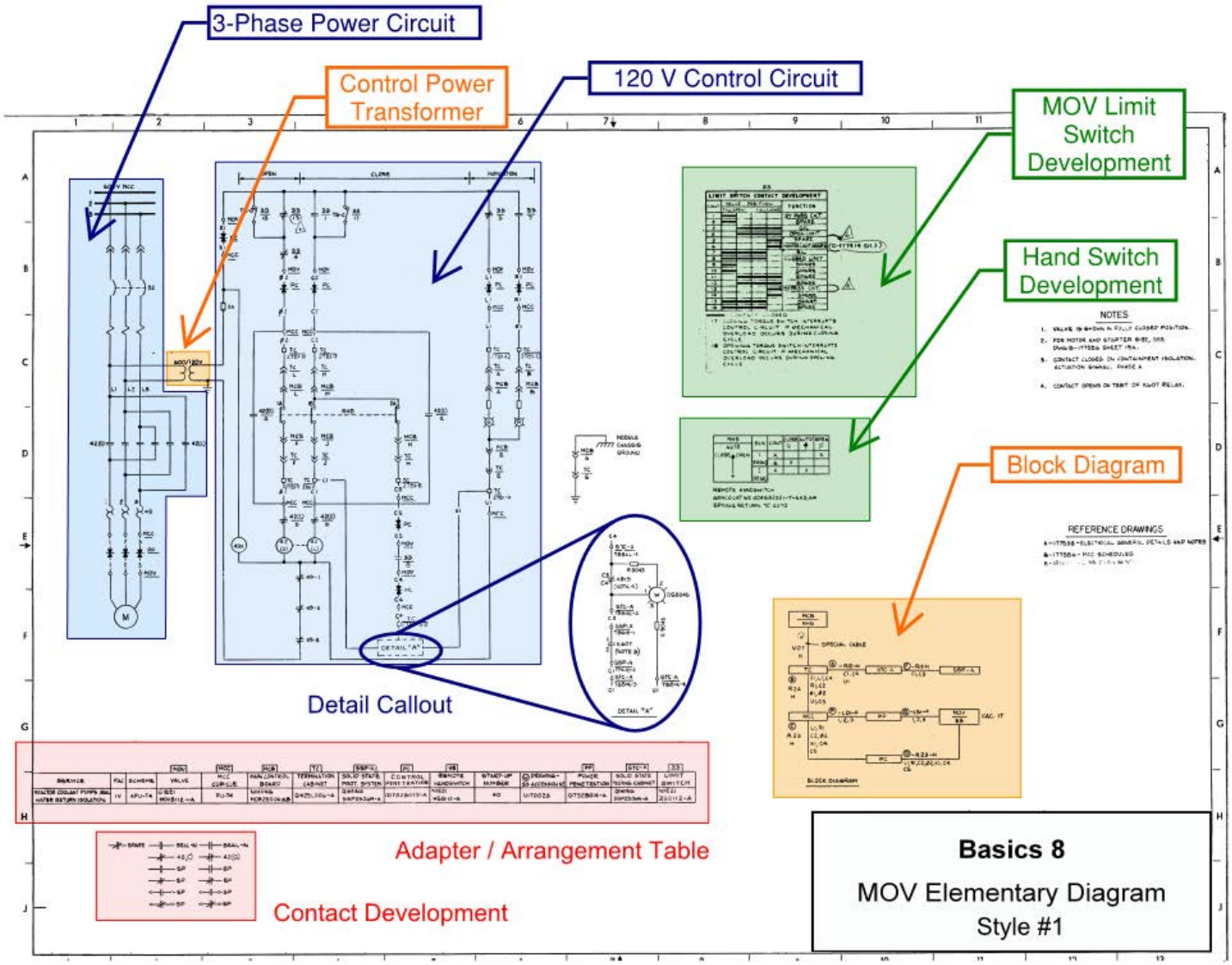




MOV Actuator



MOV Elementary Diagram



Lets Walk Through MOV Operation

Power Circuit Breakers

- Medium Voltage Power Circuit Breakers
  - Power Circuit Breakers (PCB)
    - Main contacts
    - Arc chutes
    - Connection stabs
    - Operating coils and springs
  - Separate 125 VDC control power
  - Separate close and trip coils
  - Fails “as-is” on loss of control power
  - No overcurrent protection w/o control power
  - Separate trip devices – protective relays

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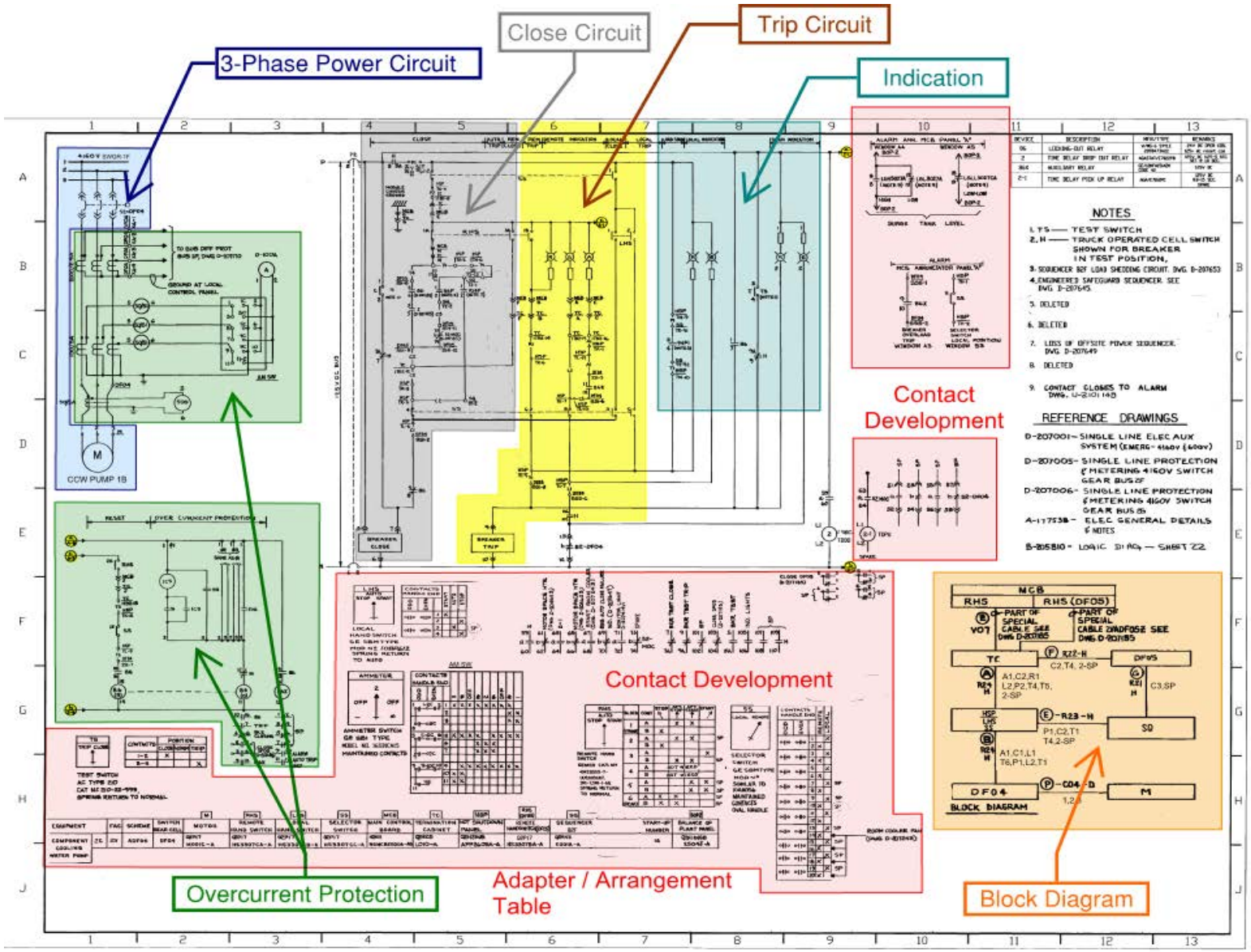
PCB Elementary Diagram



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Lets Walk Through PCB Operation

Any Questions?