Installation and Start-Up Consideration for Medium Voltage Motors and Pumps

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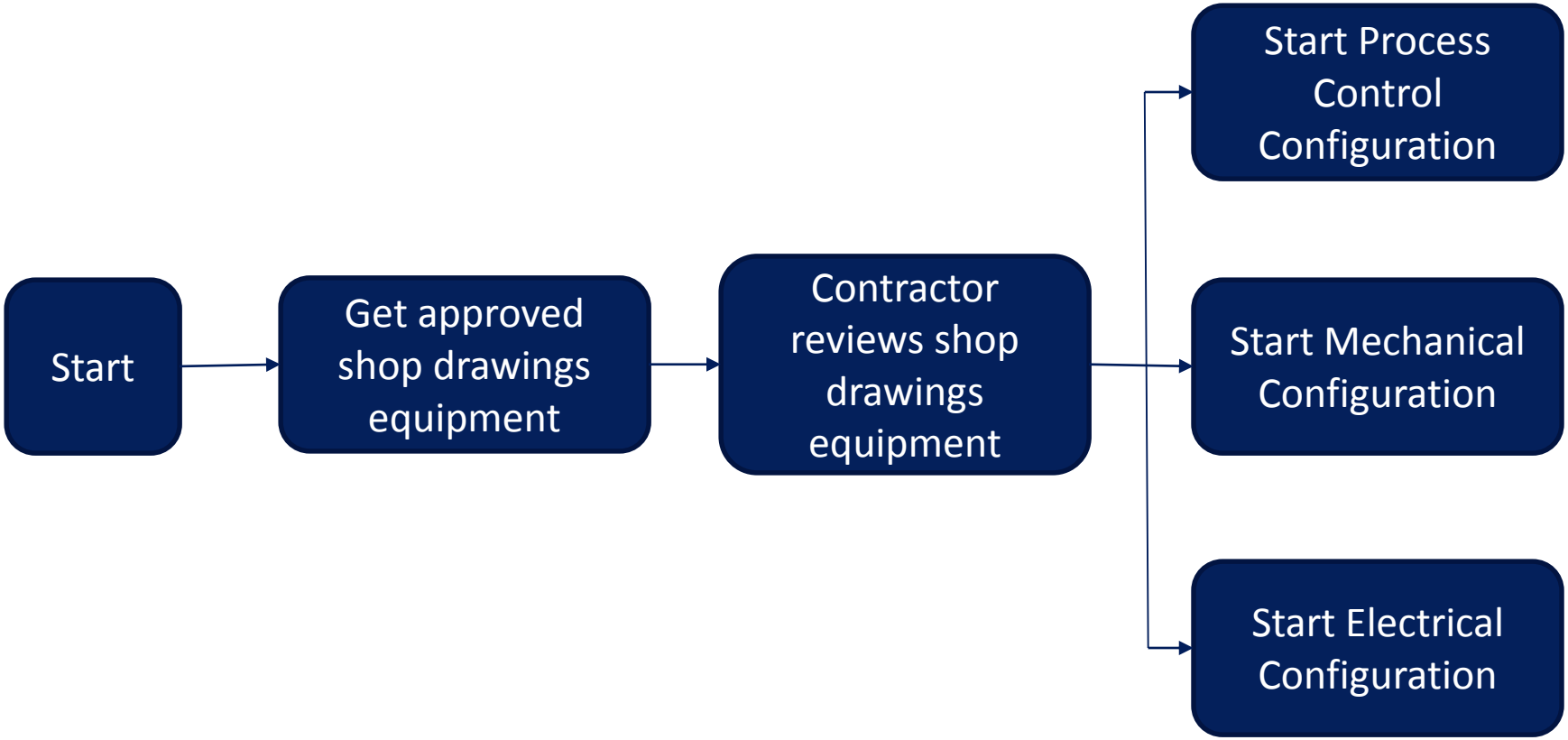
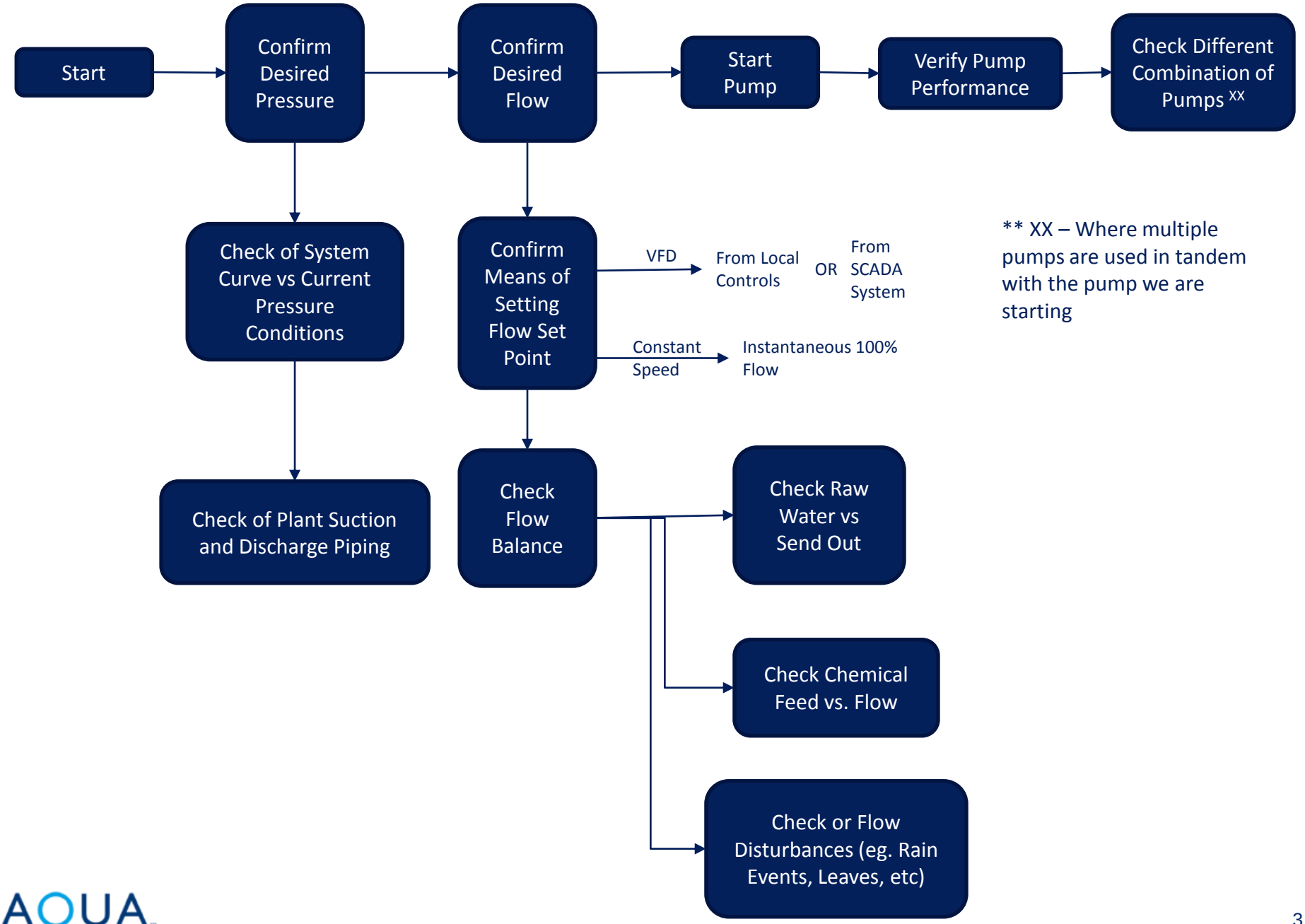
Manager, Electrical Engineering
Pennsylvania Licensed Operator

Generalized Work Breakdown Structure for Setting/Installing Pump

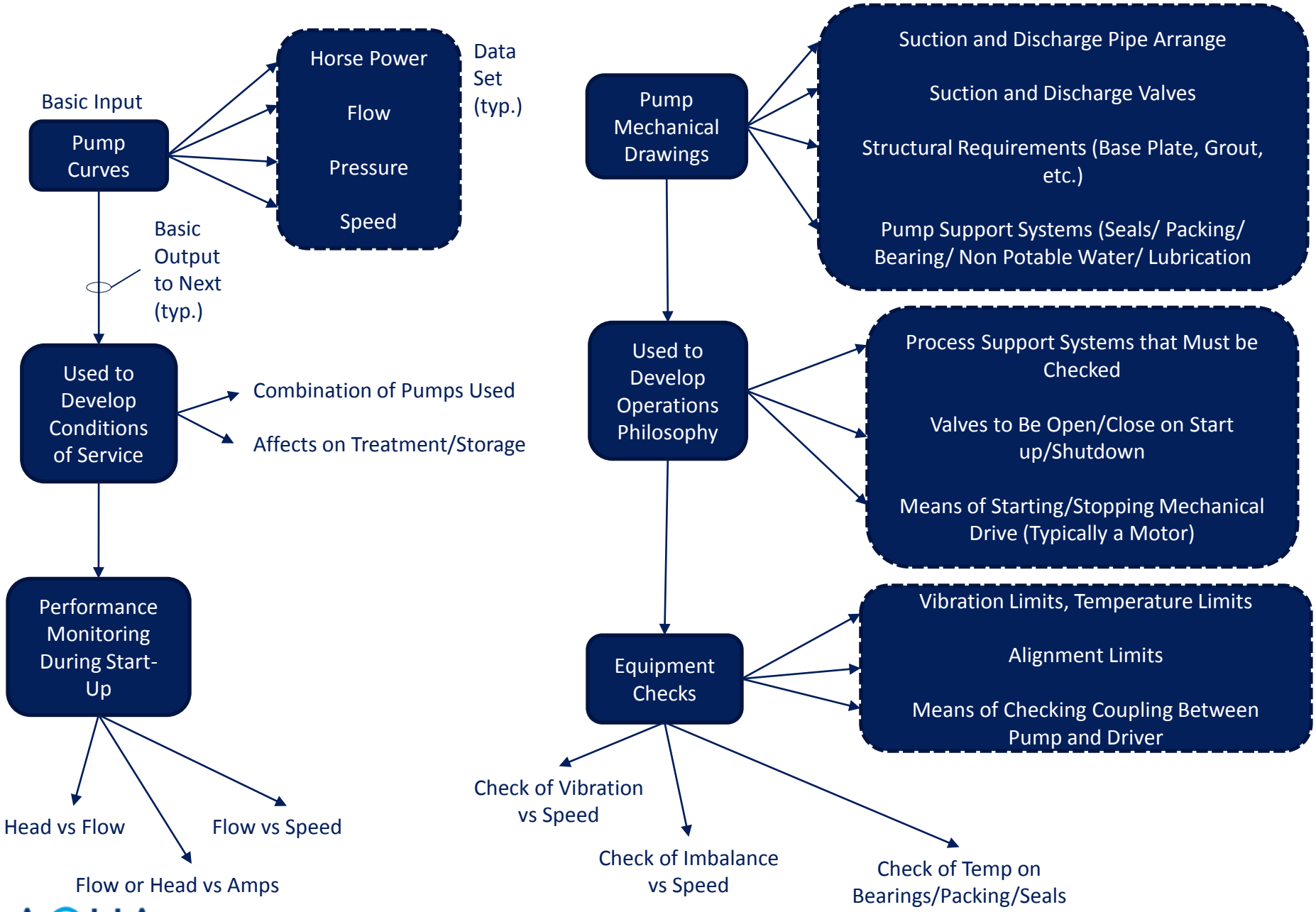


Plant Start Up Path From Operations Perspective



** XX – Where multiple pumps are used in tandem with the pump we are starting

Mechanical Documentation Flow



Electrical Documentation Flow

Basic Input

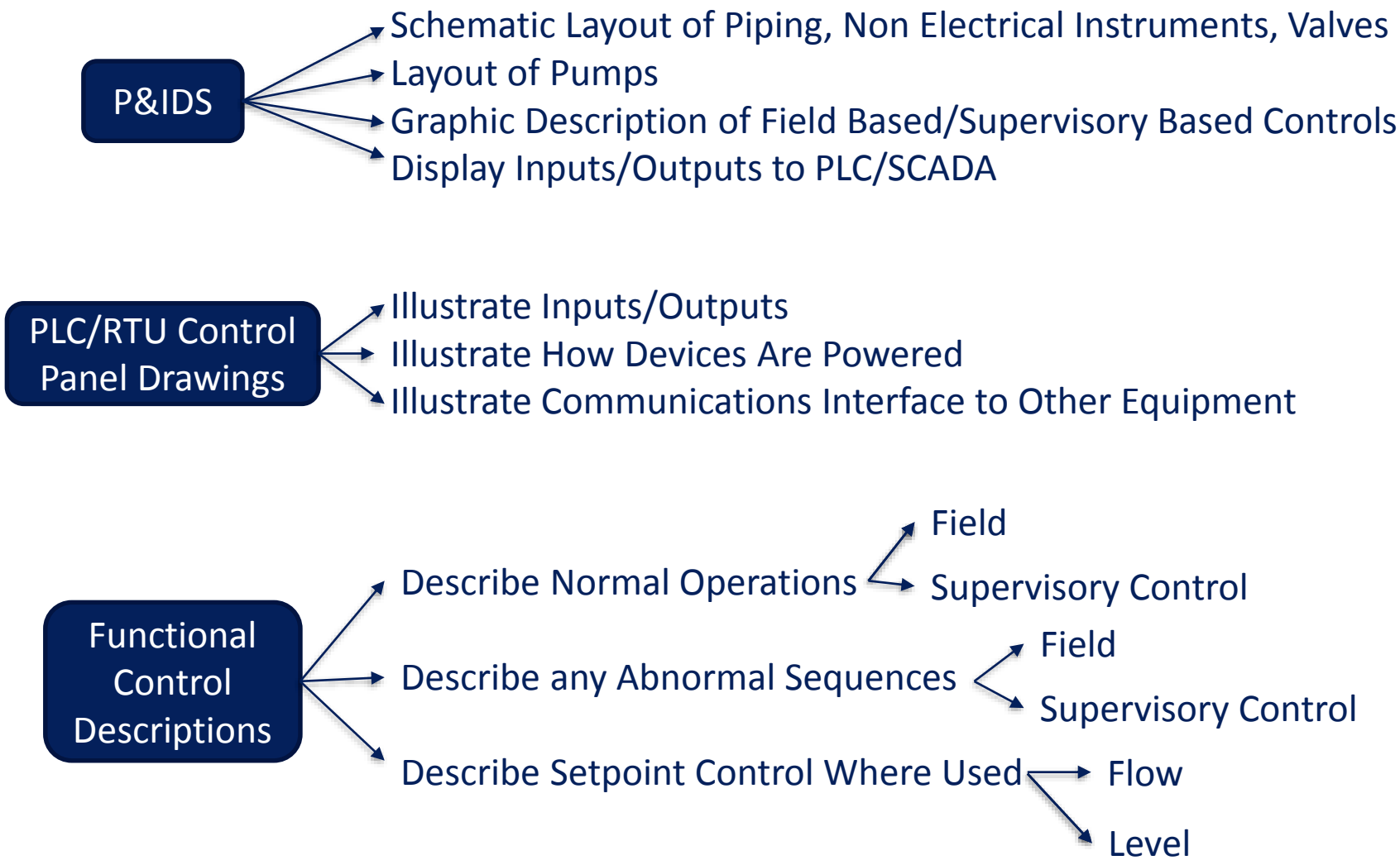
Electrical Single Line Diagrams
- Show How Loads Are Connected to Source
- Motor Starting Method
- Show Overcurrent Protection and Operation
- Show Controls Connected to Power Components

Electrical Control Schematics
- Interconnection to Fixed Devices (Switches, Transformers, etc.)
- Hardwired Interlocks for Start Up/Shutdown
- Interconnection to PLC or SCADA

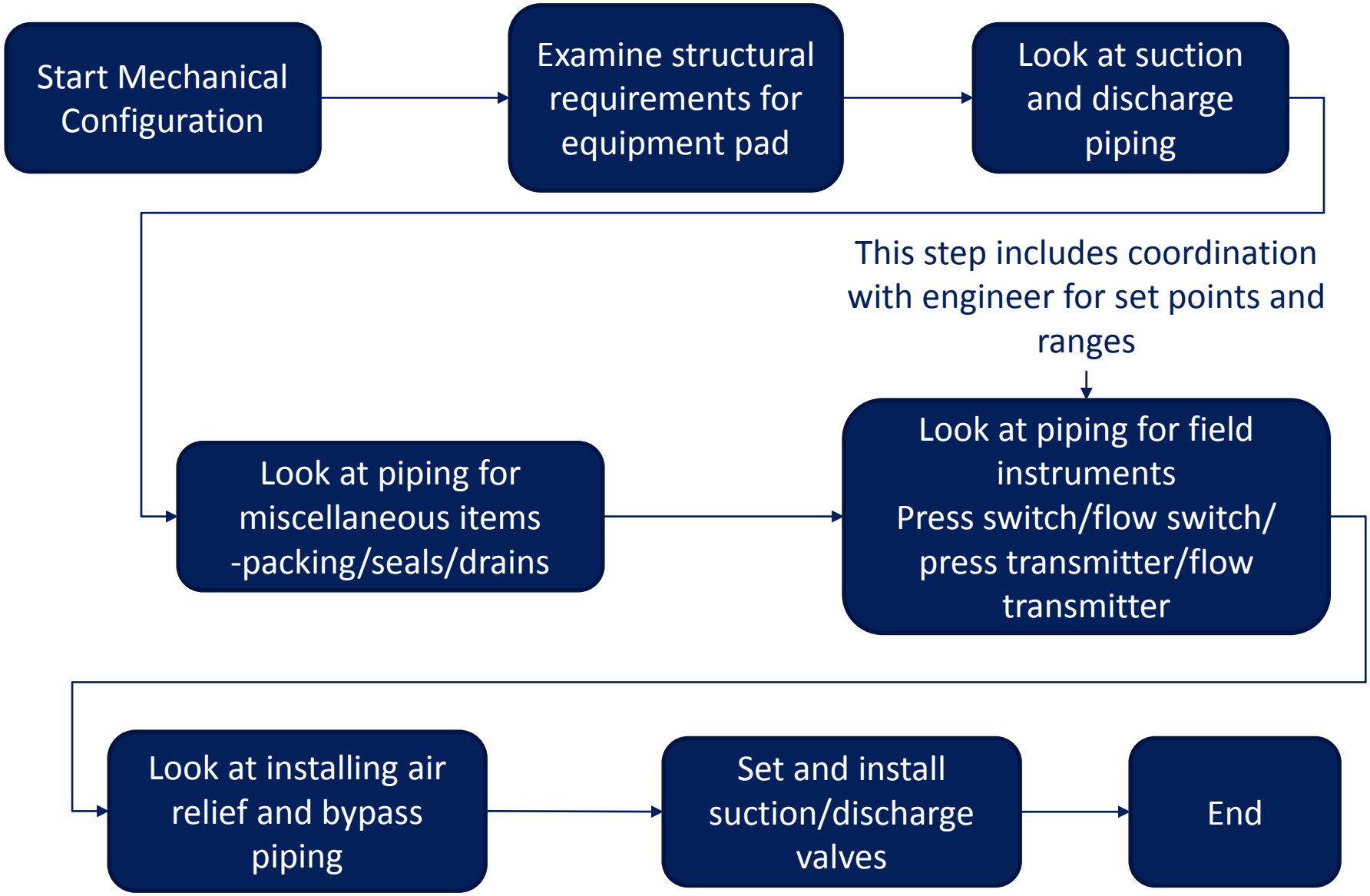
Functional Control Descriptions
- Describe Interlocks Without PLC/SCADA
- Describe Operations for PLC/SCADA
- Describe Alarm Shut Downs

Electrical Plans DWGs
- Power
- Process Control Wiring
- Control Interconnecting Drawings

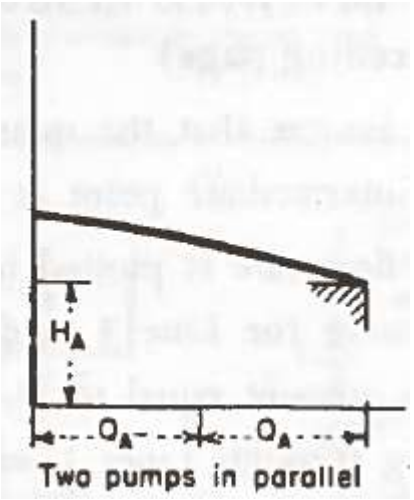
Process Control Documentation Flow



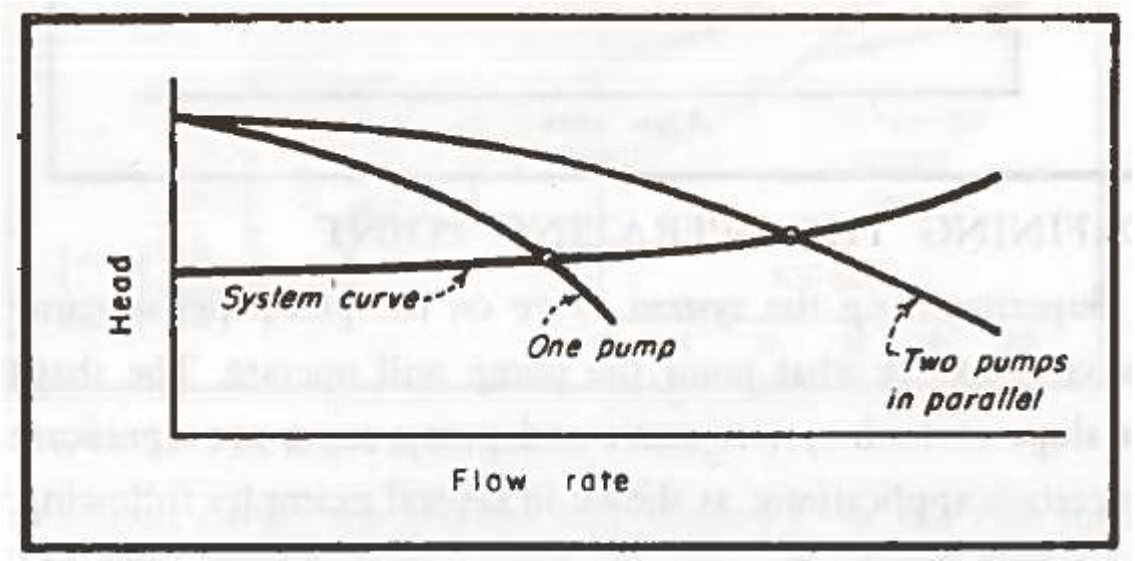
Mechanical Configuration Process Flow Chart



Parallel Operation of Pumps

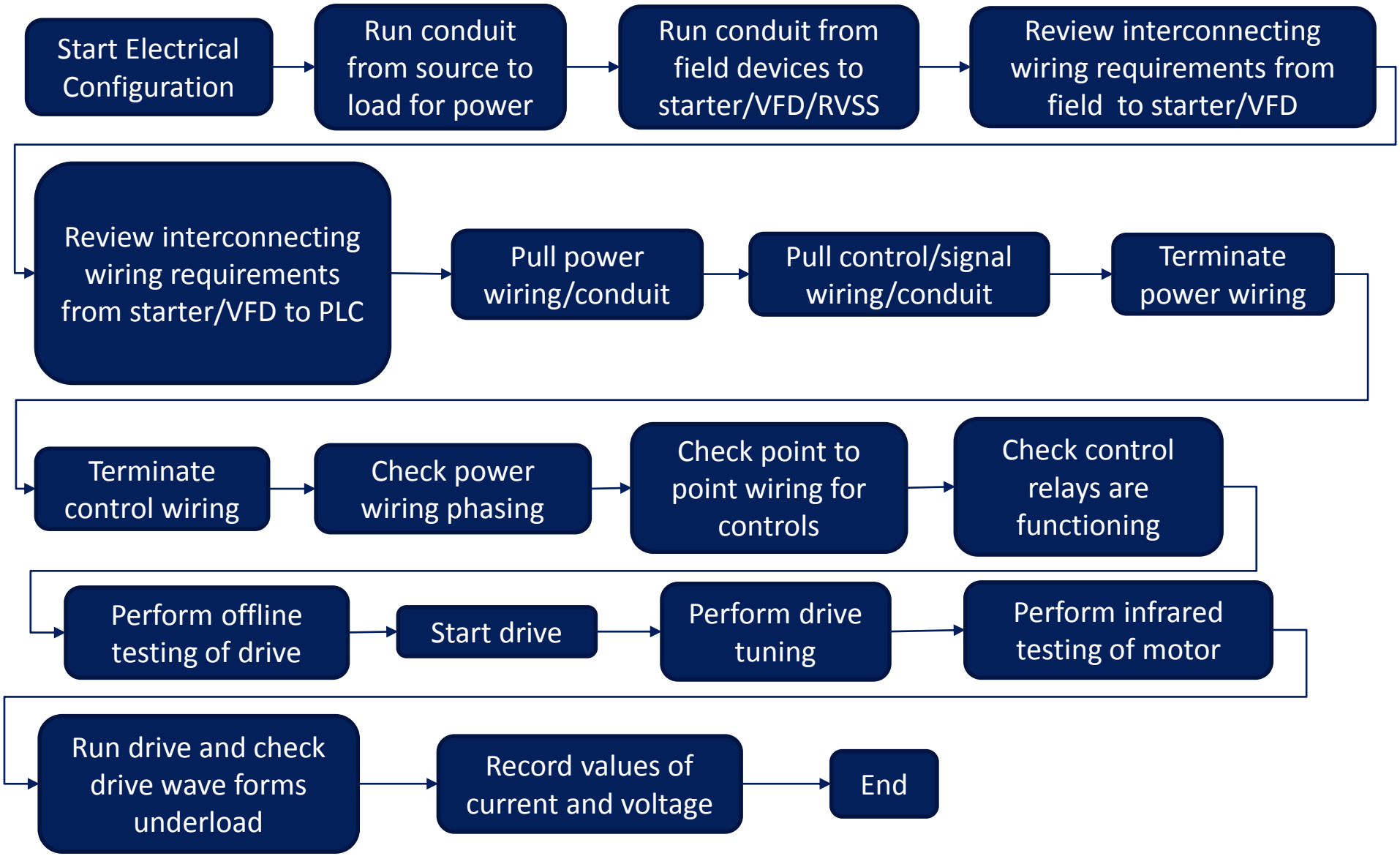


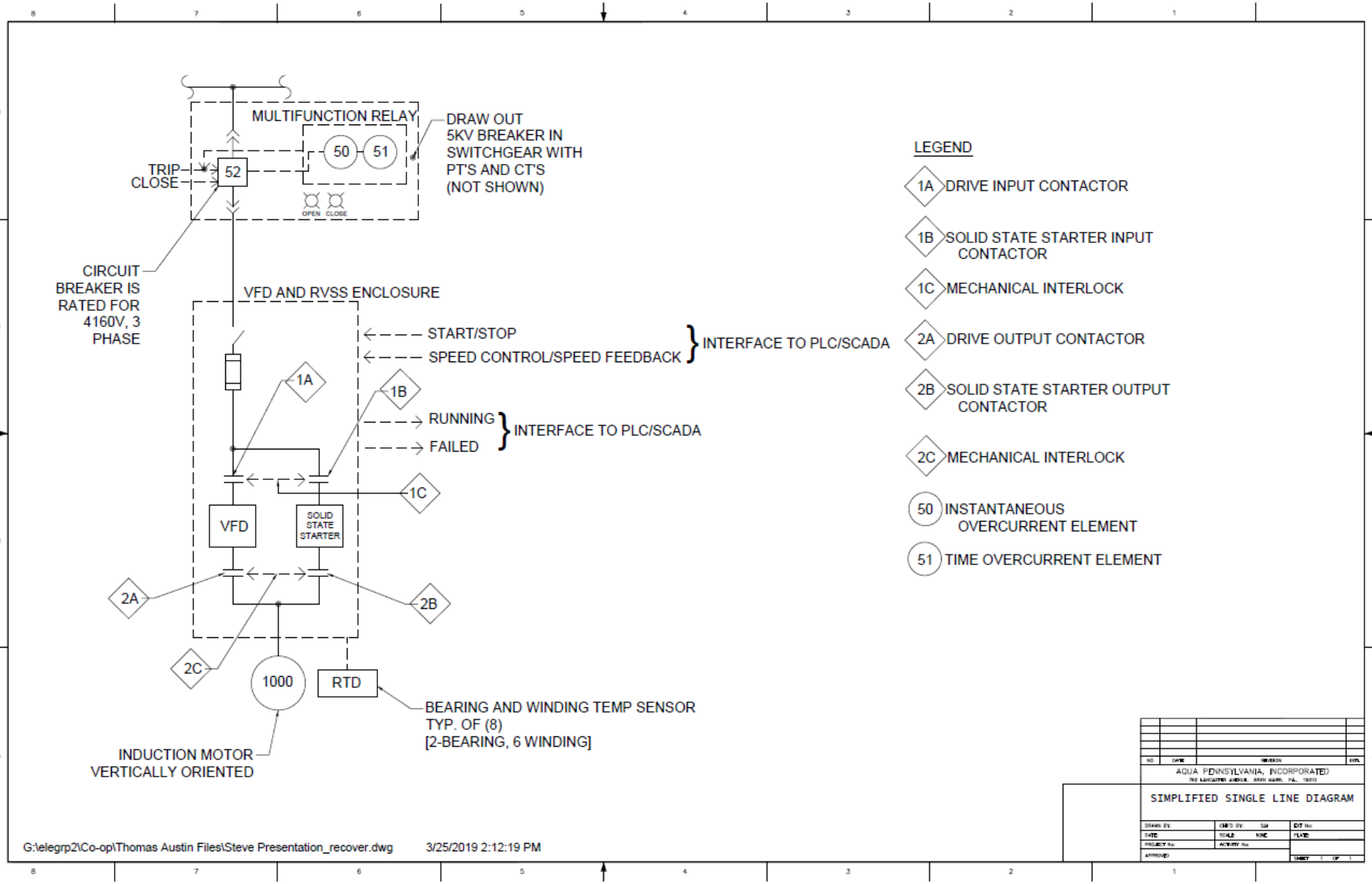
For 2 pumps in parallel
Head (pressure) should not change but flow increases



For 2 pumps in parallel
We shift over on the system head curve

Electrical Configuration Process Flow Chart




MULTIFUNCTION RELAY
50
51
52
TRIP
CLOSE
OPEN
CLOSE
DRAW OUT 5KV BREAKER IN SWITCHGEAR WITH PT'S AND CT'S (NOT SHOWN)
CIRCUIT BREAKER IS RATED FOR 4160V, 3 PHASE
VFD AND RVSS ENCLOSURE
START/STOP
SPEED CONTROL/SPEED FEEDBACK
INTERFACE TO PLC/SCADA
1A
1B
RUNNING
FAILED
INTERFACE TO PLC/SCADA
1C
VFD
SOLID STATE STARTER
2A
2B
2C
1000
RTD
BEARING AND WINDING TEMP SENSOR TYP. OF (8) [2-BEARING, 6 WINDING]
INDUCTION MOTOR VERTICALLY ORIENTED
LEGEND
1A DRIVE INPUT CONTACTOR
1B SOLID STATE STARTER INPUT CONTACTOR
1C MECHANICAL INTERLOCK
2A DRIVE OUTPUT CONTACTOR
2B SOLID STATE STARTER OUTPUT CONTACTOR
2C MECHANICAL INTERLOCK
50 INSTANTANEOUS OVERCURRENT ELEMENT
51 TIME OVERCURRENT ELEMENT
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SIMPLIFIED SINGLE LINE DIAGRAM
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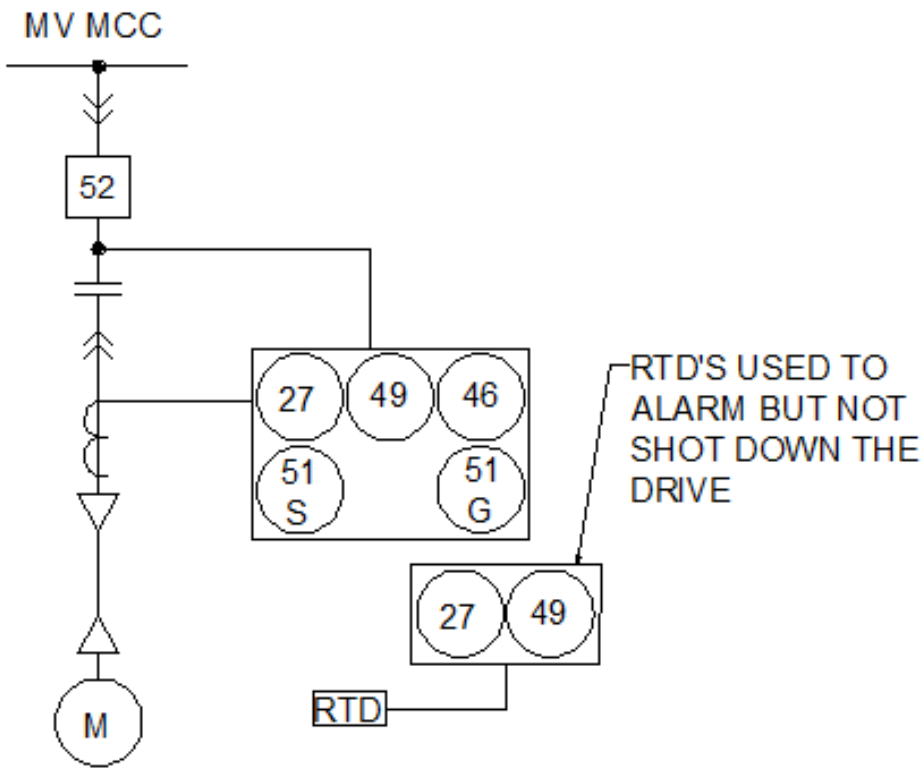
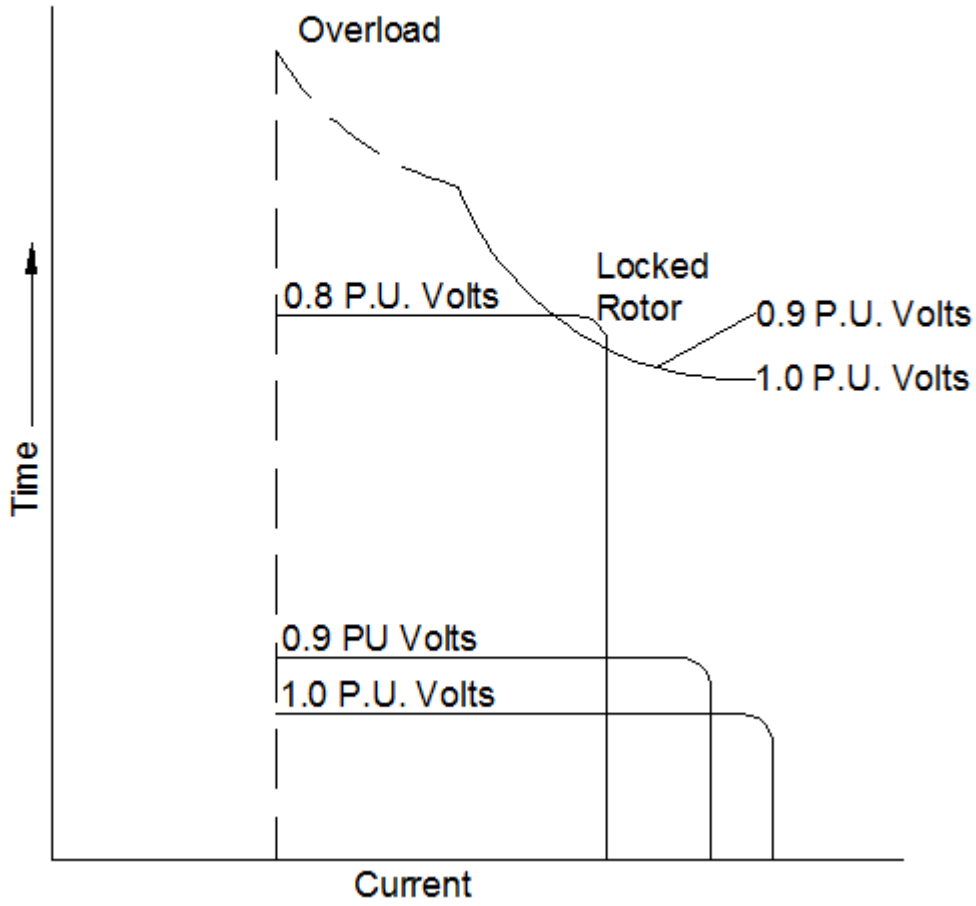


Typical protection features for MV induction motor (≤1500 hp) controlled by fused starters

Motor Protection: Typical Settings

IEEE Device Number	Function/Purpose	CT/VT	Typical Setting
27	Under voltage - Instantaneous timer - Inverse time	...	UV dropout at 80% of nominal system voltage Times: 2-3s Set 80% of system voltage with the TD set to give a delay of 1-2 s for a voltage drop from normal to zero
46	Negative-sequence or current unbalance	Phase CT	Negative sequence setting in percent of motor rated full-load current - 8% alarm - 12-15% trip 58.5-Hz trip
49	Overload	Phase CT	105% for motors with SF_6-1.0 115% for motors with SF_6-1.15
49W	Winding overtemperature	NA	130˚C alarm 135˚C alarm
51S	Locked rotor or fail to accelerate	Phase CT	10-15% more than slowest normal start time
50	Phase overcurrent or short circuit	Phase CT	1.5 to 2.0 PU locked-rotor current
51G	Ground fault	50/5 or 100/5 C30	2-5% of the neutral resistor current rating: time delay of three to six cycles

Motor time-current curve



The objective is allow some inrush current to accelerate the load from rest but not too much that large current will over heat the winding.
If pump and motor are brought together have the vendor prove that the acceleration time from rest to full speed will not damage motor winding insulation with excessive thermal stress.

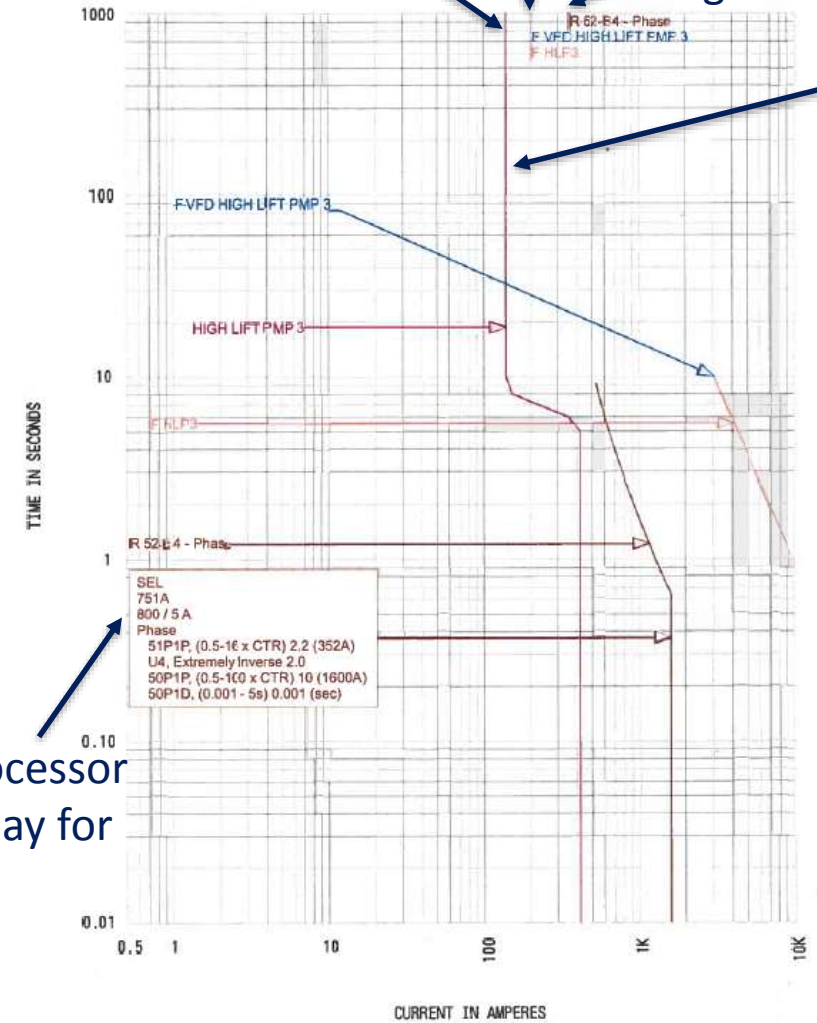
Typical Time Current Curve Plot

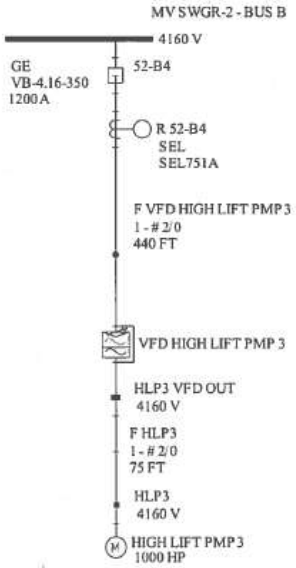
Three Phase Fault Current

Full Load Current

Single Phase Fault Current

Motor Starting Characteristic

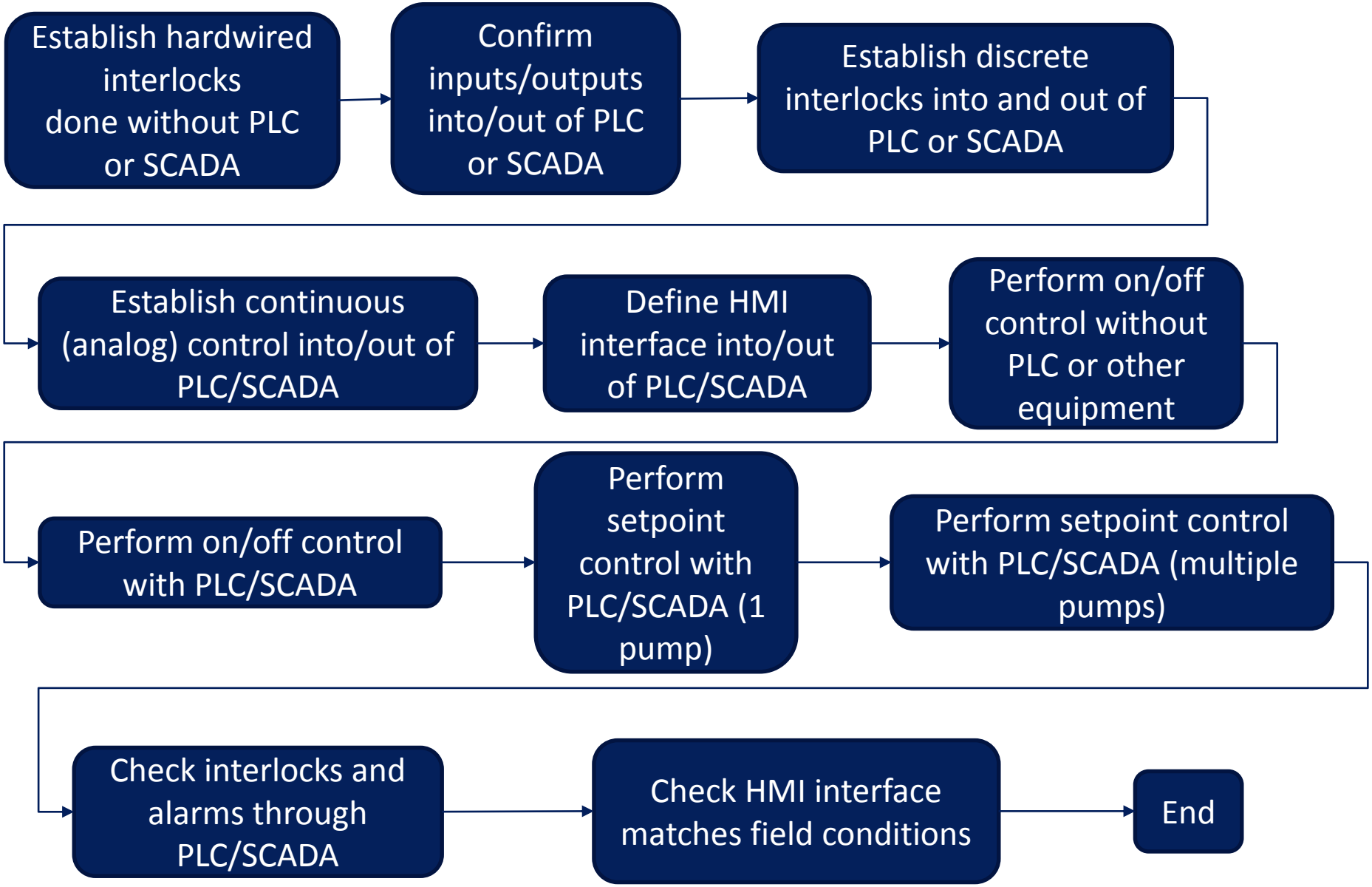




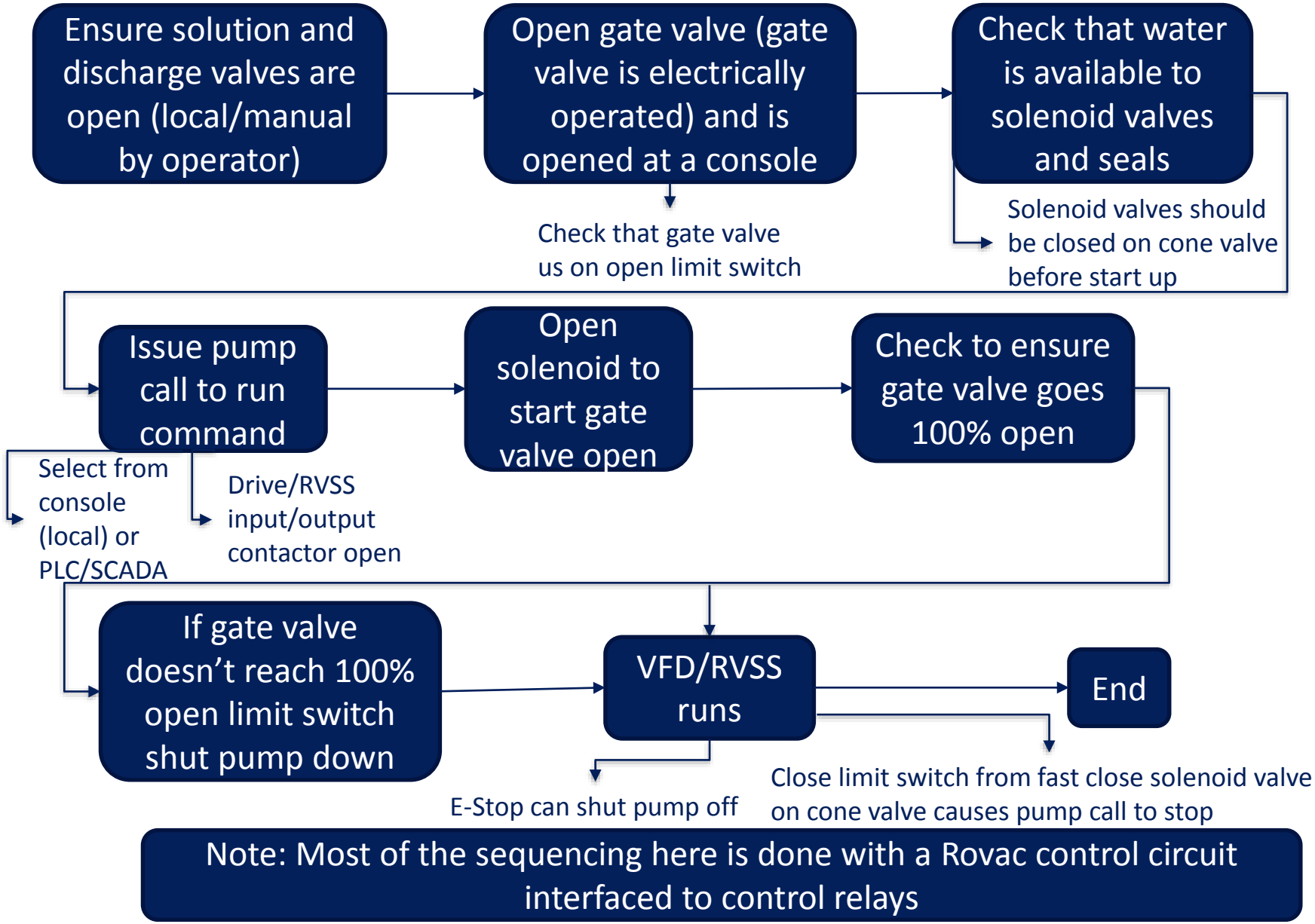
Micro Processor Based Relay for Feeder to Motor

These settings are placed on log-log paper to check to ensure motor can run without nuisances tripping but it is protected from electrical faults

Process Control Configuration Process Flow Chart



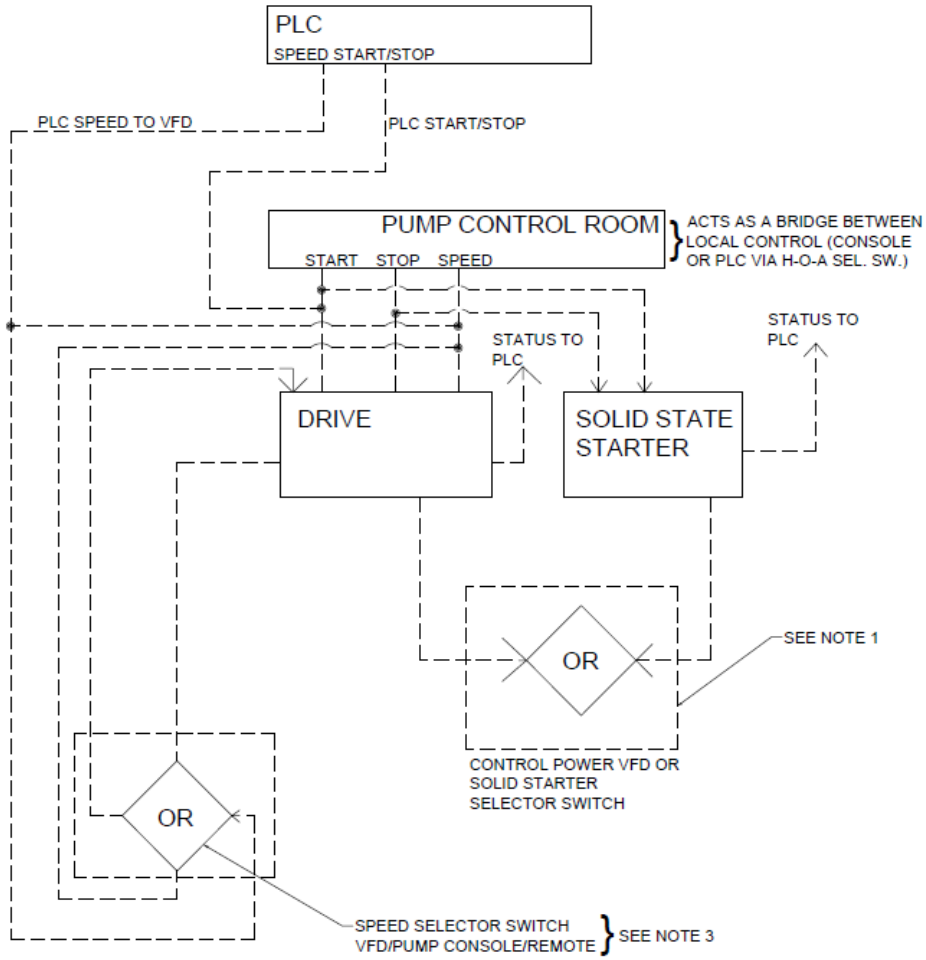
Start Up Procedure for VFD/RVSS



Note: Most of the sequencing here is done with a Rovac control circuit interfaced to control relays

Cone Valve Solenoids

Cone Valve Over View



OPERATIONS

1. USER SETS WHETHER S/HE WANTS VFD OR RVSS OPERATION AT STARTER
2. USER SELECTS WHETHER S/HE WANTS CONTROL FROM CONSOLE (LOCAL MODE) VS PLC (AUTO MODE)
3. IF VFD IS USED USER MUST SELECT IF S/HE WANTS SPEED CONTROL FROM

Ⓐ VFD AT STARTER
Ⓑ PUMP CONSOLE VIA THE SPEED POT ON CONSOLE AND PLACING VFD VFD/PUMP CONSOLE/REMOTE SELECTOR SWITCH IN PUMP CONSOLE POSITION
Ⓒ PLC VIA PLC SOFTWARE (PRESSURE/FLOW PACING ALLOWED) BY PLACING VFD/PUMP CONSOLE/REMOTE IN REMOTE POSITION

NO | DATE | REVISION | BY

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BASIC CONTROL SYSTEM
BLOCK DIAGRAM

DRAWN BY: | CHK'D BY: SM | DWG No:
DATE | SCALE NONE | PLATE
PROJECT No: | ACTIVITY No:
APPROVED | SHEET 1 OF 1

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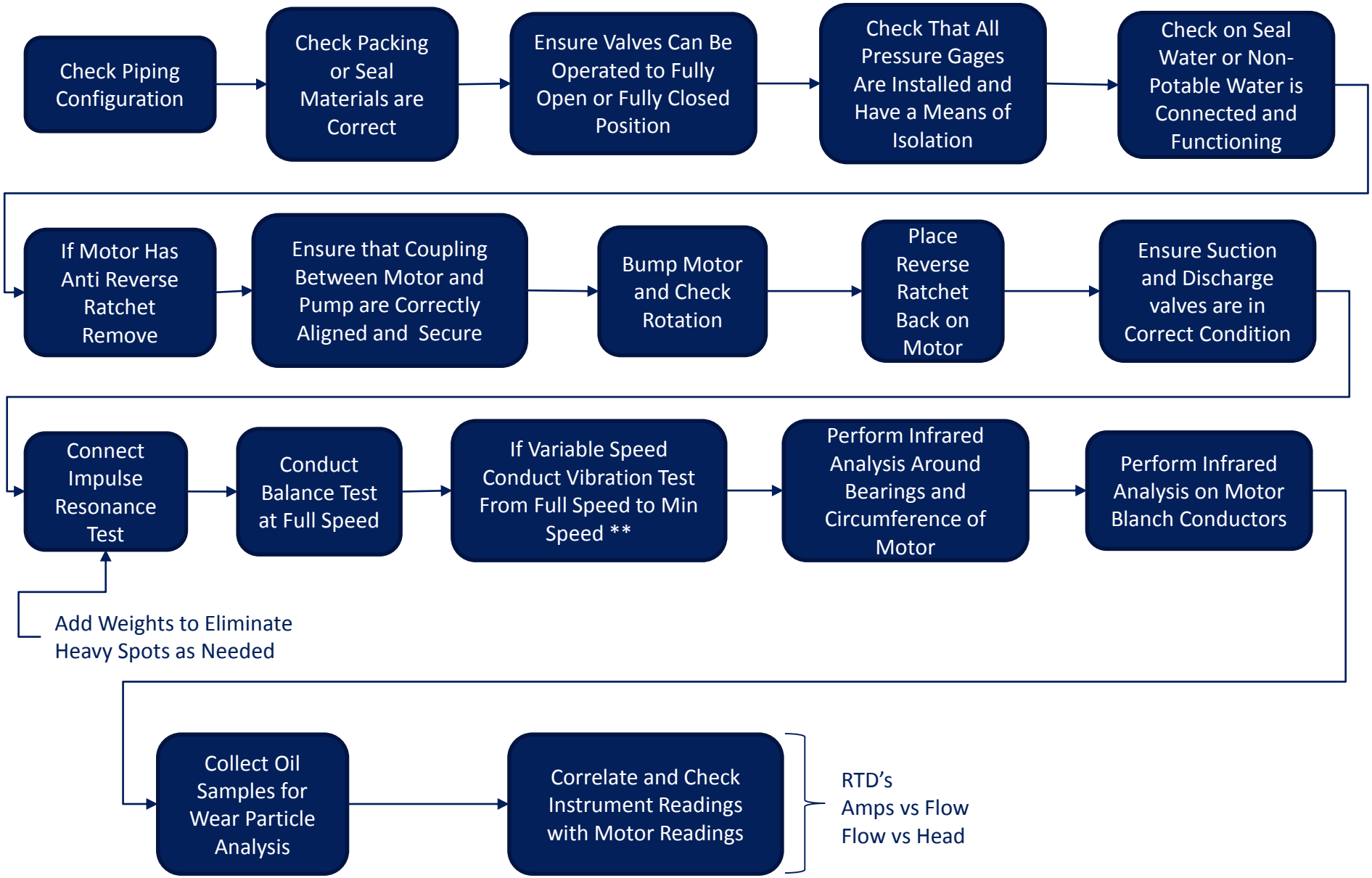
Control Console in Field

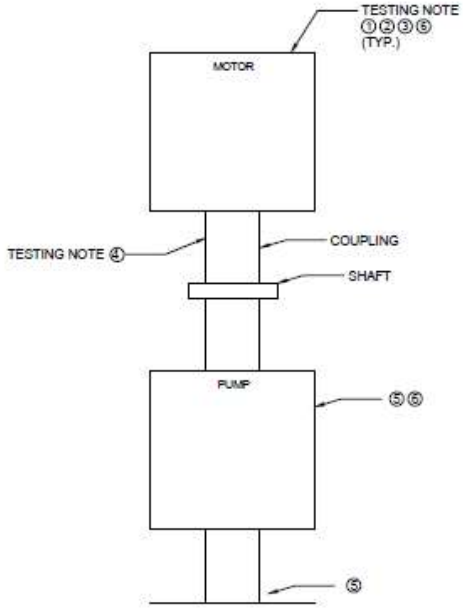
Mechanical Testing Flow



Input and Output Contactors and Control Power Selector Switch

VFD and RTD Interface

Overall Mechanical Testing Plan



Testing Keynotes for Mechanical Testing Equipment Drawing MT-1

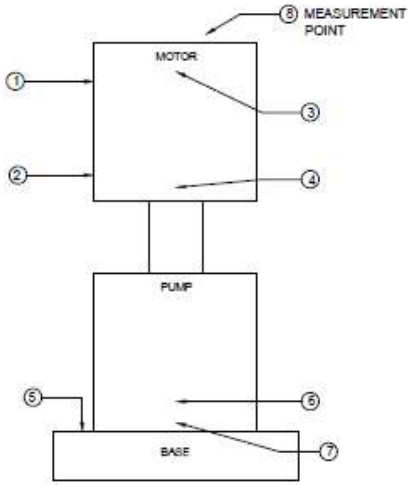
1. Contractor shall furnish the labor and materials for the following tests:
   a. Checks of motor grounding conductor and bonding for 5 ohms to ground or less
   b. Check of phase conductors for proper current carrying conductor phase identification and proper phase rotation
   c. Proper labeling of the current carrying phase conductors
   d. Inspection of motor lubricant for presence of solids or moisture
   e. Inspection of site glass for proper fill of motor lubricant
   f. Inspection of motor to ensure that the motor rotates free on bearing assembly with the motor uncoupled from the pump
   g. Inspection of space heater to ensure that proper operation is available.
   h. Coordination with the motor manufacturer for upper and lower limits of vibration and the units used (mils or mm and whether peak or peak-to-peak)
   i. Torque testing on all connections made in the motor terminal box.
   j. Confirm motor rotation before coupling the motor to the pump.

2. Contractor shall furnish materials and labor for the following tests:
   a. Polarization index test on motor windings in accordance with manufacturer's recommendations for the maximum applied voltage to the winding.

3. Contractor shall coordinate with pump vendor for proper bolting and rotation of the coupling between the shaft on the motor and the pump.

4. Contractor shall furnish all labor and material to verify the alignment of the shaft.

5. Contractor shall furnish all labor and materials to verify the following:
   a. Inspect all components (nuts, bolts, etc.) for signs of galling, rust or corrosion.
   b. Ensure bolts to pump base are treated with an anti-seize lubricant.
   c. Check pump leveling and proper insertion of anchor bolts to the pump soleplate.
   d. Check that grouting is in accordance with pump manufacturer's recommendations.
   e. Adjust suction side valves to be fully opened prior to startup of the pump.
   f. Adjust discharge valve to be partially opened in accordance with the pump manufacturer's recommendations
   g. Proper amount of water run to packing
   h. Proper adjustment of packing
   i. Proper adjustment of air relief valves (where applicable)
6. Running tests: The contractor shall furnish the materials and labor for the following:
   a. Determination of resonant frequency via the use of impact testing.
   b. Verification of alignment using orbital plot analysis along the shaft between the motor and the pump.
   c. Measurements of vibration on the motor bearing in the horizontal, vertical, and axial directions in the following conditions:
      (1) Motor uncoupled from the pump
      (2) Motor coupled to the pump and running at full speed
      (3) Motor coupled to the pump and running at speeds from 70% of full speed to 100% of full speed in increments of 1HZ
      (4) Motor coupled to the pump and running at speeds from 100% to 70% of full speed in increments of 1HZ
   d. Perform infrared measurements on:
      (1) Case of the motor
      (2) Case of the pump
      (3) Inside the motor termination box
   e. Perform measurements of shaft voltage



Vibration Testing Requirements

1. Measurement points 1, 2, 5, 6 are in line with discharge piping
2. Measurement points 3 , 4, 7 are taken 90° from discharge piping
3. Measurement point 8 is for measurement of imbalance

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MECHANICAL TESTING REQUIREMENTS

MT-1

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Iso Vibration Limits

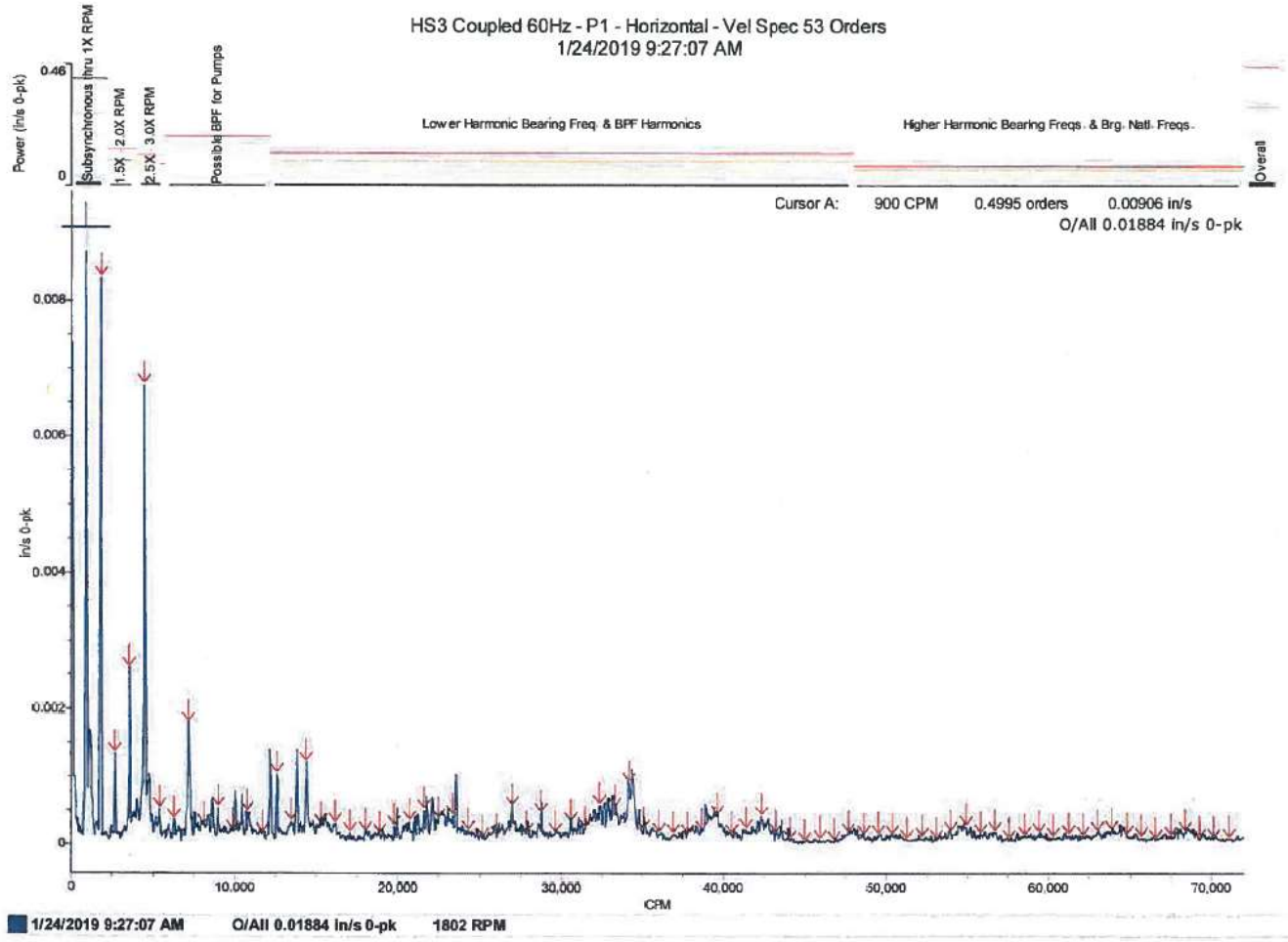
VIBRATION SEVERITY PER ISO 10816-1					
Machine		Class I	Class II	Class III	Class IV
in/s	mm/s	Small Machines	Medium Machines	Large Rigid Foundation	Large Soft Foundation
Vibration Velocity Vrms					
0.01	0.28				
0.02	0.45				
0.03	0.71		GOOD		
0.04	1.12				
0.07	1.80				
0.11	2.80		SATISFACTORY		
0.18	4.50				
0.28	7.10		UNSATISFACTORY		
0.44	11.20				
0.70	18.00				
1.10	28.00		UNACCEPTABLE		
1.77	45.90				

Use $\frac{0.2 \text{ inches}}{\text{second}}$ RMS As Acceptance Criteria

Shaft Speed (RPM)					
Less than 2,000			Greater than 2,000		
Mounting	Drive	Category	Mounting	Drive	Category
Rigid Mounting	Rigid Drive	I	Rigid Mounting	Rigid Drive	II
	Flex Drive	II		Flex Drive	III
Flexible Mounting	Rigid Drive	II	Flexible Mounting	Rigid Drive	III
	Flex Drive	III		Flex Drive	IV

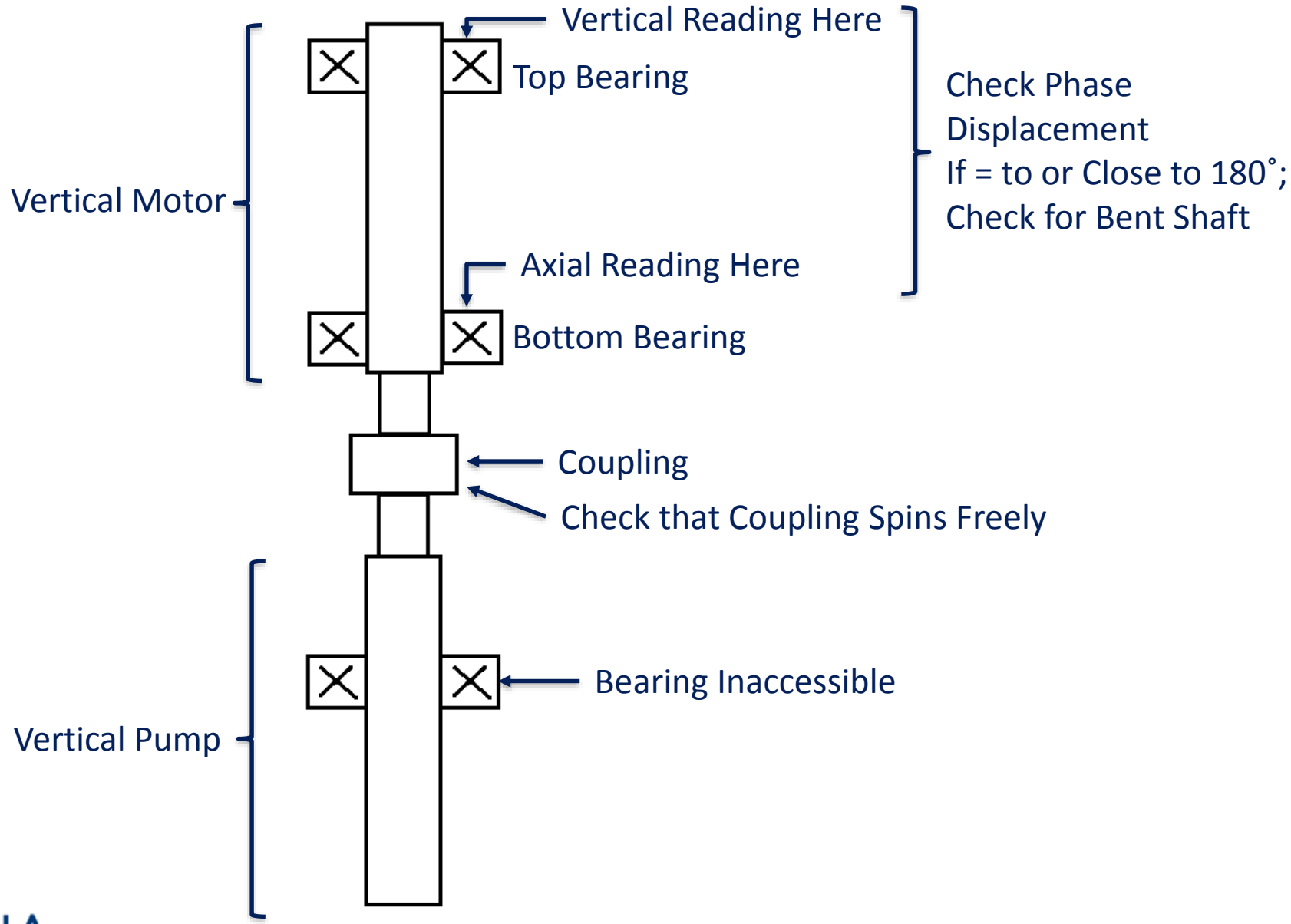
AQUA

Sample Vibration Spectra Taken on Bearing in Horizontal Plane

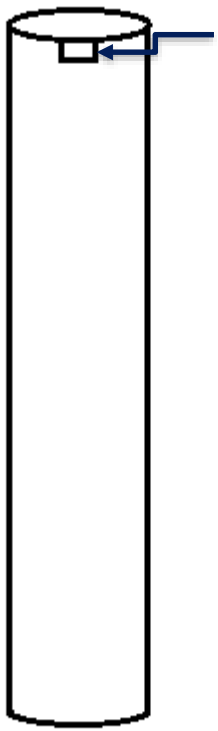


Vertical Turbine Pump and Motor

Simplified View of Shafts for Vertical Motor, Vertical Pump



Overview of Unbalance



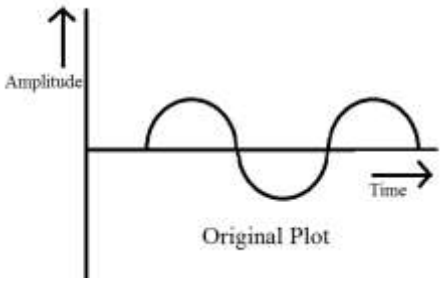
Heavy Spot needs to be counterbalanced with another weight

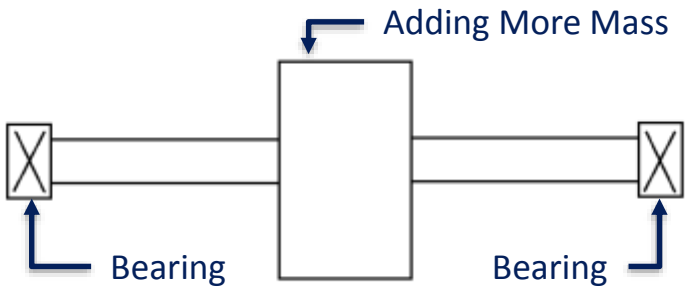
Where the weight is located and how much the counterbalance weight needs to be is worked out using vector analysis

Either single plane or 2 plane balancing can be used (beyond the scope of this presentation)

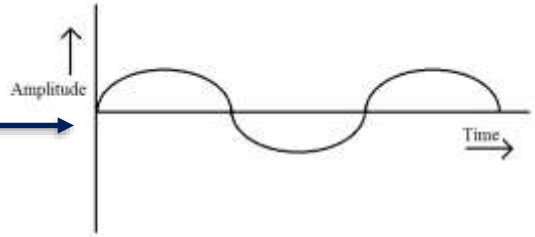
Basic Concept of Mechanical Resonance

- All mechanical parts have a frequency at which they will vibrate (such as a looseness, rotating unbalance)
- The time it takes for vibration to stop depends on dampening
- In reality a machine train will have, multiple natural frequencies
- Natural frequency can change depending upon
  A. Mass
  B. Stiffness

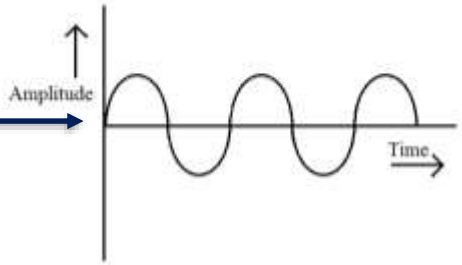




Tends to Lower Frequency eg.



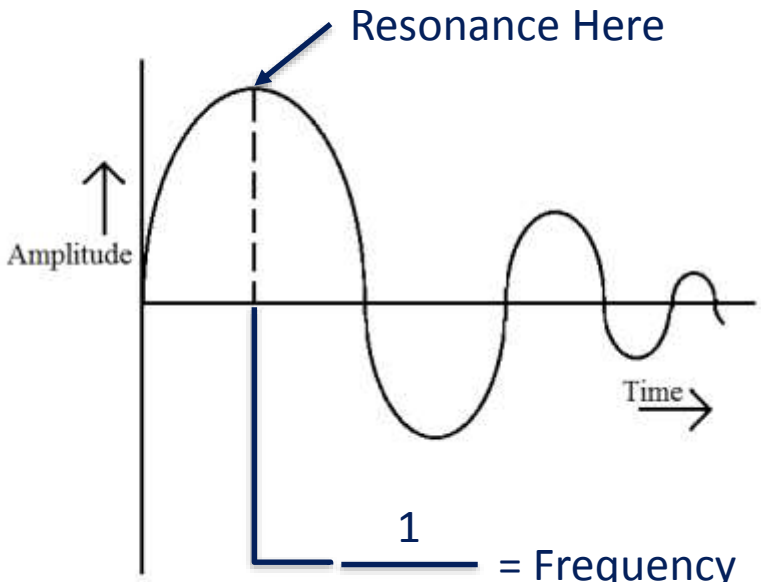
Gives us Higher Frequency eg.



Critical Speed and Resonance

Critical Speed is analogous to pushing a child on a swing (a push will cause the swing to displace in one direction or another).

If the swing is pushed again, the swing can go higher.
When we can see this behavior we have reached a point called resonance (maximum amplitude).



$$\frac{1}{\text{Time}} = \text{Frequency}$$

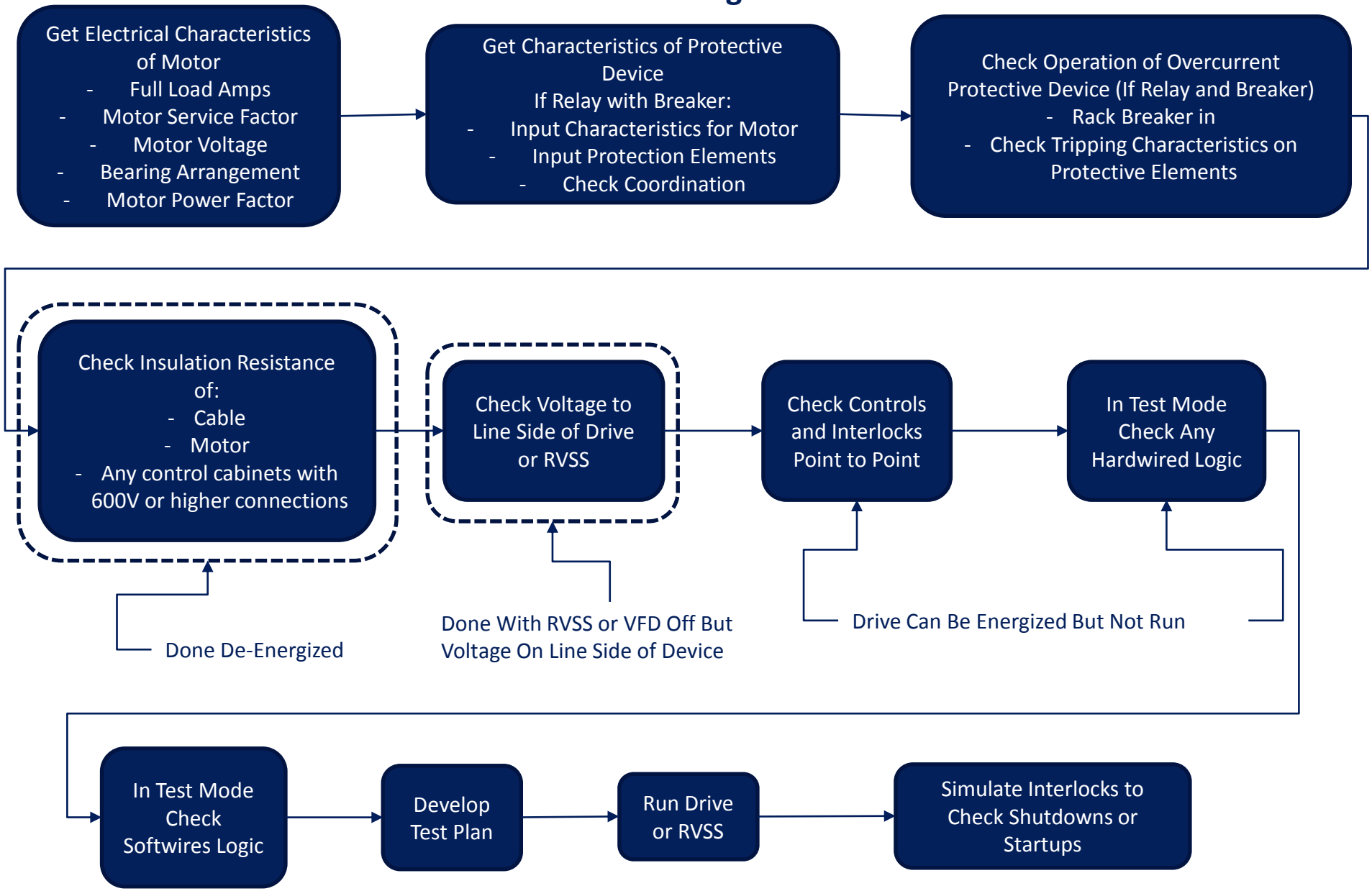
$\therefore$ This is called critical frequency because we reach maximum amplitude

VIBRATIONS AND BALANCE TESTING

- Vibration testing tells us about the health of the machine depending upon what measurements are taken (typically velocity or acceleration) and where they are taken. For the vertical turbine pump application, measurements were made at the top and bottom motor bearings.
- Order of Testing
  a. First test for natural frequencies using impact testing with the pump and motor coupled and supported from its structural attachments. You are checking to see if there are any points of resonance. If there is a point of resonance, this should be +/- 20% of the equipment running speed.
  b. Second, attach vibration sensors to allow accessible points on the machine (bearing housings are an example). If you have a variable speed machine run the machine in 1HZ increments to check for any points of resonance.
  c. Third, develop vibration spectra to check for imbalances and looseness. Imbalance can be caused by a variety of factors and looseness can be internal (inside the machine) or external (piping or structural). Vibration spectra may show hydraulic elements (blade pass frequencies, bearing frequencies and the like. The key is to look for patterns in the vibration signature to determine if a problem exists and any possible causes.
- On a vertical machine you are more likely to see vibrations in the horizontal and vertical axes. (The motor junction box is used as a reference)
- Normally, one does not expect to see a lot of axial vibration unless you have misalignment or a bent shaft

Source: Motor Technologies, courtesy of Mike Boyer.

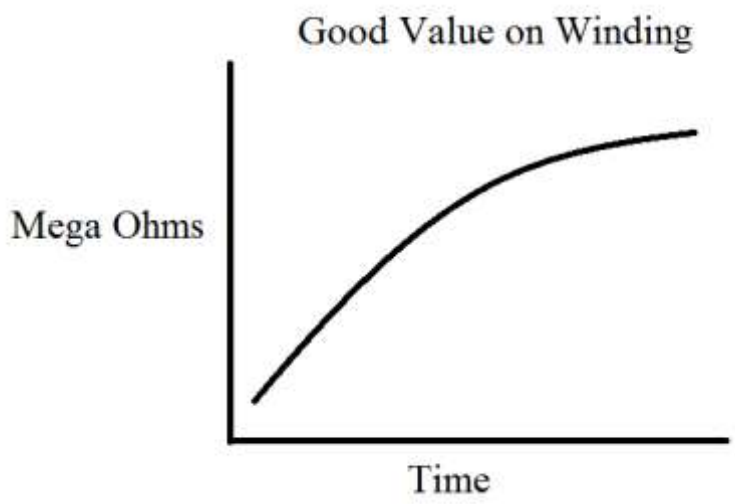
Electrical Testing Flow

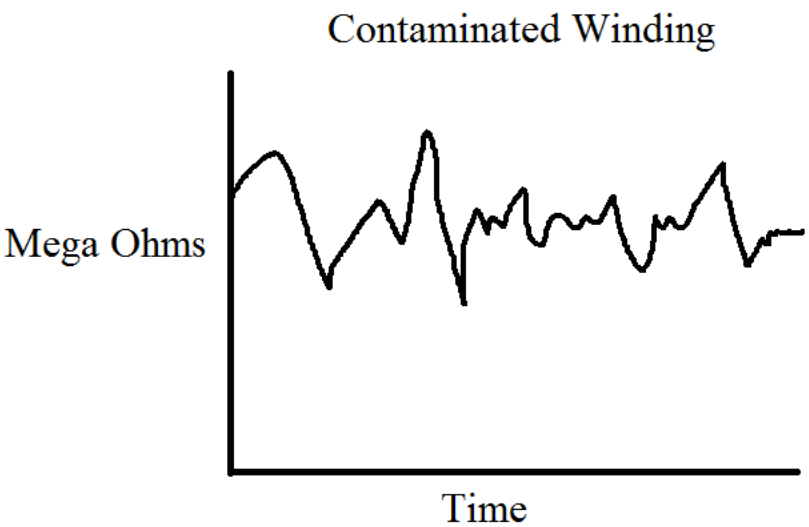


Electrical Testing Highlights

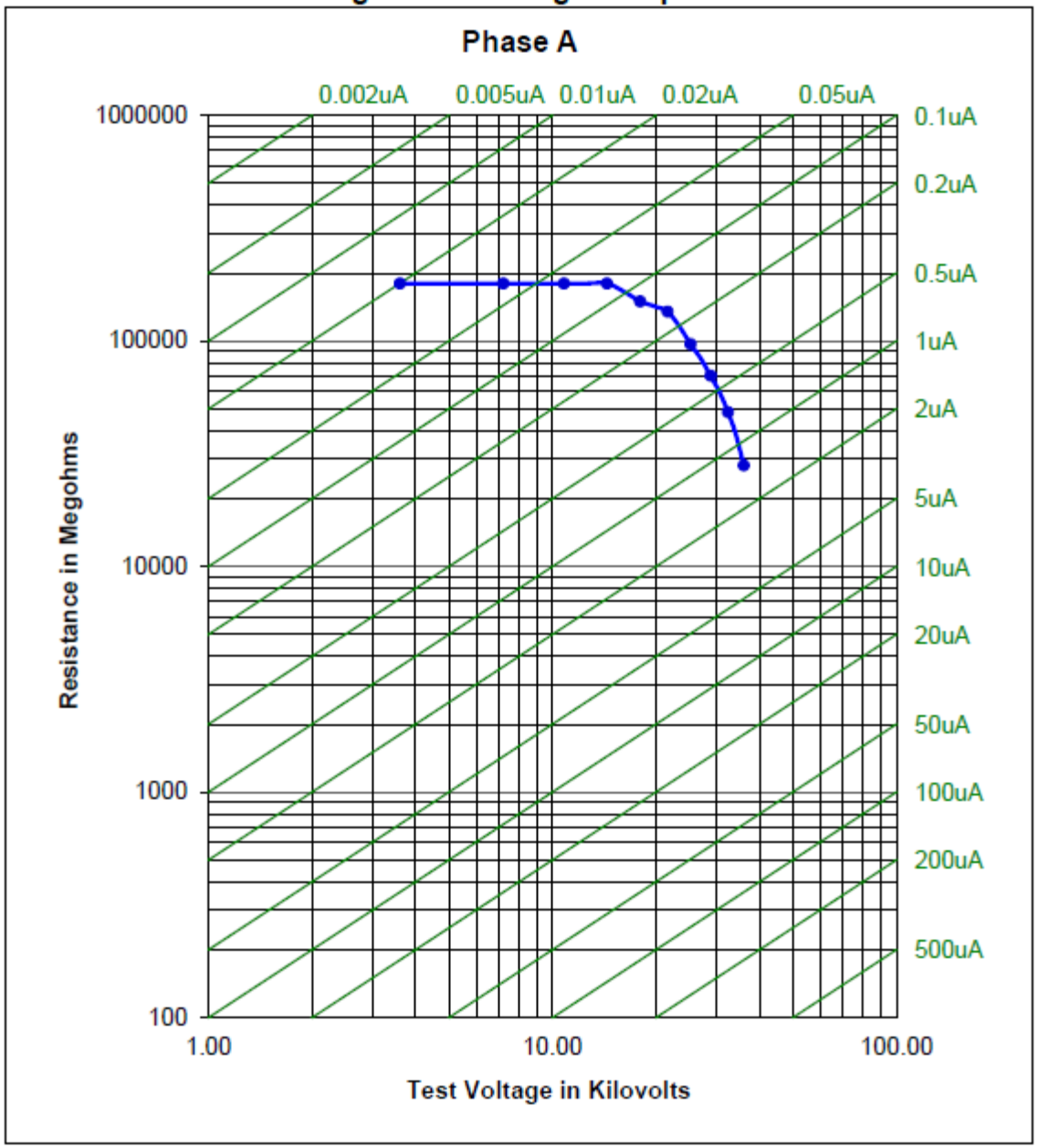
- Insulation resistance testing – check integrity of insulation by applying a known test potential. Results are measured in mega (10^6) Ohms or giga ohms. If we assume 1 per-unit value of voltage leakage current (assuming mega-ohms result from test is in the micro-amp (10^{-6}) range.
  - Get test voltage values from cable, motor, transformer manufacturer.
  - Always done de-energized before motor starters (with electronic components) are connected to load.

  - On larger pieces of equipment you may examine ratio of values between 10 minute and 1 minute readings. This is done for motors.





Greg A Vietri Inc. / Aqua Neshaminy
High Lift Building / Pump #3



Consider Phasing in Operations

- Because the RVSS operation only allows for the pump to run at fixed speed, the plant had to be sure it could take all of the water the pump produced. The production from this pump had to be balanced not only with raw water flow but with other high service pump combinations in the plant.
- VFD operation was tested in both a standalone mode (pump run by itself) AND in combination with other pumps. This was to ensure that we could run multiple pumps simultaneously.
- Testing consisted of several steps as noted previously. Once plant staff were confident that the pump could operate, the pump was left running only on the day shift.
- Once the plant was confident with the fact that the plant worked during the day, the plant put the pump on overnight.
- Once the plant was confident with the fact that the pump worked over night, the plant has run the pump continuously on VFD

Consider Human Factors and Operator Participation

- Start-up was used as a means to test all of the pump capabilities
- During start-up, plant personnel were actively part of starting and stopping the pump.
- Because of active participation during start-up, plant personnel were exposed to
  - Where the controls were located
  - What types of basic troubleshooting processes they could use
  - How to navigate a touch screen to operate the pump (the touch screen interface included alarm information and status information)
  - What the sequence for both start-up and shut down looked like
- Plant personnel got a chance to operate E-STOP types of controls on the pump at various locations and learned how to recover from these situations
- Plant personnel noted that we had issues with a bearing temperature sensor that was off-scale high and a possible cause of issues. Start-up personnel ensured that infrared imaging was used around the motor circumference where the temperature anomaly was located and we found a bad piece of instrumentation was the cause of the issue.
- Plant personnel grew accustomed to the sights and sounds they would be exposed to (developing an “operator’s ear”) to establish what feels correct.

Consider Documentation

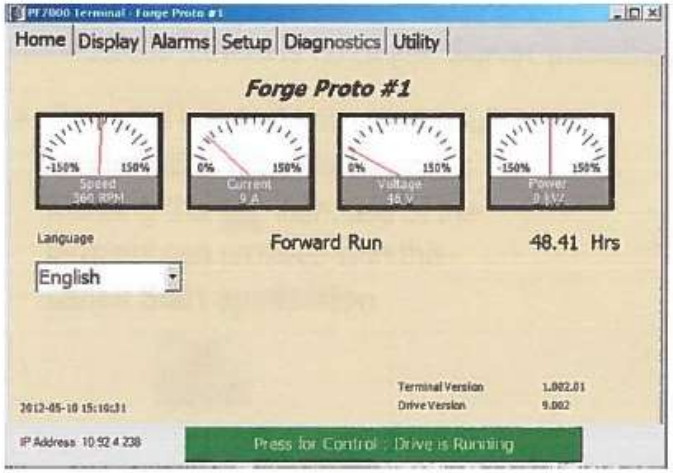
- The project featured Standard Operating Procedures (SOP) written by Operations Staff to ensure that the staff could proof test the SOPs prior to going into service
- Some video was taken (using an I-Phone) for training purposes
- Rockwell Automation prepared some basic SOP material because a networked touch screen was used internal to the drive.

Rockwell Automation PowerFlex 7000 Standard Operating Procedure

Abstract

Understanding the differing components of the PowerFlex 7000 and how they function.

The 'Terminal' does not change any of the contents or features within the PF7000, the presentation of information is the only thing that is different.



The 'Control Bar' can be accessed through the 'Terminal' (the accessibility is seen in green above) and is used for Start, Stop, and Speed Reference. An example display of this can be seen below.

Excerpt from SOP