Application Note 006
Version 001
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Network Control of an ABB ACH550 VFD

The concept of interacting with a VFD by using an Industrial Networking Protocol – such as Modbus or EtherNet/IP – is vastly superior to legacy methods that use discrete I/O wired to the terminal block. Why? Because there is so much more information available to the Control System when communicating directly with the VFD's microprocessor.

Network-available feedback tags include Speed (Hz), Power (HP, KW), Energy (MWH), Current (A), Voltage (V), Temperature (^{o}), and Fault Information. Furthermore, the network wiring is arguably simpler than discrete signal wiring – since it only relies upon a single twisted pair or Ethernet cable. On the other hand, extra know-how is required to collect and process the extra information. Therefore, in order to clarify and simplify the theory and practice of controlling and monitoring a VFD across a network, Navionics Research has developed a library of Application Notes, each designed to address networking techniques specific to a particular manufacturer. Notes are currently available for Allen Bradley (Modbus), ABB (Modbus), Eaton (Modbus), and Toshiba (Toshiba Proprietary Protocol). Others may be forthcoming.

ABB ACH550

This document was created to address the specifics of the ABB ACH550 VFD using the Modbus/RTU protocol over RS-485, which is included standard on all models within the ACH550 family. For brevity, we will refer to this drive as the "ACH550".

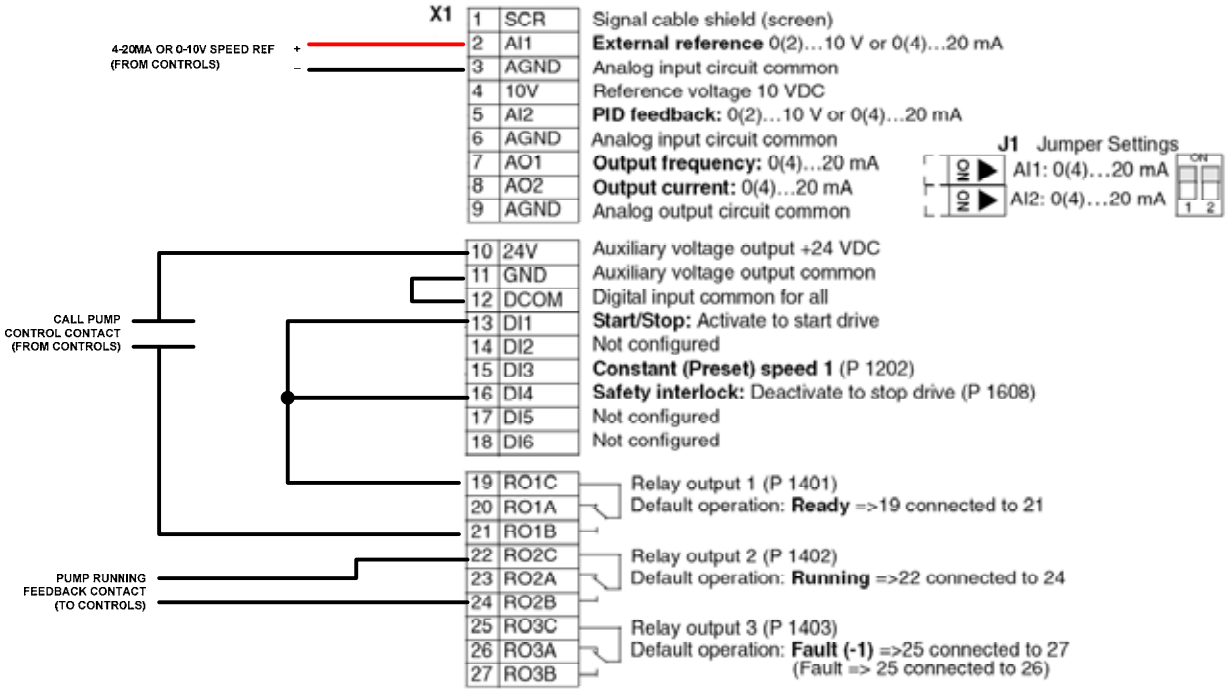
First, the following documents should be available for reference:

ABB ACH550 Manual
ABB ACH550 Fieldbus Manual

Signal Wiring

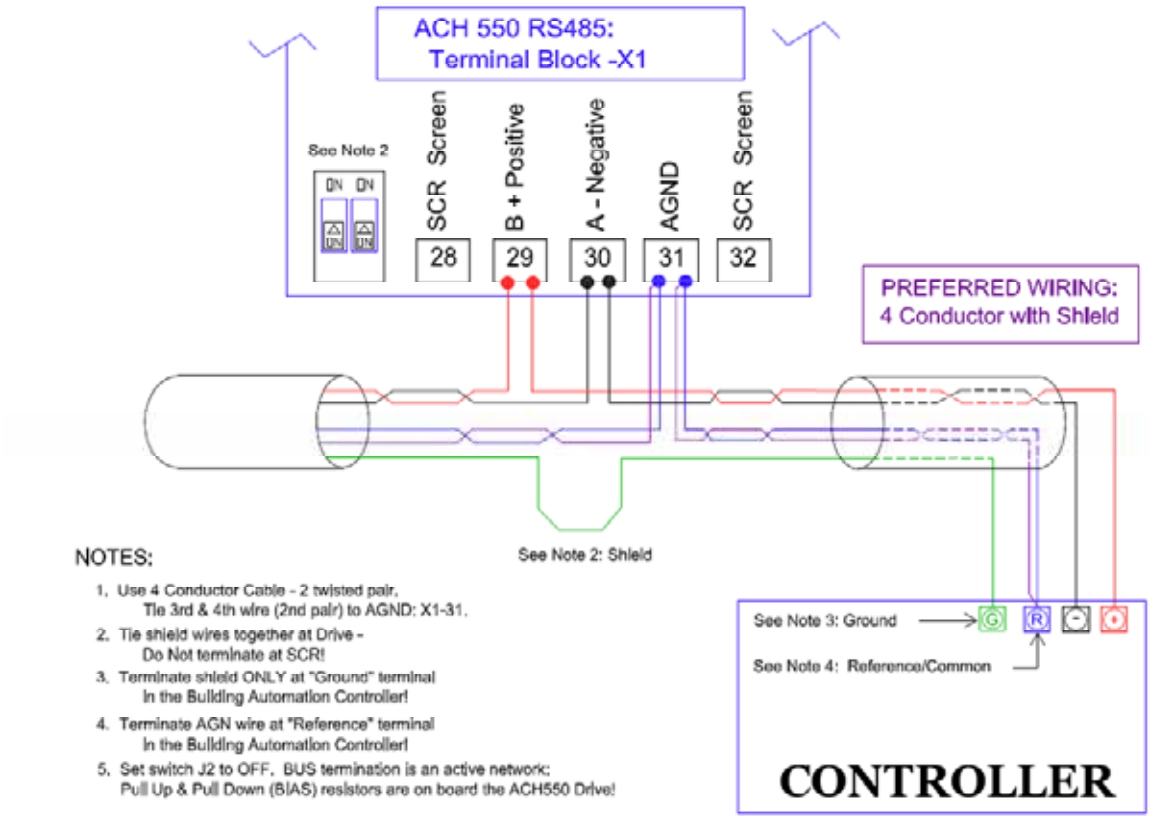
The VFD should be wired for Modbus/RTU Control/Monitoring. Note that the ACH550's RS-485 terminals are labeled in accordance with the most predominant North American Standard: 'A' is '-', and 'B' is '+'.

In addition to the Modbus/RS-485 terminals, wiring is provided for backup discrete controls with analog speed reference in case of communication bus failure: A single dry contact input is to provide a run signal to VFD Digital Input #1, and a 24V output signal via VFD Internal Relay #1 is to denote that the drive running.



Terminal Block Wiring Diagram.
Note: Jumper J1 should be set to match the Reference Signal Type.

Preferred wiring diagram



Keypad: Basic Configuration

The VFD should be configured using the Wizard Setup Screens with the Motor Nameplate Values.

9902	Application Macro	1=HVAC (Default)	_____
9904	Motor Control Mode	3=SCALAR/FREQ (Default)	_____
9905	Motor NP Volts	Motor Nameplate Rated Volts	_____
9906	Motor OL Current	Maximum Allowable Motor Current	_____
9907	Motor NP Hertz	Motor Nameplate Rated Frequency	_____
9909	Motor NP Power	Motor Nameplate Rated Horsepower	_____

Keypad: Communication & Terminal Block Configuration, Part I

The VFD should be set up with the following parameters:

9802	Protocol Selection	1	1=MODBUS (Default)
1001	EXT1 Start Command	1	1=DI1(Default). Dependent upon terminal block wiring.
1002	EXT2 Start Command	10	1=DI1 (Default), 10=MODBUS/COMM
1102	EXT1/EXT2 Sel	7	0=EXT1 (Default), 7=EXT2
1103	REF1 Sel	1	1=AI1 (Default)
1106	REF2 Sel	8	19=PID1OUT (Default), 8 = MODBUS/COMM
1601	Run Enable	0	0=None (Default)
1604	Fault Reset Sel	0	0=KEYPAD (Default)
1609	Start Enable 2	0	0=None (Default)
3018	Comm Fault Action	0	0=No Action
3019	Comm Fault Time	60	10=Default, 60 sec=Preferred
5302	Modbus Device ID	101	MODBUS Address – Set per user needs: 101,102,… ____
5303	Modbus Baud	9.6	9600 bps
5304	Modbus Parity	0	1 = 8N2 (Default) 0 = 8N1 – 8 Data Bits / N=No Parity / 1 Stop Bit
5305	Modbus Ctrl Profile	0	0 = ABB DRV LIM (For Maximum Backwards Compatibility)
5312	40007 Register Map	105	105=TORQUE
5313	40008 Register Map	106	106=POWER
5314	40009 Register Map	107	107=BUS VOLTS
5315	40010 Register Map	401	401=LAST FAULT
5316	40011 Register Map	109	109=OUTPUT VOLTS
5317	40012 Register Map	110	110=VFD TEMPERATURE

Note! – The VFD must now be power-cycled for the above settings to take effect.

After this initial Modbus configuration is performed, much of the additional Modbus configuration will be performed by the connected Master PLC via the communication port. In fact, Modbus configuration via the PLC is more desirable for many parameters, since parameters written using Modbus are volatile by default – meaning that they are not stored into the VFD's nonvolatile memory unless explicitly commanded as such. Therefore, certain parameters specific to network-operation can be discarded simply by rebooting the VFD with the Master PLC disconnected from the VFD network port.

VFD Parameters Monitored Via MODBUS:

Volatile Modbus Register Changes: The remaining parameters are controlled by the Master PLC. Again, please note that all parameter changes made by the Master PLC are discarded upon reboot of the ACH550 VFD. This fact is utilized to allow for two distinct operational control modes.

Post VFD Boot-Up Delay: It is important that the VFD be allowed to fully boot up before writing to the VFD's Modbus registers. A 15 second delay has been observed to be more than sufficient.

Modbus Addressing: ABB Drive Parameters may be accessed (read/write) via Modbus communications. For example, ABB Parameter 1001 is hosted at Modbus Address 41001, which is often referenced as Modbus Address 1000 in Zero-Based Modbus Addressing Nomenclature.

REGISTER (ZERO-BASED)	**CONTENTS**
0	CONTROL WORD
1	REFERENCE 1 (FROM EXT1)
2	REFERENCE 2 (FROM EXT2)
3	**STATUS WORD**
4	OUTPUT FREQUENCY
5	OUTPUT CURRENT
6	TORQUE
7	POWER
8	BUS VOLTS
9	LAST FAULT
10	OUTPUT VOLTS
11	VFD TEMPERATURE

STATUS WORD DETAIL (BITMAP)

	0	RDY_ON	1 = Ready to Operate, 0 = Emergency OFF
	1	RDY_RUN	1 = Operating, 0 = Emergency OFF
	2	RDY_REF	1 = Operating, 0 = Emergency STOP
	3	TRIPPED	1 = Operation Enabled, 0 = Operation Inhibited
	4	OFF_2_STA*	
	5	OFF_3_STA*	1 = RFG Out Enabled, 0 = RFG Out Hold
	6	SWC_ON_INHIB	1 = RFG Input Enabled, 0 = RFG Input Force to Zero
	7	ALARM	1 = Fault Reset, 0 = Continue Normal Operation
	8	AT_SETPOINT	
	9	REMOTE	
	10	ABOVE_LIMIT	
	11	EXT2	1 = Select EXT2 Control, 0 = Select EXT1 Control
\	12	RUN_ENABLE	
	13	-N/A-	
	14	-N/A-	
	15	-N/A-	

VFD Parameters Controlled Via MODBUS:

REGISTER (ZERO-BASED)	CONTENTS
0	**CONTROL WORD**
2	SPEED REFERENCE 2

CONTROL WORD DETAIL (BITMAP)

	0	OFF1 CONTROL	1 = Ready to Operate, 0 = Emergency OFF
	1	OFF2 CONTROL	1 = Operating, 0 = Emergency OFF
	2	OFF3 CONTROL	1 = Operating, 0 = Emergency STOP
	3	INHIBIT OPERATION	1 = Operation Enabled, 0 = Operation Inhibited
	4	-UNUSED-	
	5	RAMP HOLD	1 = RFG Out Enabled, 0 = RFG Out Hold
	6	RAMP IN ZERO	1 = RFG Input Enabled, 0 = RFG Input Force to Zero
	7	RESET	0→1 = Fault Reset, 0 = Continue Normal Operation
	8	-UNUSED-	
	9	-UNUSED-	
	10	-UNUSED-	
	11	EXT CTRL LOC	1 = Select EXT2 Control, 0 = Select EXT1 Control
\	12	-UNUSED-	
	13	-UNUSED-	
	14	-UNUSED-	
	15	-UNUSED-	

Backup/Alternative VFD Control Via Terminal Block

How should the system be configured to handle a Modbus communication failure? First and foremost, the VFD should be configured to shut down if it stops receiving commands from the Master PLC. A 60 second timeout should be sufficient for this purpose. When the VFD stops due to comm loss, it will show a Fault Code 28.

After a Modbus communication fault is detected, NRI's standard backup control method consists of parallel, discrete (ON/OFF) control circuitry. The activation of this circuitry requires the operator to perform the following steps:

1. REBOOT THE VFD (CLEARS ALL RAM-ONLY SETTINGS)
2. CLEAR THE VFD FAULT AT THE KEYPAD
3. MAKE SURE THE VFD IS IN "AUTO" MODE (ALLOWS REMOTE CONTROL).
4. ACTIVATE MASTER PLC SETPOINT:

    DISCRETE_VFD_CONTROL = YES/TRUE
    ..or..
    NETWORK_VFD_CONTROL = NO/FALSE

The parallel, discrete control circuitry consists of three pairs of low-voltage wires: One for ON/OFF control of the drive, one for SPEED REFERENCE, and one for FEEDBACK/MONITORING. Through pair 1, a single dry contact will provide the run signal to the drive. If a speed reference pair (4-20mA or 0-10VDC) is provided, then the speed can be modulated. If not, then the VFD can be set to run at a user-defined PRESET SPEED. Through the final pair, a single contact output will provide RUN feedback to the Master PLC: When the ACH550 is "At Desired Frequency", a 24VDC signal will be transmitted. Until the Modbus communication link is re-established/repaired, this method allows for the VFD to run ON/OFF based on an analog speed reference, or based upon a preset speed with controlled ramp-up and ramp-down times. Please note that when a VFD is configured for preset speed, the VFD will run only at a single speed, and that no speed throttling will occur in this mode.

Detailed VFD Monitoring

Now that network communication to the ACH550 has been achieved, the PLC programmer now has READ access to valuable VFD internal information.

Available DISCRETE tags for reading include (not a complete list):

VFD_READY
VFD_ACTIVE (RUNNING)
VFD_ALARM
VFD_FAULTED
VFD_AT_REFERENCE_SPEED

Available ANALOG tags for reading include (not a complete list):

VFD_OUTPUT_SPEED
VFD_OUTPUT_AMPS
VFD_OUTPUT_VOLTS
VFD_DC_BUS_VOLTS
VFD_OUTPUT_POWER_KW
VFD_ENERGY_KWH
VFD_TEMPERATURE
VFD_ACTIVE_FAULT_CODE

Feedback Control Strategies

In a Water Utility, the VFD will typically be installed to control the speed of a pump motor. Available telemetry data may include pump discharge pressure, pump suction pressure, pump rate-of-flow, in addition to the data available from the drive itself. This extra data, when combined with the VFD control algorithm, may be used to implement closed-loop feedback control strategies. For example, an upper limit may be placed on the pump discharge pressure – or a lower limit on the pump suction pressure – or both. Other possibilities are to implement an upper limit on the rate-of-flow, or an upper limit on the power consumption. In any of these cases, the speed of the VFD will be throttled up or down in order to maintain the pressures and/or flow and/or power consumption within the desired envelope.

Cavitation Traps

Ideally, pump "no flow" conditions are detected by monitoring a flow meter. In situations where a flow meter is not available, and because the ACH550 provides realtime power consumption of the pump motor to the Master PLC, it is possible that the PLC can detect and/or alarm cavitation conditions – situations where the pump is not moving water as evidenced by the power consumption of the motor falling below the normal range.

Feedback Control

In a Water Utility, the VFD will typically be installed to control the speed of a pump motor. Available telemetry data may include pump discharge pressure, pump suction pressure, and pump rate-of-flow. This extra data, when combined with the VFD, may be used to implement closed-loop feedback control

VFD Reset Via Modbus:

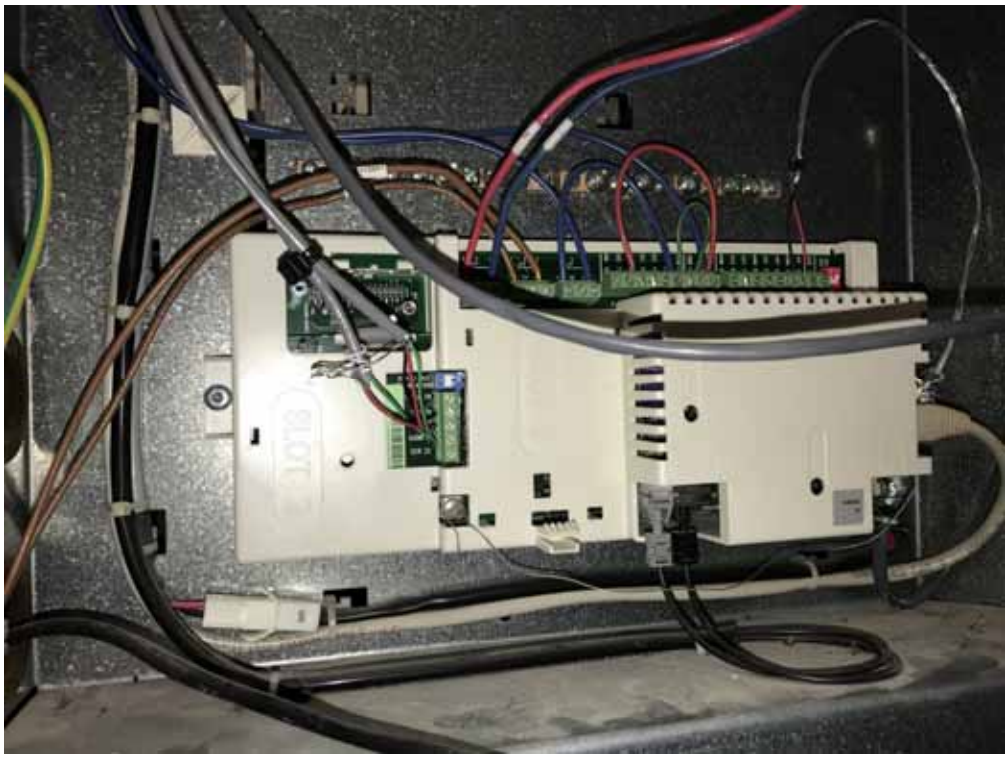
Because the ACH550 provides actual VFD fault information to the Master PLC, this information can be alarmed and the operator notified of the problem. The information is transmitted as a decimal fault code, and the Operator may refer to the following document to decode the fault:

https://wireless-telemetry.com/PDF/ABB_VFD_Fault_Codes.pdf

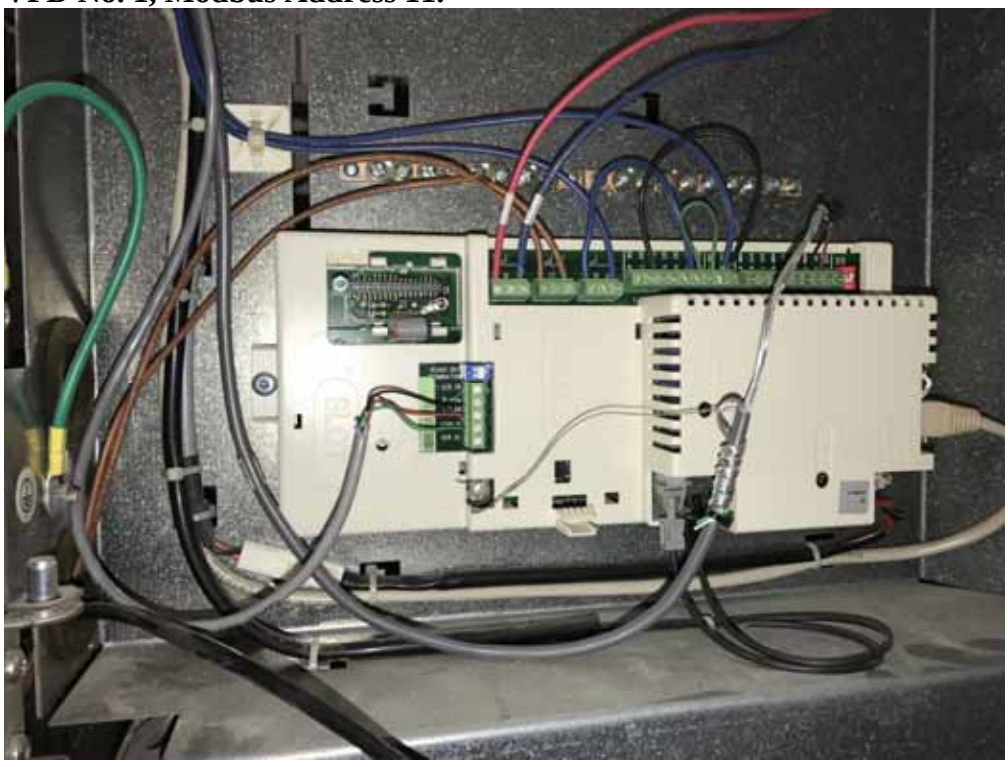
Alternatively, the ABB ACH550 User Manual can be referenced to decode fault information.

After decoding the fault, the Operator may reset the fault remotely using a provided "one-shot" pushbutton setting within the Telemetry Control System.

An ABB Model ACH550 VFD.
At a Water Plant, Feeding a 250HP High Service Pump.



VFD No. 1, Modbus Address 11.



VFD No. 2, Modbus Address 12. Note the 120 Ohm Termination Resistor Activated.

Configuration Keypad for ABB Model ACH550 VFD

Sample Generic Control Logic Source Code with VFD High-Service Pump Control

```
$NCH - Plant - ioz.15 (installed)
   4     # Number of Discrete Setpoints
  18     # Number of Analog   Setpoints
   8     # Number of Integer  Setpoints
  12     # Number of Discrete Input Modules
  12     # Number of Analog   Input Modules
   0     # Number of Integer  Input Modules
  22     # Number of Discrete Flag States
  20     # Number of Analog   Flag States
   9     # Number of Integer  Flag States
  12     # Number of Relay    Output Modules
  12     # Number of Analog   Output Modules
# Remote Setup Information ... (No Blank Lines Allowed...)
   4     # Number of Dependent Sites (Dependent Sites Follow)
   012      # Intake Pump Station
   001      # 1 Elev Tank
   013      # 13 Elev Tank
   014      # 14 Elev Tank
# Variable Name Definitions ... (Blank Lines Allowed...)

#
# Raw->Head Tank->Claricones->Filters->150KG C/W->Xfer Pmps->1MG GST
#

#
# MODBUS I/O MODULES...
#
#  M_SIU  -  MODBUS FCN 3 INPUT, SHORT INTEGER UNSIGNED  (16 BIT)
#  M_SIS  -  MODBUS FCN 3 INPUT, SHORT INTEGER   SIGNED  (16 BIT)
#  M_LIU  -  MODBUS FCN 3 INPUT, LONG  INTEGER UNSIGNED  (32 BIT)
#  M_LIS  -  MODBUS FCN 3 INPUT, LONG  INTEGER   SIGNED  (32 BIT)
#  M_FI   -  MODBUS FCN 3 INPUT, FLOATING POINT          (32 BIT)
#

# ALIAS     INFL_METER_MODULE                   M_LIU  4   0
# ALIAS     INFL_FLOW_MODULE                    M_LIS  4   4
# ALIAS     INFL_METER_FAULT_MODULE             M_SIU  4  14

# ALIAS     EFFL_METER_MODULE                   M_LIU  5   0
# ALIAS     EFFL_FLOW_MODULE                    M_LIS  5   4
# ALIAS     EFFL_METER_FAULT_MODULE             M_SIU  5  14

ALIAS     GST_PSI_MODULE                      M_FI   1   2

ALIAS     CLEARWELL_PSI_MODULE                M_FI   2   2

ALIAS     EFFL_PSI_MODULE                     M_FI   3   2



# ABB VFD's MODBUS...
# HIGH SVC PUMP NO. 1, ADDR=11
# HIGH SVC PUMP NO. 2, ADDR=12

# ALIAS  VFD1_SPD_RAWA         M_SIU  11  102
# ALIAS  VFD1_SPD_RAWB         M_SIU  11    4
# ALIAS  VFD2_SPD_RAWA         M_SIU  12  102
# ALIAS  VFD2_SPD_RAWB         M_SIU  12    4
```

```
#EIG


#
# GRAYHILL I/O MODULES...
#

ALIAS     HS1_FB_MODULE                          LDM    0
ALIAS     HS2_FB_MODULE                          LDM    1
ALIAS     XF1_FB_MODULE                          LDM    2
ALIAS     XF2_FB_MODULE                          LDM    3
ALIAS     POWER_OK_MODULE                        LDM    4
ALIAS     GEN_FB_MODULE                          LDM    5
ALIAS     GEN_LOFUEL_MODULE                      LDM    6

ALIAS     HS1_SSR                                LDR    0
ALIAS     HS2_SSR                                LDR    1

ALIAS     HS1_SPEED_MODULE                       LAOM   4
ALIAS     HS2_SPEED_MODULE                       LAOM   5
ALIAS     XF1_SPEED_MODULE                       LAOM   6
ALIAS     XF2_SPEED_MODULE                       LAOM   7

#
# SETPOINTS...
#

ALIAS     ALTERNATE_HI_SVC                       LDS    0
ALIAS     HI_SVC_VFD_NETWORKING                  LDS    1
ALIAS     HI_SVC1_RESET_ONESHOT                  LDS    2
ALIAS     HI_SVC2_RESET_ONESHOT                  LDS    3

ALIAS     HI_SVC_MINSPEED_%                      LAS    0
ALIAS     HI_SVC_MAXSPEED_%                      LAS    1
ALIAS     HI_SVC_FAILOVER_SPEED_%                LAS    2
ALIAS     EFFL_LIMIT_PSI                         LAS    3
ALIAS     HI_SVC_GAIN                            LAS    4
ALIAS     HI_SVC_MAXSTEP                         LAS    5
ALIAS     EFFL_FLOW_DETECT_GPM                   LAS    6
ALIAS     INFL_FLOW_DETECT_GPM                   LAS    7
ALIAS     TIMER_1_START_HOUR                     LAS    8
ALIAS     TIMER_1_STOP_HOUR                      LAS    9
ALIAS     TIMER_2_START_HOUR                     LAS   10
ALIAS     TIMER_2_STOP_HOUR                      LAS   11
ALIAS     TIMER_3_START_HOUR                     LAS   12
ALIAS     TIMER_3_STOP_HOUR                      LAS   13
ALIAS     PRESSURE_MODE_ON_PSI                   LAS   14
ALIAS     PRESSURE_MODE_RUNTIME_HRS              LAS   15
ALIAS     LOW_GST_FT                             LAS   16
ALIAS     LOW_GST_RELEASE_FT                     LAS   17

ALIAS     CALL_INTAKE_1{OFF-ON}                  LIS    0
ALIAS     CALL_INTAKE_2{OFF-ON}                  LIS    1
ALIAS     HI_SVC_1{AUTO-ON-OFF}                  LIS    2
ALIAS     HI_SVC_2{AUTO-ON-OFF}                  LIS    3
ALIAS     HI_SVC_MODE{RADIO-PRESS-TIMER}         LIS    4
ALIAS     HI_SVC_FAILOVER{PRESS-TIMER}           LIS    5
ALIAS     LEAD_HI_SVC{P1-P2}                     LIS    6
ALIAS     LAG_HI_SVC{P1-P2}                      LIS    7


#
# D1  // ON=GREEN          , OFF=BLANK
# D2  // ON=RED/BLINKING   , OFF=BLANK
```

```
# D3  // ON=GREEN          , OFF=RED/BLINKING
# D4  // ON=GREEN/BLINKING , OFF=BLANK
#
# LOCAL FLAGS...
#

DISPL_D3  POWER                                LDF    0
DISPL_D4  CALL_INTAKE_1                        LDF    1
DISPL_D4  CALL_INTAKE_2                        LDF    2
DISPL_D4  HI_SVC_PUMP_1                        LDF    3
DISPL_D4  HI_SVC_PUMP_2                        LDF    4
DISPL_D3  RADIO_MODE                           LDF    5
DISPL_D2  PRESSURE_MODE                        LDF    6
DISPL_D2  TIMER_MODE                           LDF    7
$BLANK

DISPL_D4  XFER_PUMP_1                          LDF    8
DISPL_D4  XFER_PUMP_2                          LDF    9
$BLANK

DISPL_D2  LOW_GST                              LDF   10
DISPL_D2  GENERATOR                            LDF   11
DISPL_D2  GENERATOR_LO_FUEL                    LDF   12
DISPL_D2  COMM_FAIL_TO_TOWERS                  LDF   13
DISPL_D2  COMM_FAIL_TO_INTAKE                  LDF   14
$BLANK 3

DISPL_D2  EFFL_XDUCER_FAIL                     LDF   15
DISPL_D2  CLEARWELL_XDUCER_FAIL                LDF   16
DISPL_D2  GST_XDUCER_FAIL                      LDF   17
$BLANK

DISPL_D2  HI_SVC_PUMP_1_FAIL                   LDF   18
DISPL_D2  HI_SVC_PUMP_2_FAIL                   LDF   19
DISPL_D2  HI_SVC1_VFD_COMM_FAIL                LDF   20
DISPL_D2  HI_SVC2_VFD_COMM_FAIL                LDF   21
$BLANK

DISPL     EFFL_PSI                             LAF    0
DISPL     EFFL_FLOW_GPM                        LAF    1
DISPL     HI_SVC_VFD_SPEED_%                   LAF    2
$BLANK

DISPL     CLEARWELL_FT                         LAF    3
DISPL     CLEARWELL_KGAL                       LAF    4
$BLANK

DISPL     GST_FT                               LAF    5
DISPL     GST_KGAL                             LAF    6
DISPL     INFL_FLOW_GPM                        LAF    7
DISPL     PROCESS_FLOW_GPM                     LAF    8
$PAGE

DISPL     HI_SVC1_KW                           LAF    9
DISPL     HI_SVC2_KW                           LAF   10
DISPL     HI_SVC1_GPK                          LAF   11
DISPL     HI_SVC2_GPK                          LAF   12
DISPL     HI_SVC1_DEGF                         LAF   13
DISPL     HI_SVC2_DEGF                         LAF   14
DISPL     HI_SVC1_FAULT_CODE                   LAF   15
DISPL     HI_SVC2_FAULT_CODE                   LAF   16
$BLANK 2

DISPL     UTIL_AB_VOLTS                        LAF   17
```

```
DISPL     UTIL_BC_VOLTS                       LAF   18
DISPL     UTIL_CA_VOLTS                       LAF   19
$BLANK 7

DISPL     EFFL_METER_GAL                      LIF    0
DISPL     INFL_METER_GAL                      LIF    1
DISPL     PROCESS_METER_GAL                   LIF    2
DISPL     HI_SVC_1_RUNTIME_MIN                LIF    3
DISPL     HI_SVC_2_RUNTIME_MIN                LIF    4
DISPL     XFER_PUMP_1_RUNTIME_MIN             LIF    5
DISPL     XFER_PUMP_2_RUNTIME_MIN             LIF    6
DISPL     LEAD_HI_SVC_PUMP                    LIF    7
DISPL     RTU_UPTIME_MIN                      LIF    8
$PAGE

#
# REMOTE FLAGS...
#

DISPL_D3   COMM_TO_INTAKE                     VLD    0
DISPL_D4   INTAKE_PUMP_1                      RDF    0   1
DISPL_D4   INTAKE_PUMP_2                      RDF    0   2
$BLANK

DISPL_D3   COMM_TO_TWR01                      VLD    1
DISPL      TWR01_LEVEL_FT                     RAF    1   0
DISPL      TWR01_LEVEL_KGAL                   RAF    1   1
DISPL      TWR01_INFL_PSI                     RAF    1   2
$BLANK
DISPL_D4   TWR01_CALL_PLANT                   RDF    1   1
DISPL_D4   TWR01_FULL                         RDF    1   2
DISPL_D4   TWR01_VALVE_OPEN                   RDF    1   4
DISPL_D2   TWR01_XDUCER_FAIL                  RDF    1  10
$BLANK

DISPL_D3   COMM_TO_TWR13                      VLD    2
DISPL      TWR13_LEVEL_FT                     RAF    2   0
DISPL      TWR13_LEVEL_KGAL                   RAF    2   1
DISPL      TWR13_INFL_PSI                     RAF    2   2
$BLANK 2

DISPL_D4   TWR13_CALL_PLANT                   RDF    2   1
DISPL_D4   TWR13_FULL                         RDF    2   2
DISPL_D4   TWR13_VALVE_OPEN                   RDF    2   4
DISPL_D2   TWR13_XDUCER_FAIL                  RDF    2  10
$BLANK

DISPL_D3   COMM_TO_TWR14                      VLD    3
DISPL      TWR14_LEVEL_FT                     RAF    3   0
DISPL      TWR14_LEVEL_KGAL                   RAF    3   1
DISPL      TWR14_INFL_PSI                     RAF    3   2
$BLANK

DISPL_D4   TWR14_CALL_PLANT                   RDF    3   1
DISPL_D4   TWR14_FULL                         RDF    3   2
DISPL_D4   TWR14_VALVE_OPEN                   RDF    3   4
DISPL_D2   TWR14_XDUCER_FAIL                  RDF    3  10
$BLANK

#
# TIMERS...
#

ALIAS     POWER_FAIL_TIMER                    TMR    0
```

```
ALIAS     POWER_OK_TIMER                    TMR    1
ALIAS     HS_1_FAIL_TIMER                   TMR    2
ALIAS     HS_2_FAIL_TIMER                   TMR    3
ALIAS     PRESSURE_ON_TIMER                 TMR    4
ALIAS     PRESSURE_RUNTIME_TIMER            TMR    5
ALIAS     HS_1_DELAY_TIMER                  TMR    6
ALIAS     HS_2_DELAY_TIMER                  TMR    7
ALIAS     HS_1_OFF_TIMER                    TMR    8
ALIAS     HS_2_OFF_TIMER                    TMR    9
ALIAS     LOW_GST_TIMER                     TMR   10
ALIAS     LOW_GST_OFF_TIMER                 TMR   11
ALIAS     VFD1_COMM_FAIL_TIMER              TMR   12
ALIAS     VFD2_COMM_FAIL_TIMER              TMR   13
ALIAS     VFD1_OK_TIMER                     TMR   14
ALIAS     VFD2_OK_TIMER                     TMR   15


#
# USR VARIABLES...
#

ALIAS     HS1_RUNTIME_SECS                  USR    0
ALIAS     HS2_RUNTIME_SECS                  USR    1
ALIAS     XP1_RUNTIME_SECS                  USR    2
ALIAS     XP2_RUNTIME_SECS                  USR    3

ALIAS     LEAD_PUMP_DEF                     USR    4
ALIAS     LAG_PUMP_DEF                      USR    5

ALIAS     LASTCALL_TIME                     USR    6
ALIAS     DELTA_TIME                        USR    7

ALIAS     TOWER_LEAD                        USR    8
ALIAS     PRESSURE_LEAD                     USR    9
ALIAS     TIMER_LEAD                        USR   10

ALIAS     NEW_LEAD_STATE                    USR   11
ALIAS     LEAD_TURNING_ON                   USR   12
ALIAS     LEAD_TURNING_OFF                  USR   13
ALIAS     LEAD_STATE                        USR   14
ALIAS     LAG_STATE                         USR   15
ALIAS     LOCAL_P1                          USR   16
ALIAS     LOCAL_P2                          USR   17

ALIAS     TOWER_CONTROL_FAIL                USR   18

ALIAS     SEQUENCE_POINTER_1                USR   19
ALIAS     SEQUENCE_POINTER_2                USR   20

ALIAS     TRY_1_FAIL                        USR   21
ALIAS     TRY_2_FAIL                        USR   22

ALIAS     AOK                               USR   23

ALIAS     P1_FINAL                          USR   24
ALIAS     P2_FINAL                          USR   25

ALIAS     INFL_FLOWING_USR                  USR   26
ALIAS     EFFL_FLOWING_USR                  USR   27

ALIAS     PUMP_FAIL_NOW_USR                 USR   28
ALIAS     DETENTION_WORKING_USR             USR   29

ALIAS     LEAD_TIMER                        USR   30
```

```
ALIAS     INFL_EMETER_FAULT_USR              USR   31
ALIAS     INFL_METER_FAULT_USR               USR   32
ALIAS     EFFL_EMETER_FAULT_USR              USR   33
ALIAS     EFFL_METER_FAULT_USR               USR   34

ALIAS     ALL_XDUCER_FAIL                    USR   35
ALIAS     COMM_TO_ALL_TOWERS                 USR   36

ALIAS     HS1_CONTROL_FB                     USR   37
ALIAS     HS1_REF1_FB                        USR   38
ALIAS     HS1_REF2_FB                        USR   39
ALIAS     HS1_STATUS_FB                      USR   40
ALIAS     HS1_SPEED_FB                       USR   41
ALIAS     HS1_AMPS_FB                        USR   42
ALIAS     HS1_TORQUE_FB                      USR   43
ALIAS     HS1_POWER_FB                       USR   44
ALIAS     HS1_BUSV_FB                        USR   45
ALIAS     HS1_LFAULT_FB                      USR   46
ALIAS     HS1_OUTV_FB                        USR   47
ALIAS     HS1_TEMP_FB                        USR   48

ALIAS     HS2_CONTROL_FB                     USR   49
ALIAS     HS2_REF1_FB                        USR   50
ALIAS     HS2_REF2_FB                        USR   51
ALIAS     HS2_STATUS_FB                      USR   52
ALIAS     HS2_SPEED_FB                       USR   53
ALIAS     HS2_AMPS_FB                        USR   54
ALIAS     HS2_TORQUE_FB                      USR   55
ALIAS     HS2_POWER_FB                       USR   56
ALIAS     HS2_BUSV_FB                        USR   57
ALIAS     HS2_LFAULT_FB                      USR   58
ALIAS     HS2_OUTV_FB                        USR   59
ALIAS     HS2_TEMP_FB                        USR   60

ALIAS     CW_1                               USR   61
ALIAS     CW_2                               USR   62
ALIAS     CW_3                               USR   63
ALIAS     CW_4                               USR   64
ALIAS     CW_5                               USR   65
ALIAS     CW_STATE                           USR   66
ALIAS     VIRTUAL_SPEED_FB                   USR   67
ALIAS     CW_EXT1                            USR   68
ALIAS     CW_EXT2                            USR   69

ALIAS     HS1_SSR_USR                        USR   70
ALIAS     HS2_SSR_USR                        USR   71


$NCL


# NCL Program
#
# Station : Water Treatment Plant
# Author  : Jim Mimlitz, Navionics Research Inc.
#

      LBL      MAIN


# IF FIRSTRUN, INITIALIZE VARIABLES AND TIMERS ...
```

```
        FIRSTRUN?
        IF_FALSE
        GOTO     9

        GOSUB    SANITY_CHECKS

        GOSUB    MY_HS_SEQUENCE_SETUP
        LOAD     LEAD_PUMP_DEF
        PSTORE   LEAD_HI_SVC_PUMP

        LOAD     0
        STORE    HI_SVC_PUMP_1_FAIL
        STORE    HI_SVC_PUMP_2_FAIL
        STORE    TRY_1_FAIL
        STORE    TRY_2_FAIL
        STORE    HS_1_FAIL_TIMER
        STORE    HS_2_FAIL_TIMER
        STORE    VFD1_COMM_FAIL_TIMER
        STORE    VFD2_COMM_FAIL_TIMER
        STORE    HS1_SSR_USR
        STORE    HS2_SSR_USR
        STORE    VFD1_OK_TIMER
        STORE    VFD2_OK_TIMER
        POP

        LOAD     15
        SDELAY   VFD1_OK_TIMER
        SDELAY   VFD2_OK_TIMER
        POP

        LOAD     180
        SDELAY   HS_1_OFF_TIMER
        SDELAY   HS_2_OFF_TIMER
        POP

        LOAD     10.0
        PSDELAY  POWER_FAIL_TIMER
        LOAD     300.0
        PSDELAY  POWER_OK_TIMER

        LOAD     600.0
        PSDELAY  PRESSURE_ON_TIMER

        LOAD     20.0
        SDELAY   HS_1_DELAY_TIMER
        SDELAY   HS_2_DELAY_TIMER
        POP

        LOAD     420.0
        SDELAY   HS_1_FAIL_TIMER
        SDELAY   HS_2_FAIL_TIMER
        POP

        LOAD     60
        SDELAY   VFD1_COMM_FAIL_TIMER
        SDELAY   VFD2_COMM_FAIL_TIMER
        POP

        LOAD     30.0
        SDELAY   LOW_GST_TIMER
        SDELAY   LOW_GST_OFF_TIMER
        POP

# FROM P.34 OF EFB CONTROL MANUAL
```

```
# STATE DIAGRAM VALUES...

# CHANGES VFD STATE TO "READY TO SWITCH ON"...
      LOAD     0x0006
      PSTORE   CW_1

# CHANGES VFD STATE TO "READY TO OPERATE"...
      LOAD     0x0007
      PSTORE   CW_2

# CHANGES VFD STATE TO "OPERATION ENABLED"
# VFD STARTS, BUT WILL NOT ACCELERATE...
      LOAD     0x000F
      PSTORE   CW_3

# RELEASES RAMP FUNCTION GENERATOR OUTPUT.
# CHANGES VFD STATE TO "RFG: ACCELERATOR ENABLED"...
      LOAD     0x002F
      PSTORE   CW_4

# RELEASES THE RAMP FUNCTION GENERATOR OUTPUT.
# CHANGES VFD STATE TO "OPERATING".
# THE VFD ACCELERATES TO THE GIVEN REFERENCE, AND
# FOLLOWS THE REFERENCE...
      LOAD     0x006F
      PSTORE   CW_5

# CONTROL WORD THAT ENABLES EXT1 CONTROL (DI1 & AIN1)
# AND EXT2 (MODBUS)...

      LOAD     0x0000
      PSTORE   CW_EXT1

      LOAD     0x0800
      PSTORE   CW_EXT2

9     POP

      FIRSTRUN?
      NEW_SETPOINTS?
      |
      IF_FALSE
      GOTO     10

      GOSUB    SANITY_CHECKS
      GOSUB    MY_HS_SEQUENCE_SETUP
      LOAD     LEAD_PUMP_DEF
      PSTORE   LEAD_HI_SVC_PUMP

      LOAD     PRESSURE_MODE_RUNTIME_HRS
      LOAD     3600.0
      *
      PSDELAY  PRESSURE_RUNTIME_TIMER

10    POP


# RESET VFD'S, IF REQUESTED...

      NEW_SETPOINTS?
      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     HI_SVC1_RESET_ONESHOT
      &
      &
```

```
      IF_FALSE
      GOTO     15

# SET FAULT_RESET_SEL TO COMM...
      LOAD     8
      PSTORE   M_SOU  11   1603

      LOAD     0X0080
      PSTORE   M_SOU  11  0
      LOAD     200
      DELAY_MS
      LOAD     CW_1
      PSTORE   M_SOU  11  0
      LOAD     200
      DELAY_MS
      LOAD     CW_2
      PSTORE   M_SOU  11  0

# SET FAULT_RESET_SEL TO KEYPAD...
      LOAD     0
      PSTORE   M_SOU  11   1603

      LOAD     0
      PSTORE   HI_SVC1_RESET_ONESHOT
15    POP

      NEW_SETPOINTS?
      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     HI_SVC2_RESET_ONESHOT
      &
      &
      IF_FALSE
      GOTO     16

# SET FAULT_RESET_SEL TO COMM...
      LOAD     8
      PSTORE   M_SOU  12   1603

      LOAD     0X0080
      PSTORE   M_SOU  12  0
      LOAD     200
      DELAY_MS
      LOAD     CW_1
      PSTORE   M_SOU  12  0
      LOAD     200
      DELAY_MS
      LOAD     CW_2
      PSTORE   M_SOU  12  0

# SET FAULT_RESET_SEL TO KEYPAD...
      LOAD     0
      PSTORE   M_SOU  12   1603

      LOAD     0
      PSTORE   HI_SVC2_RESET_ONESHOT
16    POP



# READ MODBUS INPUT MODULES...

# EIG SHARK VOLTAGE METERS, MODBUS...
# ALIAS   UTIL_AB_IMOD              M_FI  20  0x03ED
# ALIAS   UTIL_BC_IMOD              M_FI  20  0x03EF
```

```
# ALIAS   UTIL_CA_IMOD               M_FI  20  0x03F1
# SHARK KSB VOLTAGES...
# MODBUS BLOCK TRANSFERS...
# LOADM <DEVICE ID> <INDEX-40001> <N_REGISTERS_TO_READ>

      LOADM       20  0x03ED   6

      CAST_FLOAT  0
      PSTORE      UTIL_AB_VOLTS

      CAST_FLOAT  2
      PSTORE      UTIL_BC_VOLTS

      CAST_FLOAT  4
      PSTORE      UTIL_CA_VOLTS


# MODBUS BLOCK TRANSFERS...
# LOADM <DEVICE ID> <INDEX-40001> <N_REGISTERS_TO_READ>

# MODBUS DEVICE 4...
# INFLUENT FLOW METER...

      LOADM       4  0  20

      CAST_ULONG  0
      LOAD        10.0
      *
      PSTORE      INFL_METER_GAL

      CAST_LONG   4
      LOAD        0.001
      *
      PSTORE      INFL_FLOW_GPM

      CAST_INT    14
      PSTORE      INFL_METER_FAULT_USR

      MA_VLD
      !
      PSTORE      INFL_EMETER_FAULT_USR


# MODBUS DEVICE 5...
# EFFLUENT FLOW METER, PROCESS FLOW METER...

      LOADM       5  0  20

      CAST_ULONG  0
      LOAD        10.0
      *
      PSTORE      EFFL_METER_GAL

      CAST_ULONG  2
      PSTORE      PROCESS_METER_GAL

      CAST_LONG   4
      LOAD        0.001
      *
      PSTORE      EFFL_FLOW_GPM

      CAST_LONG   6
      LOAD        0.001
      *
```

```
      PSTORE      PROCESS_FLOW_GPM

      CAST_INT    14
      PSTORE      EFFL_METER_FAULT_USR

      MA_VLD
      !
      PSTORE      EFFL_EMETER_FAULT_USR


# SINGLE-REGISTER MODBUS READS FROM KELLER TRANSDUCERS...

      LOAD     EFFL_PSI_MODULE
      LOAD     14.5037744
      *
      PSTORE   EFFL_PSI
      MA_VLD
      !
      PSTORE   EFFL_XDUCER_FAIL

      LOAD     GST_PSI_MODULE
      LOAD     14.5037744
      *
      LOAD     2.3067
      *
      LOAD     2.45833
      +
      STORE    GST_FT
      LOAD     28.0
      /
      LOAD     1000.0
      *
      PSTORE   GST_KGAL
      MA_VLD
      !
      PSTORE   GST_XDUCER_FAIL

      LOAD     CLEARWELL_PSI_MODULE
      LOAD     14.5037744
      *
      LOAD     2.3067
      *
      LOAD     3.0
      +
      STORE    CLEARWELL_FT
      LOAD     10.0
      /
      LOAD     150.0
      *
      PSTORE   CLEARWELL_KGAL
      MA_VLD
      !
      PSTORE   CLEARWELL_XDUCER_FAIL


# READ DATA FROM VFD 1...

      LOAD        HI_SVC_VFD_NETWORKING
      LOAD        VFD1_OK_TIMER
      &
      IF_FALSE
      GOTO        210
      LOADM       11    0   4
# CONTROL WORD...
```

```
      CAST_UINT   0
      PSTORE      HS1_CONTROL_FB
# REFERENCE 1...
      CAST_UINT   1
      PSTORE      HS1_REF1_FB
# REFERENCE 2...
      CAST_UINT   2
      PSTORE      HS1_REF2_FB
# STATUS WORD...
      CAST_UINT   3
      PSTORE      HS1_STATUS_FB

      LOADM       11  102   10
# SPEED (HZ) x 10...
      CAST_UINT   0
      LOAD        600
      /
      LOAD        100
      *
      PSTORE      HS1_SPEED_FB
# CURRENT (A) X 10...
      CAST_UINT   1
      LOAD        0.1
      *
      PSTORE      HS1_AMPS_FB
# TORQUE (%) x 10...
      CAST_UINT   2
      LOAD        0.1
      *
      PSTORE      HS1_TORQUE_FB
# POWER (KW) x 10...
      CAST_UINT   3
      LOAD        0.1
      *
      PSTORE      HS1_POWER_FB
# DC BUS (V)...
      CAST_UINT   4
      PSTORE      HS1_BUSV_FB
# OUTPUT VOLTAGE (V)...
      CAST_UINT   5
      PSTORE      HS1_OUTV_FB
# TRANSISTOR TEMP (C) x 10...
      CAST_UINT   6
      LOAD        0.18
      *
      LOAD        32
      +
      PSTORE      HS1_TEMP_FB

      LOADM       11  400   1
# LAST FAULT...
      CAST_UINT   0
      PSTORE      HS1_LFAULT_FB

      MA_VLD
      !
      PSTORE      VFD1_COMM_FAIL_TIMER

210   POP

      LOAD        HS1_SSR
      LOAD        HS1_FB_MODULE
      |
      IF_TRUE
```

```
      GOTO        211
      LOAD        0
      STORE       HS1_POWER_FB
      STORE       HS1_SPEED_FB
      STORE       HS1_AMPS_FB
      STORE       HS1_TORQUE_FB
      STORE       HS1_POWER_FB
      STORE       HS1_BUSV_FB
      STORE       HS1_OUTV_FB
      POP
      LOAD        32
      PSTORE      HS1_TEMP_FB
211   POP


      LOAD     HS1_POWER_FB
      PSTORE   HI_SVC1_KW

      LOAD     HS1_TEMP_FB
      PSTORE   HI_SVC1_DEGF

      LOAD     EFFL_FLOW_GPM
      LOAD     60
      *
      LOAD     HI_SVC1_KW
      LOAD     0.1
      MAX
      /
      LOAD     HI_SVC1_KW
      !
      !
      *
      PSTORE   HI_SVC1_GPK

      LOAD     HS1_STATUS_FB
      BITMASK  3
      LOAD     HS1_LFAULT_FB
      *
      PSTORE   HI_SVC1_FAULT_CODE

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     HS1_SSR
      LOAD     HS1_FB_MODULE
      |
      &
      LOAD     VFD1_COMM_FAIL_TIMER
      &
      PSTORE   HI_SVC1_VFD_COMM_FAIL


# READ DATA FROM VFD 2...

      LOAD        HI_SVC_VFD_NETWORKING
      LOAD        VFD2_OK_TIMER
      &
      IF_FALSE
      GOTO        220
      LOADM       12    0   4
# CONTROL WORD...
      CAST_UINT   0
      PSTORE      HS2_CONTROL_FB
# REFERENCE 1...
      CAST_UINT   1
      PSTORE      HS2_REF1_FB
```

```
# REFERENCE 2...
      CAST_UINT   2
      PSTORE      HS2_REF2_FB
# STATUS WORD...
      CAST_UINT   3
      PSTORE      HS2_STATUS_FB

      LOADM       12  102   10
# SPEED (HZ) x 10...
      CAST_UINT   0
      LOAD        600
      /
      LOAD        100
      *
      PSTORE      HS2_SPEED_FB
# CURRENT (A) X 10...
      CAST_UINT   1
      LOAD        0.1
      *
      PSTORE      HS2_AMPS_FB
# TORQUE (%) x 10...
      CAST_UINT   2
      LOAD        0.1
      *
      PSTORE      HS2_TORQUE_FB
# POWER (KW) x 10...
      CAST_UINT   3
      LOAD        0.1
      *
      PSTORE      HS2_POWER_FB
# DC BUS (V)...
      CAST_UINT   4
      PSTORE      HS2_BUSV_FB
# OUTPUT VOLTAGE (V)...
      CAST_UINT   5
      PSTORE      HS2_OUTV_FB
# TRANSISTOR TEMP (C) x 10...
      CAST_UINT   6
      LOAD        0.18
      *
      LOAD        32
      +
      PSTORE      HS2_TEMP_FB

      LOADM       12  400   1
# LAST FAULT...
      CAST_UINT   0
      PSTORE      HS2_LFAULT_FB

      MA_VLD
      !
      PSTORE      VFD2_COMM_FAIL_TIMER

220   POP

      LOAD        HS2_SSR
      LOAD        HS2_FB_MODULE
      |
      IF_TRUE
      GOTO        221
      LOAD        0
      STORE       HS2_POWER_FB
      STORE       HS2_SPEED_FB
      STORE       HS2_AMPS_FB
```

```
      STORE       HS2_TORQUE_FB
      STORE       HS2_POWER_FB
      STORE       HS2_BUSV_FB
      STORE       HS2_OUTV_FB
      POP
      LOAD        32
      PSTORE      HS2_TEMP_FB
221   POP


      LOAD     HS2_POWER_FB
      PSTORE   HI_SVC2_KW

      LOAD     HS2_TEMP_FB
      PSTORE   HI_SVC2_DEGF

      LOAD     EFFL_FLOW_GPM
      LOAD     60
      *
      LOAD     HI_SVC2_KW
      LOAD     0.1
      MAX
      /
      LOAD     HI_SVC2_KW
      !
      !
      *
      PSTORE   HI_SVC2_GPK

      LOAD     HS2_STATUS_FB
      BITMASK  3
      LOAD     HS2_LFAULT_FB
      *
      PSTORE   HI_SVC2_FAULT_CODE

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     HS2_SSR
      LOAD     HS2_FB_MODULE
      |
      &
      LOAD     VFD2_COMM_FAIL_TIMER
      &
      PSTORE   HI_SVC2_VFD_COMM_FAIL


# READ GRAYHILL I/O MODULES...

      LOAD     POWER_OK_MODULE
      !
      PSTORE   POWER_FAIL_TIMER
      LOAD     POWER_FAIL_TIMER
      !
      PSTORE   POWER_OK_TIMER
      LOAD     POWER_OK_TIMER
      PSTORE   POWER

      LOAD     INFL_FLOW_GPM
      LOAD     INFL_FLOW_DETECT_GPM
      Y>=X?
      LOAD     INFL_METER_FAULT_USR
      LOAD     INFL_EMETER_FAULT_USR
      |
      |
      PSTORE   INFL_FLOWING_USR
```

```
      LOAD     EFFL_FLOW_GPM
      LOAD     EFFL_FLOW_DETECT_GPM
      Y>=X?
      LOAD     EFFL_METER_FAULT_USR
      LOAD     EFFL_EMETER_FAULT_USR
      |
      |
      PSTORE   EFFL_FLOWING_USR

      LOAD     HS1_FB_MODULE
      LOAD     EFFL_FLOWING_USR
      &
      PSTORE   HI_SVC_PUMP_1

      LOAD     HS2_FB_MODULE
      LOAD     EFFL_FLOWING_USR
      &
      PSTORE   HI_SVC_PUMP_2

      LOAD     XF1_FB_MODULE
      PSTORE   XFER_PUMP_1

      LOAD     XF2_FB_MODULE
      PSTORE   XFER_PUMP_2

      LOAD     GEN_FB_MODULE
      !
      PSTORE   GENERATOR

      LOAD     GEN_LOFUEL_MODULE
      PSTORE   GENERATOR_LO_FUEL


# ASSIGN LEAD HI SVC PUMP DEF...

      LOAD     LEAD_PUMP_DEF
      PSTORE   LEAD_HI_SVC_PUMP


# TIME CALCULATOR ...

      SYSTIME
      LOAD     LASTCALL_TIME
      -
      PSTORE   DELTA_TIME
      SYSTIME
      PSTORE   LASTCALL_TIME


# SYSTEM UPTIME CALCULATOR ...

      UPTIME
      LOAD     60.0
      /
      PSTORE   RTU_UPTIME_MIN


# COMM HANDLER...

      LOAD     COMM_TO_TWR01
      !
      LOAD     COMM_TO_TWR13
```

```
      !
      LOAD     COMM_TO_TWR14
      !
      &
      &
      !
      PSTORE   COMM_TO_ALL_TOWERS

      LOAD     TWR01_XDUCER_FAIL
      LOAD     COMM_TO_TWR01
      &
      LOAD     TWR13_XDUCER_FAIL
      LOAD     COMM_TO_TWR13
      &
      LOAD     TWR14_XDUCER_FAIL
      LOAD     COMM_TO_TWR14
      &
      &
      &
      PSTORE   ALL_XDUCER_FAIL

      LOAD     COMM_TO_TWR01
      LOAD     COMM_TO_TWR13
      LOAD     COMM_TO_TWR14
      &
      &
      !
      PSTORE   COMM_FAIL_TO_TOWERS


# LAKE INTAKE HANDLER...


      LOAD     CALL_INTAKE_1{OFF-ON}
      LOAD     2.0
      Y=X?
      PSTORE   CALL_INTAKE_1

      LOAD     CALL_INTAKE_2{OFF-ON}
      LOAD     2.0
      Y=X?
      PSTORE   CALL_INTAKE_2


# BPS_MODE_CALC ...


      LOADA    HI_SVC_MODE{RADIO-PRESS-TIMER}
      LOADA    HI_SVC_FAILOVER{PRESS-TIMER}
      LOADA    COMM_TO_ALL_TOWERS
      LOADA    ALL_XDUCER_FAIL
      MACRO    BPS_MODE_CALC
      POP
      PSTORE   TIMER_MODE
      LOAD     EFFL_XDUCER_FAIL
      !
      &
      PSTORE   PRESSURE_MODE
      PSTORE   RADIO_MODE


# TIMER HANDLER ...

      LOAD     TIMER_1_START_HOUR
```

```
      LOAD     TIMER_1_STOP_HOUR
      BETWEEN_HOURS
      LOAD     TIMER_2_START_HOUR
      LOAD     TIMER_2_STOP_HOUR
      BETWEEN_HOURS
      LOAD     TIMER_3_START_HOUR
      LOAD     TIMER_3_STOP_HOUR
      BETWEEN_HOURS
      |
      |
      LOAD     TIMER_MODE
      &
      PSTORE   TIMER_LEAD


# TOWER HANDLER...

      LOAD     TWR01_CALL_PLANT
      LOAD     TWR01_VALVE_OPEN
      LOAD     COMM_TO_TWR01
      &
      &
      LOAD     TWR13_CALL_PLANT
      LOAD     TWR13_VALVE_OPEN
      LOAD     COMM_TO_TWR13
      &
      &
      LOAD     TWR14_CALL_PLANT
      LOAD     TWR14_VALVE_OPEN
      LOAD     COMM_TO_TWR14
      &
      &
      |
      |
      LOAD     TWR01_FULL
      !
      LOAD     TWR01_VALVE_OPEN
      LOAD     COMM_TO_TWR01
      &
      &
      LOAD     TWR13_FULL
      !
      LOAD     TWR13_VALVE_OPEN
      LOAD     COMM_TO_TWR13
      &
      &
      LOAD     TWR14_FULL
      !
      LOAD     TWR14_VALVE_OPEN
      LOAD     COMM_TO_TWR13
      &
      &
      |
      |
      LOAD     TOWER_LEAD
      &
      |
      LOAD     RADIO_MODE
      &
      PSTORE   TOWER_LEAD


# PRESSURE-LEAD HANDLER ...
```

```
      LOAD     PUMP_FAIL_NOW_USR
      IF_FALSE
      GOTO     354
      TIMEOUT  PRESSURE_RUNTIME_TIMER
      LOAD     0.0
      PSTORE   PRESSURE_ON_TIMER
354   POP


      LOADA    EFFL_PSI
      LOADA    PRESSURE_MODE_ON_PSI
      LOADA    PRESSURE_ON_TIMER
      LOADA    PRESSURE_RUNTIME_TIMER
      MACRO    HYBRID_PRESSURE_LO
      LOAD     PRESSURE_MODE
      &
      PSTORE   PRESSURE_LEAD


# LEAD_STATE CALC ...

      LOAD     TOWER_LEAD
      LOAD     PRESSURE_LEAD
      LOAD     TIMER_LEAD
      |
      |
      STORE    NEW_LEAD_STATE
      LOAD     LEAD_STATE
      !
      &
      STORE    LEAD_TURNING_ON
      LOAD     NEW_LEAD_STATE
      !
      LOAD     LEAD_STATE
      &
      STORE    LEAD_TURNING_OFF
      |
      IF_FALSE
      GOTO     40
      LOAD     0
      PSTORE   LEAD_TIMER
40    POP

      LOAD     NEW_LEAD_STATE
      PSTORE   LEAD_STATE


# LOCAL_P1 & LOCAL_P2 CALC ...

      LOAD     LEAD_STATE
      LOAD     LEAD_PUMP_DEF
      LOAD     1.0
      X=Y?
      &
      PSTORE   LOCAL_P1

      LOAD     LEAD_STATE
      LOAD     LEAD_PUMP_DEF
      LOAD     2.0
      X=Y?
      &
      PSTORE   LOCAL_P2
```

```
# LOW GST...

      LOADA    GST_FT
      LOADA    LOW_GST_FT
      LOADA    LOW_GST_RELEASE_FT
      LOADA    LOW_GST_TIMER
      LOADA    LOW_GST_OFF_TIMER
      LOADA    LOW_GST
      MACRO    HYSTERESIS_LO_W_TIMER
      LOAD     GST_XDUCER_FAIL
      !
      &
      PSTORE   LOW_GST


# AOK CALC...
# POWER FAIL OR LOW_GST WILL INHIBIT HI SVC PUMPS.
# IF GST XDUCER FAILS, THEN LOW_GST WILL INHIBIT
# HI SVC PUMPS.

      LOAD     POWER
      LOAD     LOW_GST
      !
      &
      PSTORE   AOK


# FINAL P1 CALC ...

      LOAD     LOCAL_P1
      LOAD     HI_SVC_1{AUTO-ON-OFF}
      LOAD     2.0
      X=Y?
      |
      LOAD     AOK
      &
      LOAD     HI_SVC_1{AUTO-ON-OFF}
      LOAD     3.0
      X=Y?
      !
      &
      LOAD     HS2_SSR_USR
      !
      &
      PSTORE   HS_1_DELAY_TIMER
      LOAD     HS_1_DELAY_TIMER
      STORE    P1_FINAL
      !
      PSTORE   HS_1_OFF_TIMER
      LOAD     HS_1_OFF_TIMER
      !
      LOAD     P1_FINAL
      |
      PSTORE   HS1_SSR

      LOAD     HS1_SSR
      LOAD     HS1_FB_MODULE
      |
      PSTORE   VFD1_OK_TIMER


# FOR ABB VFD'S, THE MODBUS REGISTER FOR A DRIVE
# PARAMETER CAN BE DERIVED AS:
#  MODBUS_ADDR (ZERO-BASED) = DRIVE_PARAM - 1
```

```
# FOR EXAMPLE, DRIVE_PARAMETER 1002 = MODBUS_ADDR 1001

# HI SVC VFD
# ENABLE NETWORK CONTROL OF DRIVES, IF DESIRED...

#     IF NETWORKING ON...
# AND IF TELEMETRY CALLING FOR PUMP 1...
# AND IF VFD1 IS FULLY BOOTED UP...
# AND IF VFD1 HAS NOT BEEN CONFIGURED...
# THEN CONFIGURE VFD1 FOR COMM OPERATION...

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     HS1_SSR
      &
      LOAD     VFD1_OK_TIMER
      &
      LOAD     HS1_SSR_USR
      !
      &
      IF_FALSE
      GOTO     511

# SET FAULT_RESET_SEL TO COMM...
      LOAD     8
      PSTORE   M_SOU  11   1603
# SET COMM_FAULT_ACTION TO FAULT...
      LOAD     1
      PSTORE   M_SOU  11   3017

# PREP VFD BY STEPPING THROUGH NECESSARY STATES...
      LOAD     0X0080
      PSTORE   M_SOU  11  0
      LOAD     200
      DELAY_MS
      LOAD     CW_1
      PSTORE   M_SOU  11  0
      LOAD     200
      DELAY_MS
      LOAD     CW_2
      PSTORE   M_SOU  11  0

# ASSIGN VALUE TO HS1_SSR_USR
      LOAD     HS1_SSR
      PSTORE   HS1_SSR_USR

# RESET FAULT_RESET_SEL TO KEYPAD...
      LOAD     0
      PSTORE   M_SOU  11   1603

511   POP


# THIS SHOULD BE RUN IF NETWORKING IS ON,
# IN ORDER TO TURN ON OR OFF VFD1...

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     VFD1_OK_TIMER
      &
      IF_FALSE
      GOTO     512

      LOAD     HS1_SSR
      LOAD     CW_5
      LOAD     CW_EXT2
```

```
      +
      LOAD     CW_2
      -
      *
      LOAD     CW_2
      +
      PSTORE   M_SOU  11   0

512   POP



# PUMP 1 IS ON, BUT RTU IS NOT CALLING FOR IT.
# CONFIGURE FOR MANUAL MODE...

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     VFD1_OK_TIMER
      &
      LOAD     HS1_SSR
      !
      &
      IF_FALSE
      GOTO     513
# SET FAULT_RESET_SEL TO KEYPAD...
      LOAD     0
      PSTORE   M_SOU  11   1603
# SET COMM_FAULT_ACTION TO NO_ACTION...
      LOAD     0
      PSTORE   M_SOU  11   3017
513   POP


# VFD1 IS OFF. NEED TO ZERO OUT HS1_SSR_USR...
# IF HS1_SSR IS OFF, THEN ZERO OUT HS1_SSR_USR

      LOAD     HS1_SSR_USR
      LOAD     HS1_SSR
      &
      PSTORE   HS1_SSR_USR


# P1 FAIL CALC ...

      LOAD     HS1_SSR
      LOAD     HI_SVC_PUMP_1
      XOR
      PSTORE   HS_1_FAIL_TIMER
      LOAD     HS_1_FAIL_TIMER
      STORE    TRY_1_FAIL
      LOAD     HI_SVC_PUMP_1_FAIL
      LOAD     HI_SVC_PUMP_1
      !
      &
      |
      PSTORE   HI_SVC_PUMP_1_FAIL



# FINAL P2 CALC ...

      LOAD     LOCAL_P2
      LOAD     HI_SVC_2{AUTO-ON-OFF}
      LOAD     2.0
      X=Y?
```

```
      |
      LOAD     AOK
      &
      LOAD     HI_SVC_2{AUTO-ON-OFF}
      LOAD     3.0
      X=Y?
      !
      &
      LOAD     HS1_SSR_USR
      !
      &
      PSTORE   HS_2_DELAY_TIMER
      LOAD     HS_2_DELAY_TIMER
      STORE    P2_FINAL
      !
      PSTORE   HS_2_OFF_TIMER
      LOAD     HS_2_OFF_TIMER
      !
      LOAD     P2_FINAL
      |
      PSTORE   HS2_SSR

      LOAD     HS2_SSR
      LOAD     HS2_FB_MODULE
      |
      PSTORE   VFD2_OK_TIMER



# FOR ABB VFD'S, THE MODBUS REGISTER FOR A DRIVE
# PARAMETER CAN BE DERIVED AS:
#  MODBUS_ADDR (ZERO-BASED) = DRIVE_PARAM - 1
# FOR EXAMPLE, DRIVE_PARAMETER 1002 = MODBUS_ADDR 1001

# HI SVC VFD
# ENABLE NETWORK CONTROL OF DRIVES, IF DESIRED...

#     IF NETWORKING ON...
# AND IF TELEMETRY CALLING FOR PUMP 2...
# AND IF VFD2 IS FULLY BOOTED UP...
# AND IF VFD2 HAS NOT BEEN CONFIGURED...
# THEN CONFIGURE VFD2 FOR COMM OPERATION...

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     HS2_SSR
      &
      LOAD     VFD2_OK_TIMER
      &
      LOAD     HS2_SSR_USR
      !
      &
      IF_FALSE
      GOTO    611
# SET FAULT_RESET_SEL TO COMM...
      LOAD     8
      PSTORE   M_SOU  12   1603
# SET COMM_FAULT_ACTION TO FAULT...
      LOAD     1
      PSTORE   M_SOU  12   3017

# PREP VFD BY STEPPING THROUGH NECESSARY STATES...
      LOAD     0X0080
      PSTORE   M_SOU  12  0
      LOAD     200
```

```
      DELAY_MS
      LOAD     CW_1
      PSTORE   M_SOU  12  0
      LOAD     200
      DELAY_MS
      LOAD     CW_2
      PSTORE   M_SOU  12  0

# RESET FAULT_RESET_SEL TO KEYPAD...
      LOAD     0
      PSTORE   M_SOU  12   1603

# ASSIGN VALUE TO HS2_SSR_USR
      LOAD     HS2_SSR
      PSTORE   HS2_SSR_USR

611   POP


# THIS SHOULD BE RUN IF NETWORKING IS ON,
# IN ORDER TO TURN ON OR OFF VFD2...

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     VFD2_OK_TIMER
      &
      IF_FALSE
      GOTO     612

      LOAD     HS2_SSR
      LOAD     CW_5
      LOAD     CW_EXT2
      +
      LOAD     CW_2
      -
      *
      LOAD     CW_2
      +
      PSTORE   M_SOU  12   0

612   POP



# PUMP 2 IS ON, BUT RTU IS NOT CALLING FOR IT.
# CONFIGURE FOR MANUAL MODE...

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     VFD2_OK_TIMER
      &
      LOAD     HS2_SSR
      !
      &
      IF_FALSE
      GOTO     613
# SET FAULT_RESET_SEL TO KEYPAD...
      LOAD     0
      PSTORE   M_SOU  12   1603
# SET COMM_FAULT_ACTION TO NO_ACTION...
      LOAD     0
      PSTORE   M_SOU  12   3017
613   POP


# VFD2 IS OFF. NEED TO ZERO OUT HS2_SSR_USR...
```

```
# IF HS2_SSR IS OFF, THEN ZERO OUT HS2_SSR_USR

      LOAD     HS2_SSR_USR
      LOAD     HS2_SSR
      &
      PSTORE   HS2_SSR_USR


# P2 FAIL CALC ...

      LOAD     HS2_SSR
      LOAD     HI_SVC_PUMP_2
      XOR
      PSTORE   HS_2_FAIL_TIMER
      LOAD     HS_2_FAIL_TIMER
      STORE    TRY_2_FAIL
      LOAD     HI_SVC_PUMP_2_FAIL
      LOAD     HI_SVC_PUMP_2
      !
      &
      |
      PSTORE   HI_SVC_PUMP_2_FAIL



# VFD SPEED CALCULATION...
#
# Note that when the pumps are to be shut down
#  (p1_final=0 AND p2_final=0), the discharge pressure
#  limit is artificially set to zero.  This ensures that
#  the speed is tapered down to zero before pump shutdown.
#
# Note that the vfd's are configured for a min speed
#  of 20 Hz (33%).  Control logic reflects this, too.

# VIRTUAL READ SPEED...

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     HS1_FB_MODULE
      LOAD     HS2_FB_MODULE
      |
      &
      LOAD     HS1_SPEED_FB
      LOAD     HS2_SPEED_FB
      MAX
      *

      LOAD     HI_SVC_VFD_NETWORKING
      LOAD     HS1_FB_MODULE
      LOAD     HS2_FB_MODULE
      |
      &
      !
      LOAD     HI_SVC_VFD_SPEED_%
      *

      MAX
      PSTORE   VIRTUAL_SPEED_FB


# VFD SPEED CALCULATION...
#
# Note that when the pumps are to be shut down
```

```
#  (p1_final=0 AND p2_final=0), the discharge pressure
#  limit is artificially set to zero.  This ensures that
#  the speed is tapered down to zero before pump shutdown.
#
# Note that when the station is in GST Mode, the
#  suction pressure will be ignored for VFD speed control.
#
      LOAD     HI_SVC_VFD_SPEED_%
      LOAD     HI_SVC_GAIN
      LOAD     HI_SVC_MAXSTEP
      LOAD     0.0
      LOAD     EFFL_PSI
      LOAD     0.0
      LOAD     EFFL_LIMIT_PSI
      LOAD     P1_FINAL
      LOAD     P2_FINAL
      |
      *
      MACRO    FEEDBACK_CONTROL
      LOAD     EFFL_XDUCER_FAIL
      !
      *
      LOAD     HI_SVC_FAILOVER_SPEED_%
      LOAD     EFFL_XDUCER_FAIL
      *
      +
      LOAD     HI_SVC_MINSPEED_%
      MAX
      LOAD     HI_SVC_MAXSPEED_%
      MIN
      LOAD     VIRTUAL_SPEED_FB
      LOAD     HI_SVC_MAXSTEP
      LOAD     4
      *
      +

      MIN
      LOAD     HI_SVC_MINSPEED_%
      MAX
      LOAD     HS1_SSR
      LOAD     HS2_SSR
      |
      *
      PSTORE   HI_SVC_VFD_SPEED_%

      LOAD     HI_SVC_VFD_SPEED_%
      LOAD     100.0
      /
      LOAD     HS1_SSR
      *
      LOAD     HI_SVC_VFD_NETWORKING
      !
      *
      PSTORE   HS1_SPEED_MODULE

      LOAD     HI_SVC_VFD_SPEED_%
      LOAD     100.0
      /
      LOAD     HS2_SSR
      *
      LOAD     HI_SVC_VFD_NETWORKING
      !
      *
      PSTORE   HS2_SPEED_MODULE
```

```
      LOAD     HS1_SSR
      LOAD     HI_SVC_VFD_NETWORKING
      &
      IF_FALSE
      GOTO     305
      LOAD     HS1_SSR
      LOAD     HI_SVC_VFD_SPEED_%
      *
      LOAD     100
      *
      PSTORE   M_SOU  11   2
305   POP

      LOAD     HS1_SSR
      LOAD     HI_SVC_VFD_NETWORKING
      !
      &
      IF_FALSE
      GOTO     306
      LOAD     CW_EXT1
      PSTORE   M_SOU  11   0
306   POP

      LOAD     HS2_SSR
      LOAD     HI_SVC_VFD_NETWORKING
      &
      IF_FALSE
      GOTO     307
      LOAD     HS2_SSR
      LOAD     HI_SVC_VFD_SPEED_%
      *
      LOAD     100
      *
      PSTORE   M_SOU  12   2
307   POP

      LOAD     HS2_SSR
      LOAD     HI_SVC_VFD_NETWORKING
      !
      &
      IF_FALSE
      GOTO     308
      LOAD     CW_EXT1
      PSTORE   M_SOU  12   0
308   POP


# XFER PUMP-1 RUNTIME ...
# (WILL ROLLOVER AFTER ~20 YEARS OF RUNTIME)

      LOAD     XFER_PUMP_1
      LOAD     DELTA_TIME
      *
      LOAD     XP1_RUNTIME_SECS
      +
      ABS
      LOAD     600000000.0
      %
      STORE    XP1_RUNTIME_SECS
      LOAD     60.0
      /
```

```
      PSTORE   XFER_PUMP_1_RUNTIME_MIN


# XFER PUMP-2 RUNTIME ...
# (WILL ROLLOVER AFTER ~20 YEARS OF RUNTIME)

      LOAD     XFER_PUMP_2
      LOAD     DELTA_TIME
      *
      LOAD     XP2_RUNTIME_SECS
      +
      ABS
      LOAD     600000000.0
      %
      STORE    XP2_RUNTIME_SECS
      LOAD     60.0
      /
      PSTORE   XFER_PUMP_2_RUNTIME_MIN


# PUMP-1 RUNTIME ...
# (WILL ROLLOVER AFTER ~20 YEARS OF RUNTIME)

      LOAD     HI_SVC_PUMP_1
      LOAD     DELTA_TIME
      *
      LOAD     HS1_RUNTIME_SECS
      +
      ABS
      LOAD     600000000.0
      %
      STORE    HS1_RUNTIME_SECS
      LOAD     60.0
      /
      PSTORE   HI_SVC_1_RUNTIME_MIN


# PUMP-2 RUNTIME ...
# (WILL ROLLOVER AFTER ~20 YEARS OF RUNTIME)

      LOAD     HI_SVC_PUMP_2
      LOAD     DELTA_TIME
      *
      LOAD     HS2_RUNTIME_SECS
      +
      ABS
      LOAD     600000000.0
      %
      STORE    HS2_RUNTIME_SECS
      LOAD     60.0
      /
      PSTORE   HI_SVC_2_RUNTIME_MIN


# IF THE LEAD PUMP FAILS, THE LEAD HAS RUN FOR 12 HOURS,
# OR PUMP-A JUST TURNED OFF, INCREMENT ALTERNATOR ...

      LOAD     LEAD_TIMER
      LOAD     12
      Y>X?

      LOAD     LEAD_PUMP_DEF
      LOAD     1
      X=Y?
```

```
      LOAD     TRY_1_FAIL
      LOAD     HI_SVC_1{AUTO-ON-OFF}
      LOAD     3.0
      X=Y?
      |
      &

      LOAD     LEAD_PUMP_DEF
      LOAD     2
      X=Y?
      LOAD     TRY_2_FAIL
      LOAD     HI_SVC_2{AUTO-ON-OFF}
      LOAD     3.0
      X=Y?
      |
      &

      |


# FORCE ONLY ONE ALTERNATION ON PUMP FAIL...

      COPY
      LOAD     LEAD_STATE
      &
      PSTORE   PUMP_FAIL_NOW_USR


      LOAD     LEAD_STATE
      &
      LOAD     LEAD_TURNING_OFF
      |
      |
      LOAD     ALTERNATE_HI_SVC
      &
      IF_FALSE
      GOTO     110
      LOAD     SEQUENCE_POINTER_1
      LOAD     2.0
      %
      ++
      PSTORE   SEQUENCE_POINTER_1

      LOAD     0.0
      PSTORE   LEAD_TIMER

      GOSUB    MY_HS_SEQUENCE_SETUP
      LOAD     LEAD_PUMP_DEF
      PSTORE   LEAD_HI_SVC_PUMP

110   POP


# INCREMENT LEAD TIMER ...

      LOAD     LEAD_STATE
      IF_FALSE
      GOTO     555
      LOAD     LEAD_TIMER
      LOAD     DELTA_TIME
      LOAD     3600
      /
      +
      PSTORE   LEAD_TIMER
```

```
555   POP

# FORCE ONLY ONE PUMP ALTERNATION UPON PUMP FAIL...

      LOAD     LEAD_STATE
      LOAD     PUMP_FAIL_NOW_USR
      !
      &
      PSTORE   LEAD_STATE


      END




      LBL      SANITY_CHECKS

      LOAD     2.0
      LOAD     1.0
      LOAD     SEQUENCE_POINTER_1
      MAX
      MIN
      PSTORE   SEQUENCE_POINTER_1

      LOAD     2.0
      LOAD     1.0
      LOAD     LEAD_HI_SVC{P1-P2}
      MAX
      MIN
      PSTORE   LEAD_HI_SVC{P1-P2}

      LOAD     2.0
      LOAD     1.0
      LOAD     LAG_HI_SVC{P1-P2}
      MAX
      MIN
      PSTORE   LAG_HI_SVC{P1-P2}

      LOAD     2.0
      LOAD     1.0
      LOAD     CALL_INTAKE_1{OFF-ON}
      MAX
      MIN
      PSTORE   CALL_INTAKE_1{OFF-ON}

      LOAD     2.0
      LOAD     1.0
      LOAD     CALL_INTAKE_2{OFF-ON}
      MAX
      MIN
      PSTORE   CALL_INTAKE_2{OFF-ON}

      LOAD     3.0
      LOAD     1.0
      LOAD     HI_SVC_1{AUTO-ON-OFF}
      MAX
      MIN
      PSTORE   HI_SVC_1{AUTO-ON-OFF}

      LOAD     3.0
```

```
      LOAD     1.0
      LOAD     HI_SVC_2{AUTO-ON-OFF}
      MAX
      MIN
      PSTORE   HI_SVC_2{AUTO-ON-OFF}

      LOAD     3
      LOAD     1
      LOAD     HI_SVC_MODE{RADIO-PRESS-TIMER}
      MAX
      MIN
      PSTORE   HI_SVC_MODE{RADIO-PRESS-TIMER}

      LOAD     3
      LOAD     1
      LOAD     HI_SVC_FAILOVER{PRESS-TIMER}
      MAX
      MIN
      PSTORE   HI_SVC_FAILOVER{PRESS-TIMER}

      RTN

# ========================================

      LBL      MY_HS_SEQUENCE_SETUP

      LOADA    ALTERNATE_HI_SVC
      LOADA    SEQUENCE_POINTER_1
      LOADA    LEAD_HI_SVC{P1-P2}
      LOADA    LAG_HI_SVC{P1-P2}
      LOADA    LEAD_PUMP_DEF
      LOADA    LAG_PUMP_DEF
      MACRO    PUMP_SEQUENCE_SETUP2
      RTN

# ========================================
```