Hillsborough County Maintenance Shop Submersible Pump Motor Testing Improvements

Richard D. Taylor and Daniel Hammon

Hillsborough County's Brandon Support Operations Complex (BSOC) pump shop is responsible for maintenance and testing of all the county's submersible pumps utilized within its vast wastewater collection system of almost 800 sites (totaling over 1600 individual submersible pump motors) distributed throughout the area.

All submersible pump motors are electrically tested in the BSOC prior to field installation or upon return to the shop after refurbishment or repair by the pump manufacturer. Pump shop motor testing consists of an array of 14 (unpowered motor) electrical tests using conventional handheld electrical test meters, and an additional electrical motor test that requires physically powering each pump motor at its particular operating voltage of alternating current (VAC). All of the pump motor information (including pump shop testing results) is logged and the pump history is tracked in the county's computer automated maintenance system (CAMS) database and reporting system.

The county's motor shop, in testing platform electrical motor equipment, had reached its end of life and the county desired to make equipment improvements to the motor testing platform, along with improvements in testing procedure efficiency and data collection.

The large quantity (over 1000) of pump motors maintained by the county's shop and the wide varieties of pump motors (motor horsepower [hp] varying from 3 to 200 hp, and motor three-phase operation ranging from 230 to 460 VAC) processed through it on a daily basis required a flexible testing platform that could readily be reconfigured for the specific requirements of each pump motor test.

The criteria for pump motor test platform improvements included:

Figure 1. Pump Motor Test Panel

Figure 2. Motor Starter

Figure 3. Power Cable Receptacles

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1. Simplification of the electrical equipment required for powered motor testing.
2. Simplification and improvements to testing procedures where possible.
3. Implementation of as much automation within the testing platform that could be reasonably accomplished to improve testing efficiency, while providing consistent and repeatable testing results.
4. Optimization of the user interface(s) to the CAMS database to improve testing workflow, eliminating duplicative and unnecessary data entry procedures.
5. Utilize as many of the electrical equipment and automation products the county already used within its wastewater collection system to minimize additional maintenance and support requirements for the test platform.

This article details the chronology of the design, construction, and commissioning efforts, culminating with the successful implementation of the county's and the design engineer's vision of a modern, flexible, user-friendly, automated motor testing platform. The article also highlights the collaborative thought processes and solutions to problems, combining the efforts of engineering, equipment vendors, and county maintenance and management, resulting in a practical design that meets the criteria established for the project by the county and the design engineer.

Background

All county pumps are physical assets listed and tracked within the CAMS database and reporting system. Each maintenance shop work order for a particular pump motor requires the equipment item to have been previously entered as an asset in the CAMS system. Work orders are created within the system to log each maintenance activity performed on the assets and are logged into the database used for tracking them from first to final use.

The 17 database parameters and attributes of a particular pump motor and any CAMS work order are listed in Table 1.

Specific electrical information as to motor hp, motor operating VAC, and motor full-load amps (FLAs) determines the configuration of the test stand required to safely energize the motor for an operational test, whether the motor is run "under load" or testing is performed under "no load."

A list of the 14 maintenance technicians' individual static nonenergized motor tests associated with a pump motor work order is shown in Table 2.

The remaining "unloaded motor run" tests require a maintenance technician to energize the pump motor at the operating voltage and take amperage measurements on each motor phase lead. They are shown in Table 3.

The majority of the data (18 of 21 data points) are manually collected, and data entry into the CAMS database is done by the maintenance technician performing the work order tests. The remaining three test data points (motor running amps on each phase of a three-phase pump motor) require the pump motor test panel.

"Necessity is the Mother of Invention"

The county's existing pump motor test panel (Figure 1) consisted of a three-phase 480 VAC supply, 480/240 VAC three-phase step-down transformer, reduced voltage solid-state (RVSS) motor starter, control panel containing a size-2 full-voltage nonreversing (FVNR) motor starter (Figure 2), and two power cable receptacles (Figure 3), all wall-mounted in the shop.

Greg Currington, the county's maintenance manager, indicated that the motor shop test unit was initially assembled from miscellaneous parts by county technicians. The pump motor test stand was relocated and re-assembled during a previous maintenance facility move prior to the relocation to the county's North Falkenburg Road complex in Tampa.

Testing Procedure

The motor no-load amps testing procedure consisted of the following steps:

1. Control panel selection of voltage (230 and 460 VAC) to match motor to be tested

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Table 1. Pump Motor Parameters and Attributes

No.	Field Name	Description	Notes
1	Work Order No.	Motor Test Work Order No.	Work Order
2	Date Received	Date Work Order Entered	Work Order
3	Station No.	Pump Station ID No.	Work Order
4	Area Location	Pump Station Area Location	Work Order
5	Station Location	Pump Station Address/Physical Location	Work Order
6	Priority	Testing Priority	Work Order
7	Asset No.	Capital Asset ID No.	Work Order
8	Make	Manufacturer of Pump Motor	Motor Info
9	Model No.	Mfg. Model (Pump Motor)	Motor Info
10	Serial No.	Mfg. Model S/N (Pump Motor)	Motor Info
11	HP	Horsepower of Pump Motor	Motor Info
12	Voltage	Station Voltage	Motor Info
13	Phase	Motor Electric Phase (Single/Three)	Motor Info
14	RPM	Motor Operating RPM at Full Speed, 60 Hz	Motor Info
15	Amp Rating	Motor Full-Load Amps (FLA) at Speed and 60 Hz	Motor Info
16	Motor Voltage	Motor Operating Voltage	Motor Info
17	Motor Frame Size	Motor Frame Size	Motor Info

Table 2. Pump Motor Work Orders

No.	Field Name	Description
18	Insulation MΩ Test Voltage Set at 250VDC	MΩ meter Set at 250VDC (Y/N)
19	Insulation MΩ Test Voltage Set at 500VDC	MΩ meter Set at 500VDC (Y/N)
20	3Φ Insulation MΩ Reading (T1-T2 at Stator)	Motor Winding (T1-T2 Leads) MΩ Test Results Performed at Motor Stator
21	3Φ Insulation MΩ Reading (T1-T3 at Stator)	Motor Winding (T1-T3 Leads) MΩ Test Results Performed at Motor Stator
22	3Φ Insulation MΩ Reading (T2-T3 at Stator)	Motor Winding (T2-T3 Leads) MΩ Test Results Performed at Motor Stator
23	3Φ Insulation MΩ Reading (T1-T2 at Cord End)	Motor Winding (T1-T2 Leads) MΩ Test Results Performed at End of Motor Umbilical
24	3Φ Insulation MΩ Reading (T1-T3 at Cord End)	Motor Winding (T1-T3 Leads) MΩ Test Results Performed at End of Motor Umbilical
25	3Φ Insulation MΩ Reading (T2-T3 at Cord End)	Motor Winding (T2-T3 Leads) MΩ Test Results Performed at End of Motor Umbilical
26	Moisture Sensor Ohm Reading at Stator	Motor Moisture Sensor Resistance Ω Test Results Performed at Motor Stator
27	Moisture Sensor Ohm Reading at Cord End)	Motor Moisture Sensor Resistance Ω Test Results Performed at End of Motor Umbilical
28	Thermal/Heat Sensor Ohm Reading at Stator	Motor Thermal/Heat Sensor Resistance Ω Test Results Performed at Motor Stator
29	Thermal/Heat Sensor Ohm Reading at Cord End	Motor Thermal/Heat Sensor Resistance Ω Test Results Performed at End of Motor Umbilical
30	Thermal to Ground at Stator	Motor Thermal/Heat Sensor Resistance (to Ground) Ω Test Results Performed at Motor Stator
31	Thermal to Ground at End of Cord	Motor Thermal/Heat Sensor Resistance (to Ground) Ω Test Results Performed at End of Motor Umbilical

Table 3. Unloaded Motor Run Tests

No.	Field Name	Description
32	Tested By	Testing Personnel ID / Name
33	Test Notes	Pump Motor Test Operator Notes
34	Motor Three Phase Dry Amps - (Phase A)	Motor Dry Run Three Phase Amps - Phase A
35	Motor Three Phase Dry Amps - (Phase B)	Motor Dry Run Three Phase Amps - Phase B
36	Motor Three Phase Dry Amps - (Phase C)	Motor Dry Run Three Phase Amps - Phase C
37	Date Test Completed	Motor Test Completed (Date)
38	Test Completed TOD	Test Results Completed (Time of Day)

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2. Technician connects the umbilical cable alligator clip leads to the motor leads
3. Technician plugs the umbilical cable into the appropriate receptacle (230 and 460 VAC)
4. Technician "start" of the motor amps test using the control panel pushbuttons
5. Manual use of a clamp-on ammeter to read motor amperes in each motor lead
5. Log the motor amperes data onto motor test worksheet
6. Technician "stop" of the motor amps test using the control panel pushbuttons

Several deficiencies and potential safety issues within the existing motor test system included the following:

1. There was human error in the incorrect selection of voltage in test panels matching the connected motor.
2. There was no automatic test "start," "run," or "stop" period (limiting maximum time motor was operated).
3. No automatic collection or averaging of motor amp data was done. Manual collection of motor amps for each motor lead was required in all tests.
4. There was limited overload protection in the test panel, given the wide range of motor sizes tested.
5. The motor test panel was not designed for use with motors "under load."
6. The soft-starting RVSS was used only on larger motors; FVNR motor starting was used for smaller motors.

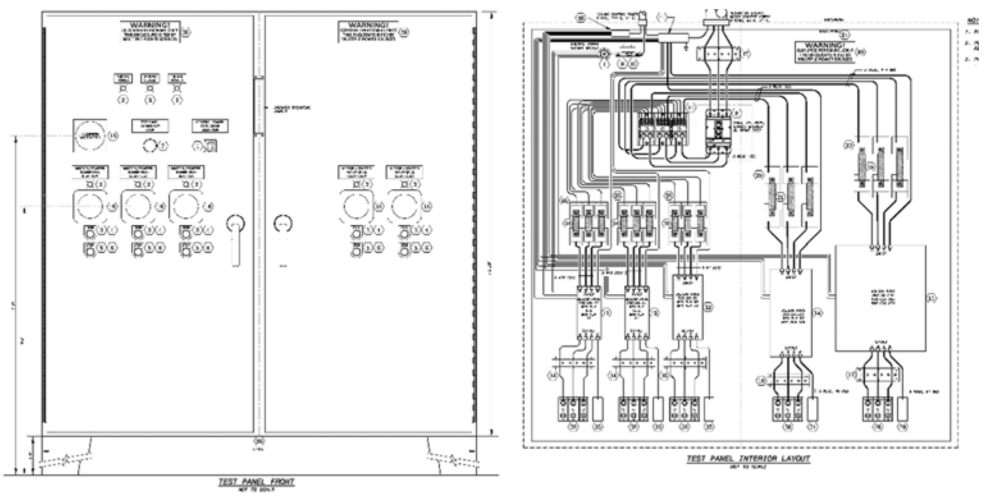

Figure 4. Preliminary Design, New Motor Test Stand Drawing, Panel Arrangement

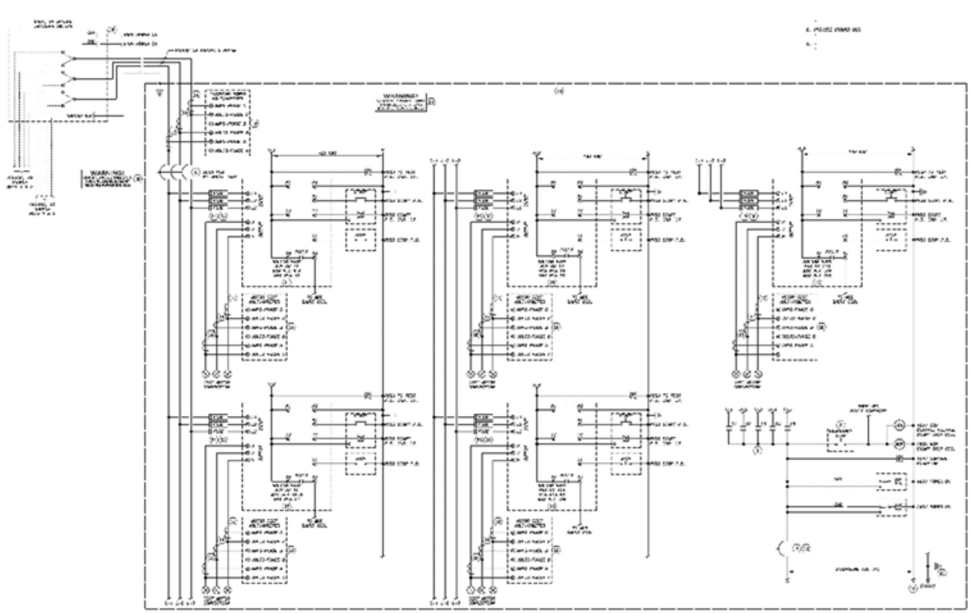

Figure 5. Preliminary Design, New Motor Test Stand, Panel Wiring Schematics

The Same Game With Different Players

The county requested that Black & Veatch design a replacement pump motor test panel to be located in the BSOC.

Black & Veatch's review of the motor hp ranges (3 to 200), coupled with the need for two different three-phase operating voltages (230 and 460 VAC), indicated that five different sizes of RVSS motor starters would be required to provide the proper electrical protection for any motor operating at full voltage and motor FLAs. The RVSS manufacturer (Solcon), used by the county in the existing pump motor test panel and within larger hp fixed-speed pump station applications, is represented by ICON Technologies, a local Tampa area firm. Black & Veatch contacted ICON and was provided with technical data for the different models of RVSS starters required for the application. The RVSS starters were capable of operation at either 230 or 460 VAC (three-phase, 60 hertz [Hz]) and are rated by maximum ampere capacity.

The unit selections covered the county's range of motor hp and amperes at 230 and 460 VAC operation:

- Unit 1 - 8.5 to 17 amps
- Unit 2 - 15.5 to 31 amps
- Unit 3 - 36 to 72 amps
- Unit 4 - 52 to 105 amps
- Unit 5 - 105 to 210 amps

Motor operation at two voltages (230 and 460 VAC) also required the continued use of a three-phase step-down transformer (480 or 240 VAC), commercially available and adequately sized, for the 210 amps at 240 VAC (112.5 kilovolt-amp [KVA]) capacity, and a voltage transfer switch to select either the 480 VAC or the 240 VAC three-phase supply.

One additional criterion, which is the potential for future use of the pump motor test stand in "under load" tests (operating a pump in a flow test stand, confirming motor efficiencies, etc.), provided the basis for the preliminary design of the pump motor test stand.

Black & Veatch developed preliminary design drawings using a free-standing two-door panel, essentially duplicating the original manually operated test panel design (Figures 4 and 5).

A New Way for a New Day

A radical idea was presented by ICON to Black & Veatch during discussions regarding the test panel design using the RVSS starters: *Why not consider an adjustable frequency drive (AFD) is lieu of an RVSS?*

Use of an AFD could potentially simplify the

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pump motor test panel design, given the ability of an AFD to "recreate" either the 460 VAC at 60 Hz, or 230 VAC at 60 Hz, voltages required for a particular motor test, even though the AFD was constantly powered from a 480 VAC three-phase source. Both Solcon's RVSS and Yaskawa Electric Corporation's AFDs were supported by ICON, which has had a long-term relationship with the county, and it selected the Yaskawa product line for the AFD-based pumping applications.

Black & Veatch presented ICON's proposed alternative to the county during a design review meeting, outlining both the benefits and issues to be addressed if this alternative were to be considered.

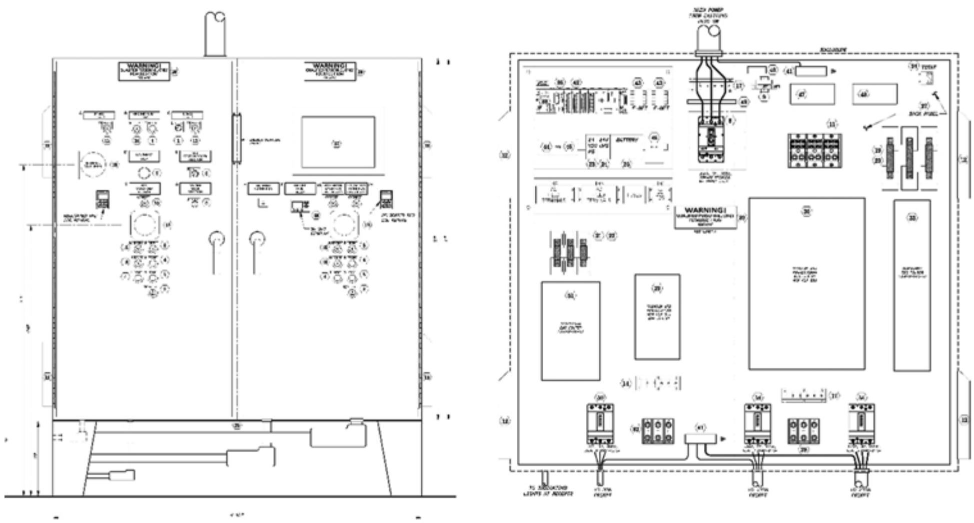

Figure 6. Final Design, New Motor Test Stand Drawing (Panel Arrangement)

Benefits

1. Simplification of electrical equipment required for powered motor testing
   a. Elimination of the manual transfer switch and 480 VAC/240 VAC transformer
   b. Fewer components (i.e., motor starters) within test panel
2. Implementation of testing automation
   a. Software-controlled test procedures automatically collects motor test data
      i. Minimizing human error
      ii. Automation would create consistent test procedures and repeatable results
3. Potential to interface to CAMS database
   a. Improvements to pump motor test workflow and procedures
   b. Elimination of duplicative and unnecessary data entry procedures
4. Utilization of electrical equipment and automation products the county already used within its wastewater collection system
   a. Yaskawa AFD
   b. Schneider Electric (Modicon) programmable logic controller (PLC) for AFD-based configuration and test

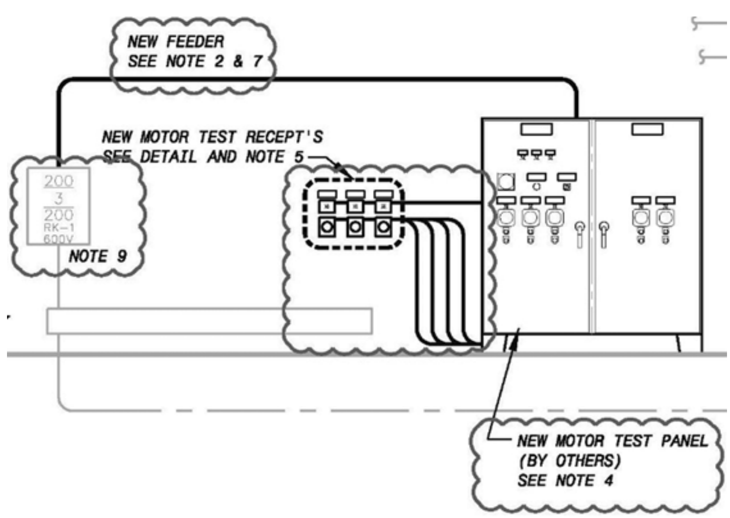

Figure 7. Updated Motor Test Stand Drawing, Field Wiring Connections and Layout

Issues

1. More-involved technical design
   a. Additional software and hardware specifications development
   b. Development of new operator interface
2. Software design of testing logic
   a. Higher technical complexity
      i. PLC to AFD communications required for AFD "test to test" reconfiguration
      ii. PLC to power metering for amperage data collection
3. Defining interface between test panel and CAMS
   a. Defining data interface between pump motor test system and CAMS computer
   b. County information technology group "buy-in" to "foreign system" interface

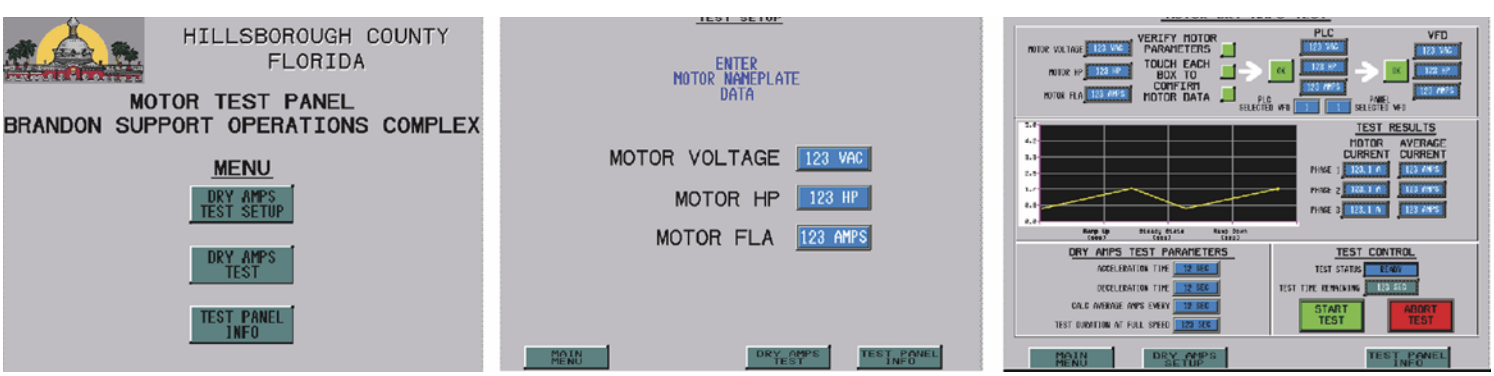

Figure 8. New Motor Shop Test Panel, Operator Interface Displays

4. Rigorous system factory acceptance testing (FAT) prior to deployment
5. Complexity of integration of test panel with CAMS
6. More-expensive design and construction

The county personnel and management were very receptive to the concept of providing the replacement test panel with the automation required for both physical pump motor testing and the potential to improve efficiency through system integration of the pump motor panel with the CAMS system. Black & Veatch developed an updated test panel design and concept for the system integration with connections to CAMS.

An evaluation of the pump motor ampere ranges indicated that only two AFDs would be required for control of all variants of the three-phase pump motors tested at the BSOC. The AFD-rated 3.1 to 31 amps would be used for the lower hp range of pump motors, while the AFD-rated 21 to 208 amps would be selected for testing the larger hp range of the county's pump motors.

The panel was designed using a "belt and suspenders" philosophy. Normal testing would be performed using PLC and an operator interface terminal (OIT), with complete automation of the testing setup. A failure of the PLC (or PLC and OIT) did not render the test panel inoperative, as an operator could select the appropriate AFD, configure it from the AFD keypad, and start/stop motor testing from the panel front-mounted selector switches and pushbuttons.

Collection and local display of pump motor amperes utilized physical current transformers (CTs) connected to the Shark multifunction meters. In a semi-automatic test scenario, the testing operator could take readings from the panel front-mounted meters, eliminating any use requirements for a clamp-on ammeter.

Three different-sized industrial welding receptacles (30, 100, and 200 amp), each connected to an equivalent amp-rated flexible "umbilical" for connection to the pump motor leads, covered the wide range of motor amp loads. The 30-amp-rated receptacle was dedicated to the small (amp-rated at 3.1 to 31) AFD. The remaining higher-ampere capacity welding receptacles (100 and 200 amp) were connected to the larger AFD.

The PLC would select which AFD was suitable for the particular motor test, configure it for the motor operating voltage and motor full load amp values, and operator feedback (OIT confirmation of motor parameters coupled with operator physical selection of the correct AFD

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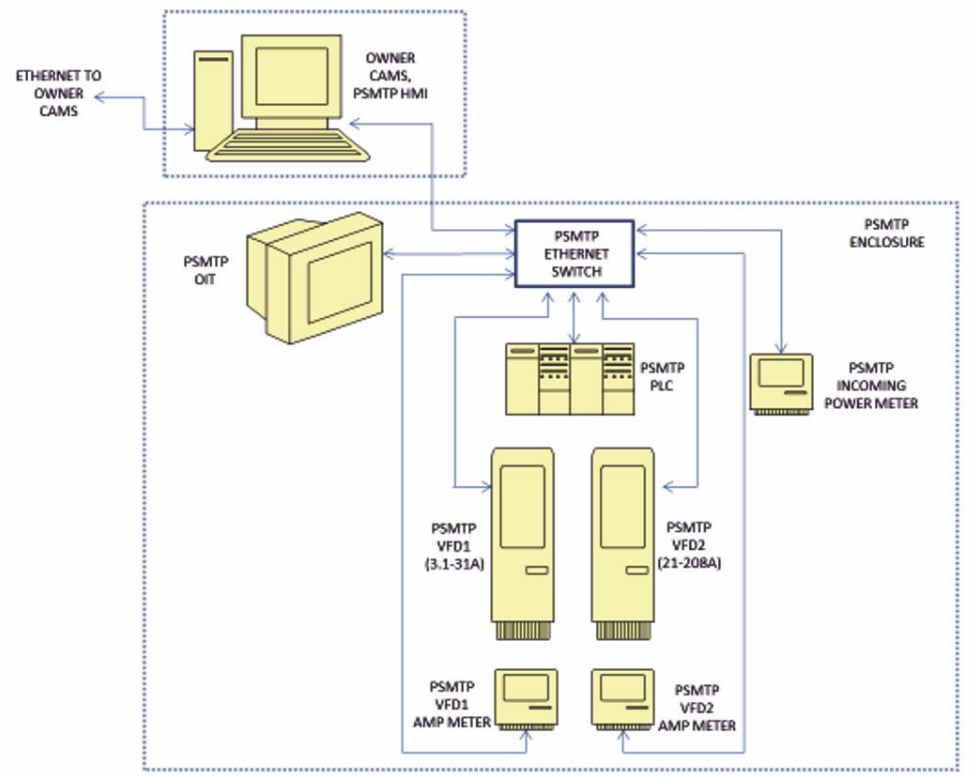

Figure 9. Preliminary Design, Motor Test Panel, CAMS, Panel Network Block Diagram

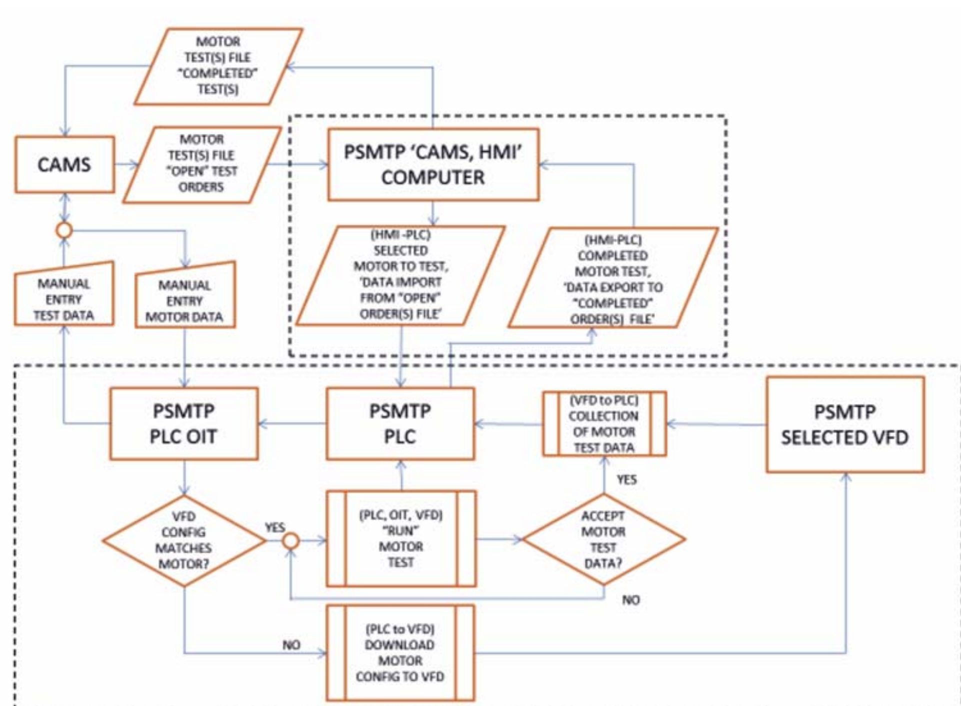

Figure 10. Preliminary Design, CAMS, Testing Operator Workflow Diagram

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test range using the panel front-mounted selector switch) would be required to confirm that the AFD and load receptacle/umbilical selection was correct for the particular pump motor test. The PLC calculated several internal AFD parameters based on motor data required for proper operation of the AFD for each motor. In the absence of the PLC, an operator would have to manually configure multiple AFD parameters for the proper operation-matching of each motor to be tested.

A PLC connected to an OIT would communicate via Ethernet to two Yaskawa AFDs and to the panel-mounted Electro-Industries Shark multifunction energy/power meters.

Safety was the highest priority in the design of all aspects of the panel hardware and software control strategy. The goal was to minimize the likelihood of AFD misconfiguration that could damage a motor and eliminate the possibility of an operator mistakenly using the lower amp-rated umbilical cable connected to the higher amp-rated AFD through use of different-sized receptacles, with only one possible "live" electrical umbilical connection possible at any time.

A priority in the design of the operator interface was to minimize the number of steps required to perform a given test, while requiring the operator to confirm each variable (motor voltage, motor full-load amps, and motor hp) before each test would proceed, given that the PLC was responsible for dynamically configuring the selected AFD for a given motor test.

Significant effort was made to fine-tune and optimize the operator interface for both safety and testing efficiency. Black & Veatch worked closely with the county's maintenance personnel and ICON to develop a bid specification that clearly defined the requirements for the PLC software control strategy and the layout of the OIT to focus on safety, simplicity, and efficiency.

In particular, the PLC performed several checks against misconfiguration, including:

1. Calculating the reasonable values for motor parameters (voltage, hp, and FLA).
2. Pushbuttons that require confirmation of each parameter (against the motor nameplate).
3. Pushbuttons to enable PLC transfer of calculated AFD configuration data to the AFD. With visual feedback (red to green), the AFD data matched the PLC.
4. Confirm that the panel selection switch matched the PLC-selected AFD and high/low range.

Once confirmed, the operator started the test and awaited the results. A real-time trend of motor amp data during each test provided feedback for tracking any observed anomalies. A test could be repeated multiple times by the operator following the identical configuration steps.

Simplify, Simplify: Application of the KISS (Keep It Simple Stupid) Principle

The initial design concept was for the new pump motor test panel to seamlessly integrate with the CAMS system (essentially eliminating paper and providing a one-operator interface for the testing of pump motors); however, the logistics of transferring transactional records data back and forth between two systems (a real-time control system optimized for operations and an accounting-type relational database system designed for recordkeeping transactions) imposed enormous additional software procedures, testing, and ultimately, costs, to reliably replicate the CAMS interface on the pump motor test panel.

During a design review meeting between the county and Black & Veatch, it become apparent that replicating the CAMS system on an independent real-time system was not going to be cost-effective. It was estimated that the cost of integrating the pump motor test panel directly into CAMS (including with the required certification testing) would potentially be double the projected cost of the test panel hardware, including associated PLC and OIT software integration required for the actual motor testing.

On closer inspection, it was determined that the three data points generated from the test panel system could easily be imputed manually by a technician into a mobile laptop connected to the county's internal data network via the BSOC WiFi network. The entire test procedure would become paperless, eliminate duplication of data entry, and offer the efficiency improvements the county desired, as well as the safety improvements provided with the new automated testing system.

After the design was contracted and approved for construction, the goal was to work closely with the panel shop/systems integrator to verify that the design was followed and to rigorously test the system before installation at the BSOC. The test panel was assembled and integrated by Economy Control Systems in its Jacksonville facility. Black & Veatch conducted a factory acceptance test prior to approving shipment of the test panel to Tampa for installation by an electrical contractor.

The installed pump motor test panel installation provides the county with a safe and efficient motor testing platform that met its initial criteria and has the capabilities to be utilized for (future) full-load motor tests.

The test panel project provided the county with the opportunity to re-evaluate its existing shop test procedures and optimize the system for both improving the workflow and the time required to enter, log, and track pump motor tests within the CAMS database.

This project illustrates the success that flows from continuous cooperation among the designer, owner, and system integrators during the planning, design, testing, and implementation stages.

Figure 11. New Pump Motor Test Stand, Final Installation