Production Battery Control System Rebuild Using a Small PLC

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Introduction

The H. T. Boyd production battery located 45 miles north of Denver City, Texas was originally built in 1958. Today, the battery serves 68 wells and handles 9600 barrels of fluid per day. The original control system consisted of relay panels dedicated to individual pieces of equipment or processes, i.e. each of the engine-driven pumps had a dedicated control panel. Over time, as the production of the field changed and equipment was replaced or added, the control system became difficult to operate, maintain, and modify. In 1989, the existing control system was revamped through the installation of a small PLC (Programmable Logic Controller). The benefits of this project were increased operator information, improved control system reliability and enhanced facility throughput. Also, the new controls reduced nuisance alarms, repair time, and the possibility of spills.

At the start of this project, the battery consisted of four storage tanks, three engine-driven main pumps, a charge pump, skim tank pump, and lact unit. During this project, a fourth main pump, electric motor driven, was added. A schematic of the facility is shown in Figure 1.

Initial Configuration

The main pumps were instrumented for the following alarms and shutdowns:

1) High pump discharge pressure
2) Low pump discharge pressure
3) Low engine lubricant level
4) Low pump lubricant level
5) Engine overspeed
6) High engine coolant temperature

Individual motor instruments were switch-gauge style units with oil-immersed contacts. The alarm/shutdown circuits were electrically normally open with the contacts closing on an alarm or shutdown condition. This circuit arrangement is often used due to the belief that it produces fewer nuisance alarms. The prime shortcoming of this contact arrangement is the lack of a self-check of the circuit integrity between the end device and the controller. The preferable arrangement is for the contacts to be closed on normal process values. Then, when the process reaches an alarm value, the contacts open to alarm or shutdown the equipment. Likewise, any failure that interrupts the control circuit causes the control system to operate, resulting in operator intervention. In contrast, systems with the contacts open on normal conditions can suffer unintentional circuit breaks, such as accidental excavations or loose terminations, without any direct indication of a problem.

Each pump's control panel was located immediately adjacent to its respective unit in the pump building. This exposed the controls to high levels of vibration, and possible flooding of the control boxes in the event of a leak.

Tanks and Controls

The four tanks at the battery were two produced water tanks, one fresh water tank, and one skim tank. Level instruments on the produced water tanks are switches with local indication. The produced water tank serving as the pump supply was set up with low alarm and low shutdown setpoints. The skim tank and fresh water tank each had high level setpoints.

Functional Requirements

The new control system was required to perform the engine and pump protection functions listed above as well as incorporate several new functions. To avoid adding additional tankage, more importance was assigned to uninterrupted operation of the gas engine powered pumps. Nuisance alarms and call-outs were to be minimized. The control system should be easy to understand and operate to maximize operator acceptance. The following items were the result of these desires:

1) Engines were to shutdown sequentially on high discharge pressure.
2) All engines were to shutdown immediately on low discharge pressure.
3) Charge pump to shutdown when all main pumps are down.
4) Start electric drive pump when any other main pump shuts down unless the shutdown was for high or low discharge pressure.
5) Activate radio alarm when all main pumps shutdown and on high tank level.
6) Consolidate the individual pump control panels into a single panel.
7) Consolidate the pump and battery alarms into a single panel.

Installation

Hardware

Standard construction methods were used for wiring between the end devices and the controller. Rigid metal conduit was used for all runs except where limited flexibility was needed. For example, the main instrument wiring runs were installed in rigid conduit and the individual drops to the engine were flexible conduit.

A single NEMA 4 (watertight, dust-tight, sleet resistant indoor and outdoor) box was used to house the PLC system and the status display, consisting of a General Electric Series One Plus controller with 1724 words of memory, base I/O (Input/Output) rack and two expansion I/,O racks with a total of 6-8 channel digital input modules, 7-8 channel digital output modules, and two spare slots.

To the greatest extent possible, the physical wiring of the inputs and outputs for a single device, such as main pump 2, were consolidated into one input or output module as required. This approach allowed the person troubleshooting the unit to concentrate on a single group of wires or single module.

Instead of a series of individual lamps to indicate equipment and alarm status, a lightbox annunciator was used. No onboard logic was purchased with the lightbox. Portions of the PLC program were dedicated to "first out", lamp test, and other functions. Approximately 30% of the memory and 70% of the output channels were dedicated to driving the annunciator.

Pump operating modes for the engine driven units were selected by standard two position (Run-Stop) selector switches. The single electric drive unit's operation was determined by a three position (Hand-Off-Auto) selector switch. Reset, alarm acknowledge, emergency stop, and lamp test pushbuttons were normally open, momentary contact units. Since the control panel was mounted outdoors all the components exposed to the weather were selected to be industrial heavy duty, weatherproof items.

Software

The program for controlling the equipment, local alarm panel, and remote alarm was developed on the General Electric Portable Programming Unit, the midpoint programming device for the GE Series One PLC. The other programming devices available were the Handheld Programmer and the GE computer based programmer. The Portable incorporates a liquid crystal display capable of displaying multiple rungs of ladder logic while indicating the realtime status of the rung components such as input contacts and output relays. The Portable can also drive a printer directly, allowing for the rapid creation of hardcopy documentation.

Once the logic was developed for the first engine, the second and third units' logic only required substituting the appropriate I/O reference numbers. Unfortunately, the Portable Programming unit did not allow for copying lines of ladder logic, so each module, although essentially identical, had to be individually keyed in. As in the hardware installation, logic modules were written for each pump as a self-contained package to minimize hunting through widely separated areas of the program while troubleshooting.

Although a programming and documentation package was available for use on a personal computer, annotation and operational notes were handwritten. The GE software was originally written for a dedicated programming unit and was extremely frustrating to try and operate on a standard personal computer. Since this project, General Electric has revised their software making it easier to use on a personal computer. Also, its capabilities were made comparable to the programming and documentation packages available from other PLC vendors and third party companies.

Other documentation, such as input/output listings, internal coil (relay) and retentive relay records, and timer/counter tables, were all prepared on a personal computer using a form generation program available at the time. For examples of these forms, please see Figures 2 through 5.

The program itself was relatively simple. The control schemes were all simple on or off logical decisions. No math or analog values were handled in this application although the PLC used does have those capabilities.

The "first out" alarm capability, as illustrated in Fig. 6, was a requirement from the operations department to expedite troubleshooting. Each alarm input was placed into a latching circuit, i.e. a circuit designed to stay "on" once it is turned on even though the alarm signal might clear by itself. The latch circuit consists of a set of contacts which parallel or bypass the alarm contacts and which are linked to the output contacts. Once the output contacts close, the bypass contacts also close and maintain a complete circuit regardless of the state of the alarm.

To finish the "first out" logic contacts linked to the other alarm/shutdown, outputs for the particular unit are added to the right of the latch. These contacts are normally closed so that when the first alarm is received, the circuit is unbroken and the latch is activated. Now, the next lines or rungs of logic contain contacts linked to the energized output contact but which are normally closed. When a signal does go into alarm, though, these normally closed contacts switch open. The open contact prevents these circuits from being completed. Thus, any alarms coming in after the initial alarm cannot be recognized or registered by the program. Pushing the reset button interrupts the "latch" and clears the alarm logic.

Sequencing the pumps off on a high pressure alarm required the use of the PLC's internal timers and counters. Because three of the four main pumps required a manual restart, minimizing the number of pumps shut down on a short term upset, would in turn, minimize the number of operator call-outs while maximizing production.

The pump sequencer used one self-resetting timer with a five-minute preset and one counter. Once the high pressure signal was detected, main pump 1 was shut down and the five-minute time delay started. If the high pressure condition persisted long enough to cause the timer to expire, a logic (internal to the PLC only) signal incremented the counter. Each time the counter incremented, a logic contact operated, triggering a physical output, which shut down the next engine in sequence. If the high pressure condition corrected itself, the timer and counter logic was disabled with only the minimum number of pumps off-line.

Start Up Corrections

Two minor bugs were discovered when the control system was commissioned. The first was in the LACT unit alarm wired directly into the PLC program which detected and reported on all bad oil signals, no matter how short in duration. A number of nuisance alarms were generated by this bug. Installing an on-delay timer programmed for a short delay prevented small slugs of BS&W from being reported. If the alarm signal persisted until the timer finished its cycle, the alarm was judged to be "real" and reported via the radio alarm system as well as diverting the oil back through the battery. This fix was installed and operational in less than an hour thanks to the programmability of the controller.

The second bug was the inability to detect when an engine died due to poor fuel quality. Abnormal conditions such as overpressure, overspeed, and over-temperature were recognized and set up in the alarm system, but the engine simply dying due to poor fuel quality or other problem had not been considered initially. Even though it would be possible to infer an engine failure from other signals, a specific alarm was requested.

To correct this problem, a proximity switch and control relay were installed on each engine. The proximity switch was mounted on the pump to detect passing gear teeth. A control relay dedicated to the proximity switch picked up the switch's signal. If the relay did not receive a signal from the switch, the control relay's contact operated a spare digital input and tripped the alarm logic in the PLC. The dedicated relay was selected over programming the same function in the PLC, due to concern over reliably reading the proximity switch's low level signal at the PLC.

Project Post Mortem

The project was successful. The control system has functioned as expected and has since been modified by contract personnel to replace one of the gas engine drivers with a second electric driver. Using the various computer programs to design and document the project was definitely a positive factor. Revisions were made much more quickly on the computer than by hand.

On-site input during the program design was very valuable in assuring the initial program met the functional requirements and minimizing "on the fly" revisions during commissioning. Operator acceptance of the system has been generally good although more training time should have been provided.

The size of the system, while adequate for the initial scope, has become a limiting factor in future work. Once the operators and engineers became comfortable with the system, additional functions were suggested but could not easily be accommodated in the existing panel. Additional input and output modules can be added as well as additional programming in the existing memory.

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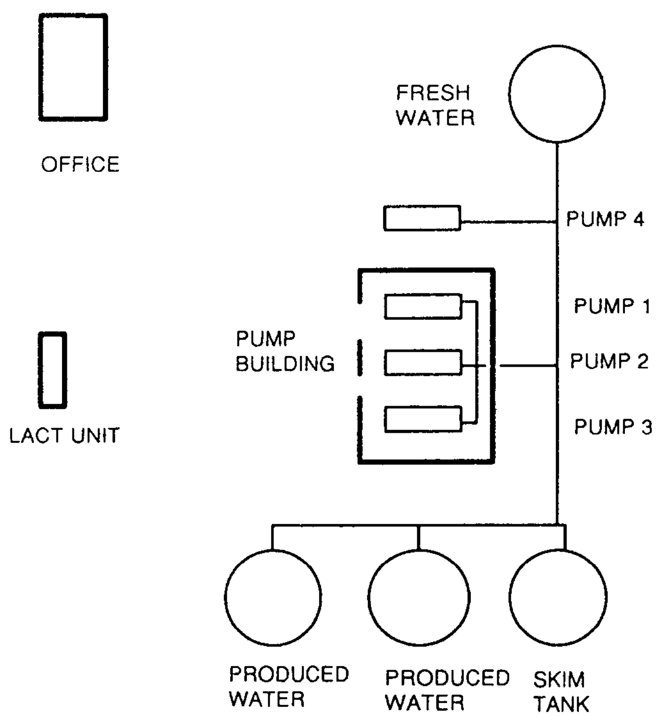

Figure 1 - H.T. Boyd battery schematic

SERIES ONE
TIMER/COUNTER RECORD

DATE: 4-17-89

LEASE: H. T. BOYD

SYSTEM: INJECTION STATION CONTROL

REFERENCE NUMBER	T/C	PRESENT (CNTS)	FUNCTIONAL DESCRIPTION
600	T	1.0	FLASHER ONE SECOND
601	T	1.0	FLASHER ONE SECOND
602			
603	T	310.	J1 SHUTDOWN BYPASS TIMER
604	T	320.	J1 SHUTDOWN BYPASS TIMER
605	T	330.	J1 SHUTDOWN BYPASS TIMER
606	T	340.	J1 SHUTDOWN BYPASS TIMER
607			
610	T	900.	J4 CYCLING TIMER (PROD WTR HI LVL)
611	T	900.	J4 CYCLING TIMER (PROD WTR HI LVL)
612			
613			
614	T	5.0	PULSE FOR C615 SEQUENCER
615	C	(6)	SEQUENCER FOR LAMP TEST
616	T	300.	HI PRESSURE SHUTDOWN SEQUENCE TIMER
617	C	(4)	HI PRESSURE SHUTDOWN SEQUENCE
620			
621			
622	T	6.0	J4 START DELAY/OPEN BYPASS VALVE
623	T	16.0	J4 START/CLOSE BYPASS VALVE
624	T	25.0	ISOLATE BYPASS VALVE MOTOR
625			
626	T	180.0	LACT ALARM DELAY TIMER
627	C	(3)	J4 AUTO START PUMP CYCLE LIMITER
630	T	900.0	J4 AUTO START PUMP CYCLE LIMITER
631			
632			
633			
634			
635			
636			
637			
640			

Figure 2

SERIES ONE
RETENTIVE RELAY RECORD

DATE: 4-17-89

LEASE: H. T. BOYD

SYSTEM: INJECTION SYSTEM CONTROL

REFERENCE NUMBER	FUNCTIONAL DESCRIPTION
340	AC FAIL ALARM
341	LACT FAIL ALARM
342	PLANT DOWN ALARM
343	PRODUCED WATER TANK HIGH ALARM
344	CHARGE PUMP STOP
345	WATER TANK LOW LEVEL
346	GENERAL ALARM
347	
350	J4 AUTO START
351	FRESH WATER TANK LOW ALARM
352	J4 RUN CHECK SYSTEM LAMP LATCH
353	J4 PUMPING CYCLE LIMITER (NOT INSTALLED AS OF DATE)
354	J1 ZERO SPEED RELAY LATCH
355	J2 ZERO SPEED RELAY LATCH
356	J3 ZERO SPEED RELAY LATCH
357	
360	
361	
362	
363	
364	
365	
366	
367	
370	
371	
372	
373	

Figure 3

SERIES ONE
INTERNAL COIL RECORD

DATE: 4-17-89

LEASE: H. T. BOYD

SYSTEM: INJECTION STATION CONTROL

COIL NO.	FUNCTIONAL DESCRIPTION	COIL NO.	FUNCTIONAL DESCRIPTION
160	EMERGENCY SHUTDOWN	230	
161	FLASHER (1 SECOND)	231	J4 HI LVL START 1 SHOT
162	CLEAR ALARMS	232	J4 HI LVL START 1 SHOT
163	LAMP TEST	233	
164		234	J4 LO DISC PRESSURE
165		235	J4 HI DISC PRESSURE
166		236	J4 PMP OIL LOW
167		237	J4 AUX CONTACT
170	J1 LO DISC PRESSURE	240	
171	J1 HI DISC PRESSURE	241	
172	J1 ENG OIL LOW	242	J4 AUTO START LO DISC
173	J1 PMP OIL LOW	243	J4 AUTO START ENG DWN
174	J1 OVERSPEED (OVRSPD)	244	SUC TANK LO ALRM 1 SHOT
175	J1 ENG HI TEMP	245	SUC TANK LO ALRM 1 SHOT
176	J1 SPARE	246	J4 AUTO START ENG OIL
177	J1 SPARE	247	J4 AUTO START PMP OIL
200		250	J4 AUTO START OVRSPEED
201	J1 ZERO SPEED	251	J4 AUTO START ENG TEMP
202	J2 ZERO SPEED	252	J4 AUTO START WTR HI
203	J3 ZERO SPEED	253	
204	J2 LO DISC PRESSURE	254	J4 START DELAY
205	J2 HI DISC PRESSURE	255	CHRG PMP STOP PMPS DWN
206	J2 ENG OIL LOW	256	
207	J2 PMP OIL LOW	275	J2 SEQ SD HI DISC PRS
210	J2 OVERSPEED (OVRSPED	260	J3 SEQ SD HI DISC PRS
211	J2 ENG HI TEMP	261	J4 SEQ SD HI DISC PRS
212	J2 SPARE	262	ALARM ACKNOWLEDGE
213	J2 SPARE	263	LACT ALARM DELAY
214		264	LAMP TEST GROUP 1
215		265	LAMP TEST GROUP 2
216		266	LAMP TEST GROUP 3
217		267	LAMP TEST GROUP 4
220	J3 LO DISC PRESSURE	270	LAMP TEST GROUP 5
221	J3 HI DISC PRESSURE		
222	J3 ENG OIL LOW		
223	J3 PMP OIL LOW		
224	J3 OVERSPEED (OVRSPD)		

Figure 4

SERIES ONE I/O SUMMARY

DATE: 4-14-89

LEASE: H. T. BOYD

SYSTEM: INJECTION STATION CONTROL

MODULE NUMBER	REF. NUMBER	CHT. NO.	IN/OUT	TAG	DEVICE DESCRIPTION	DEVICE NO/NC
00	000	0	IN	PSLL-1	J1 LO DISC PRESS	NO
	001	1	IN	PSHH-1	J1 HI DISC PRESS	NC
	002	2	IN	LSLL-1	J1 ENG OIL LOW	NO
	003	3	IN	LSLL-2	J1 PUMP OIL LOW	NO
	004	4	IN	SSHH-1	J1 ENG OVERSPEED	NO
	005	5	IN	TSHH-1	J1 ENG HI TEMP	NO
	006	6	IN	HS-1A	J1 START/RUN	NC
	007	7	IN	HS-1B	J1 STOP	NO
01	010	0	IN	SSLL-1	J1 ZERO SPEED	NO
	011	1	IN	SSLL-2	J2 ZERO SPEED	NO
	012	2	IN	LSLL-3	J2 ENG OIL LOW	NO
	013	3	IN	LSLL-4	J2 PUMP OIL LOW	NO
	014	4	IN	SSHH-2	J2 END OVERSPEED	NO
	015	5	IN	TSHH-2	J2 ENG HI TEMP	NO
	016	6	IN	HS-2A	J2 START/RUN	NC
	017	7	IN	HS-2B	J2 STOP	NO
02	020	0	IN	SSLL-3	J3 ZERO SPEED	NO
	021	1	IN		SPARE	
	022	2	IN	LSLL-5	J3 ENG OIL LOW	NO
	023	3	IN	LSLL-6	J3 PUMP OIL LOW	NO
	024	4	IN	SSHH-3	J3 END OVERSPEED	NO
	025	5	IN	TSHH-3	J3 ENG HI TEMP	NO
	026	6	IN	HS-3A	J3 START/RUN	NC
	027	7	IN	HS-3B	J3 STOP	NO
03	030	0	IN		SPARE	
	031	1	IN		SPARE	
	032	2	IN	LSLL-7	J4 PUMP OIL LOW	NO
	033	3	IN	HS-4a	J4 AUTO	NO
	034	4	IN	HS-4b	J4 HAND	NO
	035	5	IN	C1	J4 AUX CONTACT	NO
	036	6	IN	HS-5A	CHARGE PUMP ON	NO
	037	7	IN	LSHH-1	SKIM TNK HI ALRM	NC
04	040	0	IN	C2	AC FAIL ALARM	NO
	041	1	IN	C3	LACT FAIL ALARM	NO
	042	2	IN	C4	LACT BAD OIL ALRM	NO
	043	3	IN	LSHH-2	PROD WTR TKN HI	NO
	044	4	IN	LSLL-8	FRESH WTR TNK LO	NO
	045	5	IN	PSHH-2	SUCT LINE HI PRESS	NC
	046	6	IN	LSLL-9	WEST SUCT TNK LO	NO
	047	7	IN	LSLL-10	EAST SUCT TNK LO	NO

Figure 5

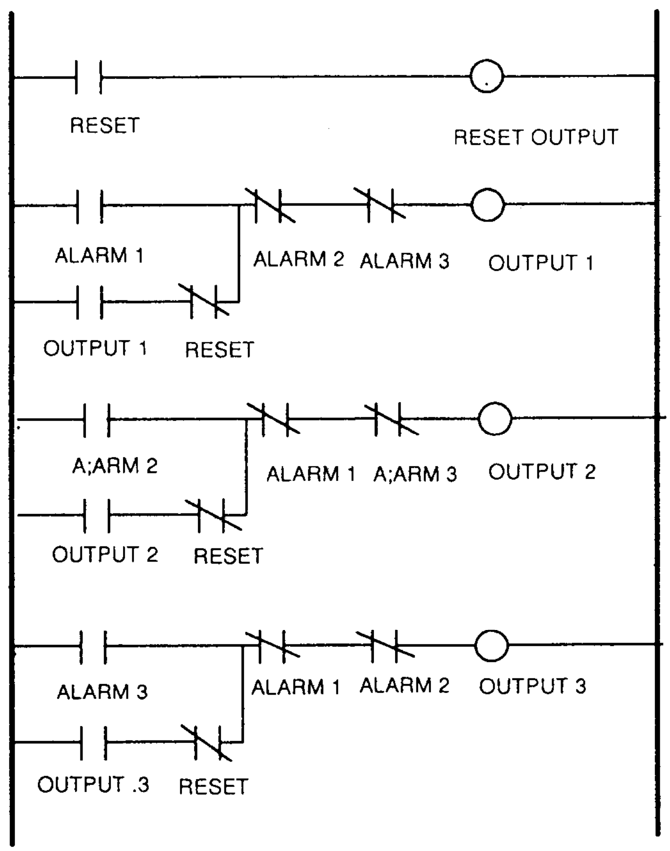

Figure 6 - "First out" logic