LEVERAGING CONTROL AND MONITORING TECHNOLOGIES TO IMPROVE RELIABILITY AND REDUCE TOTAL INSTALLED COSTS (TIC) OF ELECTRICAL TRACE HEATING SYSTEMS IN PETROCHEMICAL FACILITIES

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Abstract – Electric trace heating is commonly used by the petrochemical industry for freeze protection of water lines or temperature maintenance of process fluids. An unreliable trace heating system can impact the business significantly by damaging the process fluids/piping and potentially causing lost production. Controlling and monitoring the performance of trace heating is thus important to ensure the processes are running as desired. This paper focuses on the advances made by the trace heating industry in the control and monitoring technologies to improve the reliability of trace heating systems as well as to reduce their total installed costs. A real world case study example is used to illustrate the reduction in total installed costs using control and monitoring capabilities.

Index Terms – Electric Trace Heating, Heat Management System, Control & Monitoring, Power Distribution, Trace Heating Design, Heat Tracing, Total Installed Costs

I. INTRODUCTION

For the last several decades the petrochemical industry has significantly increased the use of electric trace heating as opposed to steam for maintaining pipes at the desired operating temperature [1]. The main driver behind this switch is the improved economics of electric trace heating due to many factors, including the ease with which it can be controlled and monitored. Control and monitoring technologies for electric trace heating systems have been discussed for quite some time [2], [3], and [4]. Depending upon the type of process, IEEE Std. 515-2011 [5], the IEEE Standard for The Testing, Design, Installation and Maintenance of Electrical Resistance Trace Heating for Industrial Applications, details the guidelines and constraints within which the trace heating must be designed and controlled [5]. For Type I processes, where the temperature should be maintained above a minimum set- point, an ambient sensing mechanical thermostat with minimal or no monitoring can be acceptable. The wide temperature excursions are tolerated and energy efficiency is not warranted in these processes. For Type II processes, where the temperature should be controlled within a moderate band, pipeline sensing control devices with some monitoring are typical. For Type III processes, where the temperature should be controlled in a narrow band, pipe sensing controllers with maximum flexibility in the selection of alarm and monitoring functions should be used. Nowadays, sophisticated control and monitoring technologies not only give users flexibility in controlling process fluid temperatures but also provide full visibility of trace heating system parameters such as process temperature, line/ground fault current, voltage, and current to track system performance. Today's control and monitoring systems are now capable of providing early and remote notification of out-of-spec conditions. This capability has enabled users to conduct scheduled preventive maintenance, centralize alarm reporting and prevent process shutdown by pro-actively addressing any issues with the trace heating system.

Recent advances in control and monitoring technologies are discussed and a real world case study is used to illustrate the impact of these advances in improving reliability and reducing total installed costs of a trace heating system.

II. CONTROL AND MONITORING ASPECTS

Before developing a control and monitoring strategy for a given application, there are several aspects to consider. The first is the control method. There are three control methods:

1) *No external control*: The trace heater (usually a self-regulating cable) is powered without any external controller and the system is allowed to reach its equilibrium temperature. This is the least energy efficient method as the cable is powered all year and the temperature reached is usually higher than the desired maintain temperature.
2) *Ambient sensing control*: The controller senses the ambient temperature and turns the trace heating system on/off when the ambient temperature reaches below/above a certain set point. The system is commonly used in many water freeze protection applications where a group of circuits is controlled by one controller, with a set point above the freezing point of water, based on the ambient temperature. It is still not energy efficient as there is no visibility or control of pipe temperatures on individual lines.
3) *Line Sensing*: In this method, the controller senses the pipe temperature and controls the trace heaters installed on the same pipe based on the desired set point. This method is typical for process maintain applications. It could be cost intensive due to increase controller and sensor wiring costs.

The second aspect to be considered is the control Mode. Three control modes are commonly used:

1) *On/Off Control*: As the name suggests, in this mode the trace heaters are either turned on or off, based on the measured temperature. If the measured temperature is above the set point plus dead band the trace heater is turned off. If the measured temperature falls below the

set point temperature, the trace heater is turned on. This mode is used for both ambient and line sensing control modes.

2) *Proportional Integral Derivative (PID) Control*: In contrast to the on/off control mode, in the PID control mode, the controller continuously monitors the measured temperature and imposes a duty cycle on the trace heater as soon as the measured temperature exceeds the set point. The duty cycle changes continuously and reaches 0, i.e. the heater is turned off, when the measured temperature is at set point plus dead band. Some manufacturers allow users to input the PID parameters while others have pre-loaded parameters to determine the duty cycle of the controllers. The benefit of this mode is that it further tightens the process temperature variation around the set point and is used mainly for line sensing applications.
3) *Proportional Ambient Sensing Control*: Some ambient sensing controllers have built-in algorithms to adjust the duty cycle of the trace heaters' power based upon the ambient temperature. If the ambient temperature is at or below the minimum design ambient temperature the heaters will be powered 100% of the time. If the measured ambient is at or above the maintain temperature the heaters will be powered on 0% of the time as shown in figure 1 below.

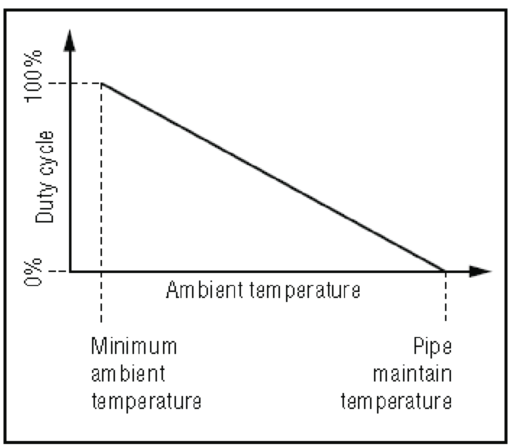

Fig. 1: Typical proportional ambient sensing control methodology

This control mode results in much tighter temperature control of groups of circuits than can be achieved by just ambient sensing. This control mode is also successfully used in process maintain applications due to its good temperature control and lower costs as compared to line sensing control.

III. HARDWARE AND SOFTWARE ADVANCES

While designing the optimum trace heating control and monitoring system, the user should also consider the recent advances in the control and monitoring hardware and software that is now available.

Solid-State Relays (SSRs): In the past, controllers for electric trace heating consisted of mechanical thermostats or on/off controllers with electro-mechanical switching. With the advancements in hardware, solid-state relays are now frequently used in trace heating controllers. Since there is no sparking, SSRs can be used in hazardous area environments where it is critical to ensure there is no spark generated during the switching operation. SSRs have no moving parts and hence do not wear out mechanically. This has enabled users to further increase the use of advanced features such as soft start for certain applications. Certain trace heaters exhibit high start-up currents, especially at low start-up temperatures. In such situations, the trace heaters are powered in a time- ramped fashion. The power output is slowly ramped up in the first few seconds of start-up to warm up the heaters before they are fully powered. Solid state relays are critical for successful soft start processes as the heaters are duty-cycled in milliseconds time frame. Solid state relays also play an important role in implementing a feature called power limiting or power clamping. This feature limits the percent of on-time to a user defined value. This is typically used to match the heater output to the heat load requirements.

Heat Sink Designs: One of the limitations of the SSR is the need to dissipate the heat generated during switching. Many trace heating manufacturers have come up with strategies to solve this problem, including de-rating of SSRs, limiting the switching current at higher ambient temperatures, and/or developing more effective heat sinks. The advances in heat sink designs have enabled users to use SSRs for higher current switching applications, thereby reducing the number of circuits and reducing power distribution costs. The following chart shows test data illustrating the effect of different heat sinks on the temperature of a typical SSR.

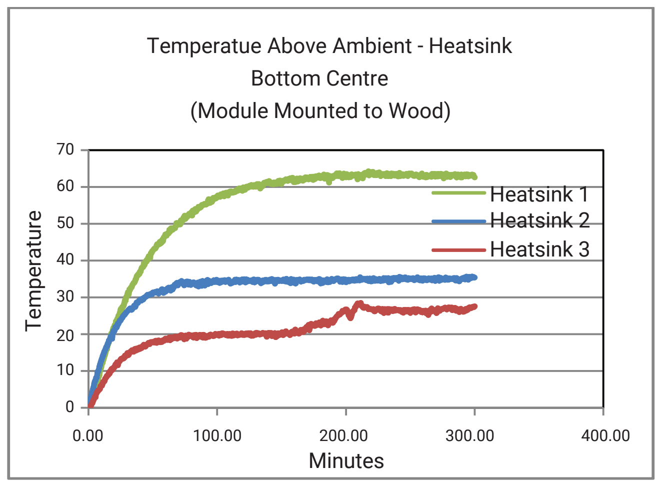

Fig. 2: Effect of heat sink design on SSR junction temperature

Ground Fault Monitoring/Tripping: With the advent of electronic controllers came the capability of monitoring various process parameters, such as line current, voltage and ground- fault current. Today's controllers include ground-fault monitoring and tripping capability, obviating the need to use expensive ground-fault breakers. They also have the ability of providing an alarm at an even lower ground-fault current setting that will provide an early warning before the circuit trips. This enables users to investigate the cause of the alarm before the circuit is turned off due to the presence of a ground fault.

Multiple temperature sensor capabilities: Modern trace heating controllers offer the capability of using multiple temperature sensors to control a circuit. This is important for applications involving temperature sensitive fluids and for those critical circuits where there is a need to monitor fluid temperatures at multiple locations and to control based on either the lowest or average temperature, in order to prevent the fluid from exceeding a particular temperature anywhere along the entire pipe.

Touch Screens: Hazardous area touchscreen capability is another hardware advancement offered by many industrial trace heating controllers. Touchscreens allow in-situ programming with very user-friendly interfaces. The touchscreen display also shows a large amount of alarm/ status information to the user at one time. This capability has made the programming, maintenance and troubleshooting of the trace heating controllers much more user friendly. A typical touchscreen of an industrial trace heating controller is shown below:

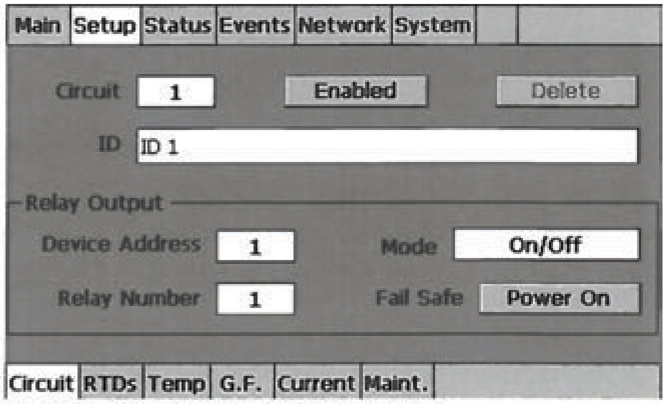

Fig. 3: Typical trace heating controller touchscreen

Advanced tools such as remote monitoring: In today's information age, users want maximum information about their process parameters. In order to avoid the expense of running conduit and wire to provide the temperature data from multiple locations, some manufacturers have developed smart temperature aggregators which gather temperature data from multiple locations and feed it to the controller using only one home run. The trace heating industry is also investigating wireless technology but no serious inroads are made as of yet in the industrial sector.

Users should not only consider the hardware advances mentioned above, but should also be aware of the advances in control and monitoring software technology to take full advantage of its capabilities.

Communications: One of the main advances of modern day controllers is their capability to communicate via Ethernet, RS-485, and/or RS-232 communication methods. This has enabled users to monitor the performance and critical parameters of their trace heating systems from a central location in the facility or even remotely from their office. Many manufacturers offer software which allows users to remotely program, monitor, and troubleshoot trace heating control systems. These programs come in standalone versions and in large enterprise versions, with multiple servers/ clients, designed for large plants with multiple units as shown below.

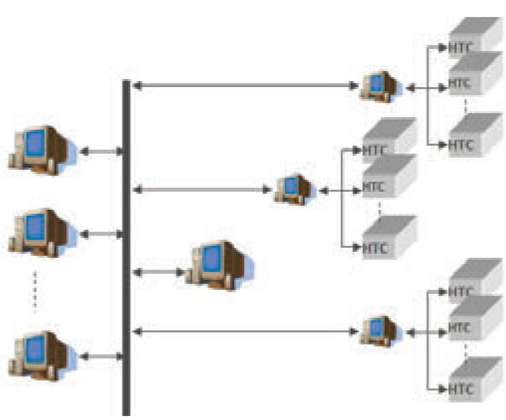

Fig. 4: Typical master / slave architecture of trace heating software for large facilities

Typically the plant is set up so that each unit has a trace heating computer that is used to access the information for that plant and pass it to the central database. This information can then be accessed by any computer on the network. These programs allow multiple user settings/ permissions for security reasons. These settings are kept on the server, so if the user logs in from any location the screen views will be exactly the same. This not only enhances the security of trace heating data by controlling user access but at the same time makes the information easily accessible and enhances communication across different sections of the plant.

Automation: With the advancements in software technology, trace heating control and monitoring software is now capable of logging and charting trace heating data, such as temperature, current, etc. allowing users can to view historic information for troubleshooting purposes. The programs also allow users to pre-program the power cycle of trace heating systems at scheduled times. This functionality comes in handy when the user needs to make sure the system is turned-off when certain scheduled activity takes place on the traced lines. Many times the trace heating system is not in use for prolonged periods, e.g., during summer months, and the user only discovers if there is any damage to the system when the system is powered back up in time for winter. The worst time to find out if there are problems with the system is when you want the system to work perfectly. Modern controllers now include auto-diagnostic features which allow them to self-test the trace heating system periodically and to provide an alarm for any out-of-spec situation.
Control and Monitoring Architectures: In addition to the advances in hardware and software, the industry offers control and monitoring systems in various architectures that can be used to optimize the total installed cost of the trace heating system.

The Single Point architecture is more traditional, starting out in the early days with Mechanical Thermostats. Today, single point electronic controllers are available which can be networked back to a central location. The characteristics of this architecture are that the control systems are usually less expensive and more affordable if a small number of circuits are required. The power wiring and tray cable costs are minimal because the controller is mounted right on the pipe. However, to bring the monitoring and status information back to a central location requires a lot of communications wiring between the individual controllers which can drive costs up. Also, maintaining pipe mounted controllers can be challenging as they may be difficult to find or reach within the three dimensional pipe rack. The Distributed architecture system typically consist of outdoor rated enclosures in sizes of 30 - 40 circuits or less which are distributed throughout the area, as close as possible to the trace heating lines they control. This minimizes the secondary power but still requires some communications wiring for monitoring. Since the panels are located on the ground, they are easier to access. Because they are in proximity to the trace heating lines, it is easier to commission or troubleshoot the system. Because they are placed in the operating plant area, the enclosures and design will usually have to be rated for operation in Hazardous Locations, which drives up the cost of the panels.

The Centralized architecture system puts all of the control panels in one location, typically within a building, and then runs secondary power cables out to the trace heating lines. This makes accessing the control panels easy but the additional distance traveled by the secondary power and communications wiring to get out to the trace heating lines can add cost quickly. Because the Heat Traced building can be located in a non-hazardous area, the panel cost can be reduced. As you can see there are a multitude of variables that can affect the choice of control and monitoring architecture and each project needs to be analyzed separately, taking into account the customer's preferences.

IV. CASE STUDY

The project was located in South Carolina and consisted of 78 lines totaling 5004 lineal feet of pipe. The initial design criteria provided by the end user are shown below:

TABLE 1 INITIAL DESIGN BASIS

PIPE SIZE	VARIABLE
Maintain Temperature	90°F (32°C)
Minimum Ambient Temperature	10°F (-12°C)
Maximum Operating Temperature	150°F (66°C)
Maximum Allowable Temperature	281°F (138°C)
T-Rating	T3 (392°F)
Area Classification	Cl D2 Group A
Maximum Circuit Breaker Size	30 A
Operating Voltage	120/208 VAC
Insulation Type and Thickness	2" Polyisocyanurate

The electrical trace heating design created using the above criteria is shown in Appendix A. This design resulted in 64 total circuits even after combining many shorter and similar pipe segments into single circuits. The design was line sensed with a temperature sensor (RTD) for each circuit. The number of circuits required the power distribution with two controller panels. The conduit and wiring required for this design is summarized below in Table II and detailed in Appendix B. The wiring included all the tray cable for secondary power and the conduit drops.

TABLE 2 CONDUIT AND WIRING REQUIREMENTS WITH INITIAL DESIGN BASIS

CONDUIT AND WIRE REQUIREMENTS (FT)	
3/4" Conduit	2040
1" Conduit	520
1 1/2" Conduit	360
2" Conduit	220
Total Tray Cable	6400
RTD Wire	6300

The total project cost with the initial design was estimated to be $687K as shown below

:

TABLE 3 TOTAL INSTALLED PROJECT COST ESTIMATE WITH INITIAL DESIGN BASIS

	MATERIAL	LABOR	TOTAL
POWER & DISTRIBUTION	$ 33,616	$ 79,813	$ 113,429
INSULATION	$ 100,704	$ 70,068	$ 170,771
ELECTRIC HEAT TRACING	$ 47,867	$ 37,892	$ 85,759
PANEL & XFMR	$ 124,312	$ 12,380	$ 136,691
ENGINEERING	$ -	$ 38,816	$ 38,816
PROJECT INDIRECTS	$ 28,410	$ 113,280	$ 141,690
		Total	$ 687,157

The material and labor costs were assumed to be typical for the area. The project indirect costs included per diems, field equipment, project management, site supervision, etc.

In order to optimize this design, it was decided to modify the initial design criteria. The customer confirmed that 277-V power was available at the facility. The higher voltage would allow for longer circuit lengths and reduce the number of circuits. Since modern controllers now provide ground-fault monitoring and protection at this voltage, there is no need to use expensive 277-V ground fault circuit breakers. The modern controllers also allow for higher current switching capability and hence further increase the opportunity to combine pipe segments into single circuits where it makes sense. The use of 277-V and larger current switching capabilities allowed us to combine more cable segments on single circuits, thereby reducing the number of circuit breakers from 64 to 29 and the number of control panels from two to one as shown in Appendix C. In order to further leverage the control and monitoring technology, we investigated the use of the Proportional Ambient Sensing Control (PASC) method. It was confirmed with the customer that the fluid could withstand temperatures up to 281°F (138°C). Hence, this process allowed for a relatively broad temperature range and didn't warrant the use of line sensing control. The proportional ambient sensing control, as explained earlier, uses only one temperature sensor (RTD) to measure actual ambient temperature and adjusts the trace heating power duty cycle from 100% to 0% between minimum ambient and maintain temperatures. This application is suited to this control mode as the maintain temperature is between the minimum and maximum ambient temperatures.

The first drawback of not using line sensing methodology is that you don't have visibility of, and circuit control based on, individual pipe temperature. The second drawback is that the heating cable duty cycle is the same for all circuits independent of pipe diameter, insulation thickness, etc. This could lead to significantly higher actual pipe temperatures where the thermal design safety factors are high, i.e. the heating cable wattage is significantly higher than the maximum heat loss for that pipe. These safety factors may be different for different pipe diameters due to standardization of pipe insulation or heating cable types by the user. In this application, the fact that the fluid had a broad range of allowable temperatures above the maintain temperature and the maintain temperature was below the maximum ambient temperature were leveraged to use the proportional ambient sensing control.

The benefit of using proportional ambient sensing is savings in conduit and wiring costs for the RTDs. In this example, the power distribution costs are shown in Table IV below and detailed in Appendix D. The conduit and tray cable required is significantly reduced due to reduction in number of circuits resulted from using 277 V.

TABLE 4 ALTERNATE DESIGN CONDUIT AND WIRE REQUIREMENTS BASIS

CONDUIT AND WIRE REQUIREMENTS (FT)	
3/4" Conduit	1176
1" Conduit	300
1 1/2" Conduit	200
2" Conduit	120
Total Tray Cable	1950
RTD Wire	0

Due to the reduction in the number of circuits and conduit/wiring requirements, the entire project's schedule is shortened, thereby further reducing the project indirect costs. The total project costs are reduced from $687K to $509K which represents a 25% total installed cost reduction as shown below:

TABLE 5 ALTERNATE DESIGN TOTAL INSTALLED PROJECT COST ESTIMATE BASIS

	MAT		LABOR		TOTAL	
POWER & DIST	$	18,196	$	37,404	$	55,600
INSULATION	$	100,704	$	70,062	$	170,766
ELECTRIC HEAT TRACING	$	44,337	$	36,174	$	80,511
PANEL & XFMR	$	68,474	$	4,283	$	72,757
ENGINEERING	$	-	$	22,199	$	22,199
PROJECT INDIRECTS	$	24,274	$	83,103	$	107,377
				Total	$	509,210

V. CONCLUSIONS

Control and monitoring represents a huge opportunity in improving reliability and reducing the installed costs of trace heating systems. Users need to not only consider the control modes and methods to be used when selecting a control system, but they also need to consider the recent advances that the industry offers in control and monitoring hardware and software to select the most optimal system for a given application. Many advances such as higher current switching capabilities, build-in ground-fault monitoring/tripping, touch screen in-situ programming and maintenance, multiple temperature sensor capabilities, remote monitoring and automation are discussed in this paper. A real world case study is used to illustrate the significant total installed costs savings resulted by using advanced control and monitoring capabilities. While the cost savings are typical, they can vary dramatically based on process parameters, ambient conditions, piping layout, power distribution type and type of trace heating system used.

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VII. VITAE

Sudhir Thorat received his BS in Chemical Engineering from the University of Mumbai, his MS in Polymer/Materials Engineering from University of Tennessee, Knoxville and an MBA from California State University, East Bay. He has held various roles for the past 14 years within nVent Thermal Management in Product Development, Product Management, Marketing and Product Support. He presently manages the Technical Support organization. He has published two international papers in the Journal of Applied Polymer Science and 2 papers in IEEE-PCIC.

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APPENDIX A

ELECTRICAL TRACE HEATING DESIGN BASED ON THE INITIAL DESIGN BASIS

Al- Tape	**N**	**A.I.T. (°F)**	**392**	**Metal Pipe**	**Y**	**Safety Factor**	**25%**	**Normal Oper Temp**	**100°F**	**Min. Amb Temp**	**10°F**
Area Class	**C1 D2**	**%Over Voltage**	**10%**	**Wind (mph)**	**25**	**Cable Adder**	**105%**	**Max. Oper Temp**	**150°F**	**Max. Amb Temp**	**105°F**
Line No.	**Pipe Size (in)**	**W/ft Reqd**	**Volts**	**Maint. Temp. (˚F)**	**Base L/F of Cable**	**Total Ckt length (ft)**	**Breaker Starting Amps**	**Max. Segment Length (ft)**	**Circuit Breaker Size**	**Num of CB**	**Num of Spaces**
1	12	8.2	208	90	70	270	26.1	305	2/P 20	2	4
2	10	7.1	208	90	9		0	0	0	0	0
3	12	8.2	208	90	8		0	0	0	0	0
4	12	8.2	208	90	97		0	0	0	0	0
5	12	8.2	208	90	9		0	0	0	0	0
6	8	5.9	208	90	53		0	0	0	0	0
7	0.75	1.6	208	90	24		0	0	0	0	0
8	12	8.2	208	90	82	279	26.9	305	2/P 20	2	4
9	10	7.1	208	90	9		0	0	0	0	0
10	12	8.2	208	90	104		0	0	0	0	0
11	12	8.2	208	90	9		0	0	0	0	0
12	8	5.9	208	90	51		0	0	0	0	0
13	0.75	1.6	208	90	24		0	0	0	0	0
14	3	3.2	208	90	540	540	31.3	385	2/P 20	2	4
15	3	3.2	208	90	422	422	24.5	385	2/P 30	1	2
16	2	2.6	120	90	11	11	1.1	210	1/P 20	1	1
17	2	2.6	120	90	11	11	1.1	210	1/P 20	1	1
18	2	2.6	120	90	5	5	0.5	210	1/P 20	1	1
19	2	2.6	120	90	9	9	0.9	210	1/P 20	1	1
20	12	8.2	120	90	11	11	2	220			
21	12	8.2	120	90	11	11	2	220			
22	10	7.1	120	90	9	9	1.6	220			
23	10	7.1	120	90	9	9	1.6	220			
24	2	2.6	120	90	13	13	1.3	210			
25	2	2.6	120	90	13	13	1.3	210			
26	6	4.8	120	90	21	21	3.7	220	1/P 20	1	1
27	6	4.8	208	90	512	512	37.8	365	2/P 30	2	4
28	6	4.8	208	90	295	295	21.8	365	2/P 30	1	2
29	6	4.8	208	90	408	408	30.1	365	2/P 20	2	4
30	3	3.2	120	90	35	35	3.6	210	1/P 20	1	1
31	6	4.8	208	90	412	412	30.4	365	2/P 20	2	4
32	3	3.2	120	90	36	36	3.7	210	1/P 20	1	1
33	6	4.8	120	90	22	22	3.9	220	1/P 20	1	1
34	6	4.8	120	90	21	21	3.7	220	1/P 20	1	1
35	8	5.9	120	90	49	49	8.7	220	1/P 20	1	1
36	8	5.9	120	90	49	49	8.7	220	1/P 20	1	1

37	0.75	1.6	120	90	4	4	0.3	270	1/P 20	1	1
38	0.75	1.6	120	90	8	8	0.6	270	1/P 20	1	1
39	0.75	1.6	120	90	4	4	0.3	270	1/P 20	1	1
40	0.75	1.6	120	90	8	8	0.6	270	1/P 20	1	1
41	2	2.6	120	90	26	26	2.7	210	1/P 20	1	1
42	2	2.6	120	90	32	32	3.3	210	1/P 20	1	1
43	2	2.6	120	90	4	4	0.4	210			
44	2	2.6	120	90	26	26	2.7	210	1/P 20	1	1
45	2	2.6	120	90	50	50	5.1	210	1/P 20	1	1
46	2	2.6	120	90	4	4	0.4	210			
47	3	3.2	120	90	53	53	5.4	210	1/P 20	1	1
48	3	3.2	120	90	46	46	4.7	210	1/P 20	1	1
49	3	3.2	208	90	350	356	20.7	385	2/P 30	1	2
50	8	5.9	208	90	3		0	0	0	0	0
51	3	3.2	120	90	110	110	11.3	210	1/P 20	1	1
52	3	3.2	120	90	11	11	1.1	210	1/P 20	1	1
53	3	3.2	120	90	105	105	10.7	210	1/P 20	1	1
54	3	3.2	120	90	46	46	4.7	210	1/P 20	1	1
55	3	3.2	208	90	350	356	20.7	385	2/P 30	1	2
56	6	4.8	208	90	3		0	0	0	0	0
57	3	3.2	208	90	259	259	15	385	2/P 20	1	2
58	3	3.2	120	90	11	11	1.1	210	1/P 20	1	1
59	4	3.8	120	90	32	32	3.3	210	1/P 20	1	1
60	4	3.8	120	90	6	6	0.6	210	1/P 20	1	1
61	4	3.8	120	90	63	63	6.4	210	1/P 20	1	1
62	4	3.8	120	90	6	6	0.6	210	1/P 20	1	1
63	6	4.8	208	90	181	440	32.5	365	2/P 30	2	4
64	6	4.8	208	90	259		0	0	0	0	0
65	6	4.8	120	90	4	4	0.7	220	1/P 20	1	1
66	6	4.8	208	90	166	540	39.9	365	2/P 30	2	4
67	6	4.8	208	90	374		0	0	0	0	0
68	6	4.8	120	90	4	4	0.7	220	1/P 20	1	1
69	8	5.9	120	90	8	8	1.4	220	1/P 20	1	1
70	8	5.9	120	90	8	8	1.4	220	1/P 20	1	1
71	24	14.6	120	90	3	6	1.1	220	1/P 20	1	1
72	3	3.2	120	90	3	3	0.3	210	1/P 20	1	1
73	8	5.9	120	90	29	29	5.2	220	1/P 20	1	1
74	24	14.6	120	90	3	6	1.1	220	1/P 20	1	1
75	2	2.6	120	90	3	3	0.3	210	1/P 20	1	1
76	3	3.2	120	90	3	3	0.3	210	1/P 20	1	1
77	0.5	1.4	120	90	4	4	0.3	270	1/P 20	1	1
78	0.5	1.4	120	90	4	4	0.3	270	1/P 20	1	1
						6259	500			64	85

APPENDIX B

SECONDARY POWER DISTRIBUTION ESTIMATE BASED ON THE INITIAL DESIGN BASIS

				Average Conduit Drop Length	Average Conduit Drop Length	Percentages for Trunk Runs					
				16	16	25%	25%	17%	17%	10%	10%
Panel	Num Of CB Reqd.	Num. of Spaces Reqd	Total Load KVA	3/4" Conduit for Power Connections	3/4" Conduit for RTD	1" Conduit for Power	1" Conduit for RTD	1 1/2" Conduit for Power	1 1/2" Conduit for RTD	2" Conduit for Power	2" Conduit for RTD
Panel 1	37	48	23.9	621	560	160	140	110	100	70	60
Panel 2	27	37	20.5	459	400	120	100	80	70	50	40
	64	85	44.4	1080	960	280	240	190	170	120	100
				2040		520		360		220	

Circuit Breakers	Num. of CB	Wire Size	L/F
1/P 20	43	12	4300
1/P 30	0	10	0
1/P 40	0	8	0
1/P 50	0	6	0
2/P 20	11	12	1100
2/P 30	10	10	1000
2/P 40	0	8	0
2/P 50	0	6	0
		Total Wire	6400
		RTD Wire	6300

Conduit Average	L/F
PER Power Connection	23
PER RTD	25

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APPENDIX C

ELECTRICAL TRACE HEATING DESIGN USING THE ALTERNATE DESIGN BASIS

Al- Tape	N	A.I.T. (°F)	392	Safety Factor	25%	Metal Pipe	Y	Normal Oper Temp	100°F	Min. Amb Temp	10°F
Area Class	C1 D2	%Over Voltage	10%	Cable Adder	105%	Wind (mph)	25	Max. Oper Temp	150°F	Max. Amb Temp	105°F
Line No.	Pipe Size (in)	W/ft Reqd	Volts	Maint. Temp. (˚F)	Base L/F of Cable	Total Ckt length (ft)	Breaker Starting Amps	Max. Segment Length (ft)	Circuit Breaker Size	Num of CB	Num of Spaces
1	12	8.2	277	90	70	270	20.4	374	1/P 30	1	1
2	10	7.1	277	90	9						
3	12	8.2	277	90	8						
4	12	8.2	277	90	97						
5	12	8.2	277	90	9						
6	8	5.9	277	90	53						
7	0.75	1.6	277	90	24						
8	12	8.2	277	90	82	279	21.1	374	1/P 30	1	1
9	10	7.1	277	90	9						
10	12	8.2	277	90	104						
11	12	8.2	277	90	9						
12	8	5.9	277	90	51						
13	0.75	1.6	277	90	24						
14	3	3.2	277	90	540	540	21	765	1/P 30	1	1
15	3	3.2	277	90	422	422	26.3	454	1/P 40	1	1
16	2	2.6	277	90	11	11	0.5	578			
17	2	2.6	277	90	11	11	0.5	578	1/P 30	1	1
18	2	2.6	277	90	5	5	0.2	578			
19	2	2.6	277	90	9	9	0.4	578			
20	12	8.2	277	90	11	11	0.8	374			
21	12	8.2	277	90	11	11	0.8	374			
22	10	7.1	277	90	9	9	0.7	374			
23	10	7.1	277	90	9	9	0.7	374			
24	2	2.6	277	90	13	13	0.5	578			
25	2	2.6	277	90	13	13	0.5	578			
26	6	4.8	277	90	21	21	1.3	454			
27	6	4.8	277	90	512	512	19.9	765	1/P 30	1	1
28	6	4.8	277	90	295	295	18.4	454	1/P 30	1	1
29	6	4.8	277	90	408	408	25.5	454	1/P 40	1	1
30	3	3.2	277	90	35	35	2.2	454			
31	6	4.8	277	90	412	412	25.7	454	1/P 40	1	1
32	3	3.2	277	90	36	36	2.3	454			
33	6	4.8	277	90	22	22	1.4	454	1/P 30	1	1
34	6	4.8	277	90	21	21	1.3	454	1/P 30	1	1
35	8	5.9	277	90	49	49	3.9	378			

36	8	5.9	277	90	49	49	3.9	378			
37	0.75	1.6	277	90	4	4	0.2	578	1/P 30	1	1
38	0.75	1.6	277	90	8	8	0.3	578			
39	0.75	1.6	277	90	4	4	0.2	578	1/P 30	1	1
40	0.75	1.6	277	90	8	8	0.3	578			
41	2	2.6	277	90	26	26	1.1	578			
42	2	2.6	277	90	32	32	1.3	578	1/P 30	1	1
43	2	2.6	277	90	4	4	0.2	578			
44	2	2.6	277	90	26	26	1.1	578	1/P 30	1	1
45	2	2.6	277	90	50	50	2	578			
46	2	2.6	277	90	4	4	0.2	578			
47	3	3.2	277	90	53	53	3.3	454			
48	3	3.2	277	90	46	46	2.9	454			
49	3	3.2	277	90	350	356	22.2	454	1/P 30	1	1
50	8	5.9	277	90	3						
51	3	3.2	277	90	110	110	6.9	454	1/P 30	1	1
52	3	3.2	277	90	11	11	0.7	454			
53	3	3.2	277	90	105	105	6.6	454			
54	3	3.2	277	90	46	46	2.9	454			
55	3	3.2	277	90	350	356	22.2	454	1/P 30	1	1
56	6	4.8	277	90	3						
57	3	3.2	277	90	259	259	16.2	454	1/P 30	1	1
58	3	3.2	277	90	11	11	0.7	454			
59	4	3.8	277	90	32	32	2	454	1/P 30	1	1
60	4	3.8	277	90	6	6	0.4	454			
61	4	3.8	277	90	63	63	3.9	454			
62	4	3.8	277	90	6	6	0.4	454			
63	6	4.8	277	90	181	440	27.5	454	1/P 40	1	1
64	6	4.8	277	90	259						
65	6	4.8	277	90	4	4	0.3	454	1/P 30	1	1
66	6	4.8	277	90	166	540	33.7	454	1/P 50	1	1
67	6	4.8	277	90	374						
68	6	4.8	277	90	4	4	0.3	454	1/P 30	1	1
69	8	5.9	277	90	8	8	0.6	378			
70	8	5.9	277	90	8	8	0.6	378			
71	24	14.6	277	90	3	6	0.5	374			
72	3	3.2	277	90	3	3	0.2	454	1/P 30	1	1
73	8	5.9	277	90	29	29	2.3	378			
74	24	14.6	277	90	3	6	0.5	374	1/P 30	1	1
75	2	2.6	277	90	3	3	0.1	578			
76	3	3.2	277	90	3	3	0.2	454			
77	0.5	1.4	277	90	4	4	0.2	578			
78	0.5	1.4	277	90	4	4	0.2	578			
						6259	373			26	26

APPENDIX D

SECONDARY POWER DISTRIBUTION ESTIMATE BASED ON THE ALTERNATE DESIGN BASIS

					Average Conduit Drop Length	Average Conduit Drop Length	Percentages for Trunk Runs					
					16	0	25%	0%	17%	0%	10%	0%
Panel	Num of CB Reqd	Num. of Spaces Reqd	Total Load Kva	Xfmr Size	3/4" Conduit for Power Connections	3/4" Conduit for RTD	1" Conduit for Power	1" Conduit for RTD	1 1/2" Conduit for Power	1 1/2" Conduit for RTD	2" Conduit for Power	2" Conduit for RTD
Panel 1	26	26	45.9	30	1176	0	300	0	200	0	120	0
	26	26	45.9		1176	0	300	0	200	0	120	0
					1176		300		200		120	

Circuit Breakers	Num of CB	Wire Size	L/F
1/P 20	0	12	0
1/P 30	21	10	1575
1/P 40	4	8	300
1/P 50	1	6	75
2/P 20	0	12	0
2/P 30	0	10	0
2/P 40	0	8	0
2/P 50	0	6	0

Conduit Average	L/F
Per Power Connection	28
Per RTD	0

Total Wire	1950	L/F
RTD Wire	0	L/F

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