2023 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM)
June 28-30, 2023. Seattle, Washington, USA

Comparison Analysis of Thermistor and RTD for Energy Transfer Station Application

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Abstract—**This paper presents the implementation of thermistor as a cost-effective alternative to resistance temperature detector (RTD) for the temperature measurement in the energy transfer station for chiller water application, and the impact of both RTDs and thermistors on the Delta T syndrome have been observed as well. An Energy Transfer Station application is developed in line with ISA-95 automation pyramid with temperature sensors as level-0, PLC as level-1 and HMI as level-2. The PLC Micro-800 system and PanelView 800 for Human Machine Interface (HMI) have been used for level-1 and level-2, respectively. The temperature transmitters are used as level-0 sensing devices for RTD and thermistors. The software development for the PLC programming and HMI graphics has been performed by using the Connected Components Workbench software.**

I. INTRODUCTION

The purpose of an Energy Transfer Station (ETS) is to transfer thermal energy from one location to another. The most modern ETS stations use the indirect method of energy transfer in which a heat exchanger is used to isolate the two locations to make sure that independent pressure conditions and temperature are maintained on both sides of the systems and water is not contaminated. The main components of an ETS are as follows: the pumps, heat exchangers, pressure independent control valves, strainers, PLC, HMI, pressure transmitters, temperature transmitters, and flowmeters along with energy meters. An ETS has two distinctive sides: primary and secondary. The primary side is connected with the chilled water supply pipeline coming from the District Cooling Plant (DCP), while the secondary side connects the building facility with ETS.

The chilled water from the DCP enters the ETS through chilled water supply pipeline and returns back to the DCP through chilled water return pipeline and heat exchanger. Temperature and pressure gauges are installed on the supply and return pipelines for visual monitoring. An energy meter is installed on the supply pipeline and return pipeline that is connected with the flowmeter and temperature sensors to measure the total energy transferred to the building. A differential pressure transmitter is installed to measure the differential pressure between primary side and secondary side. Temperature control valves installed on supply pipeline and return pipeline transfer the energy to the secondary side at desired temperature. The secondary side consists of chilled water supply and return pipelines that run from ETS to the building air handling units. For the transfer of the chilled water from the ETS to the consumer in an efficient manner, the pumps are provided with variable frequency drives. Temperature gauges and pressure gauges are installed on the pipelines for local monitoring while the temperature transmitters are installed for remote monitoring through PLC system.

An itemized study of the thermal storage tanks is performed in [1] on the cooling plant of the Dallas Airport to verify that the reset schedule proposed guarantees that the thermal storage tanks meet the peak load requirement in the summer season. When the intended temperature difference between the chilled water supply line and return line is not maintained, Low Delta-T syndrome, an undesired condition, arises. In order to maintain the building at a suitable temperature, low Delta T syndrome compels the DCP to send chilled water to the plant at excessive flow rates. As the power output is directly related to the chilled water flow, a low Delta T syndrome results in excessive water flow but does not add the power to the water circuit. As a result, the ETS runs with lower efficiency. However, if the Delta T is maintained at the desired temperature, the ETS will operate efficiently. In otherwise case, a marginal increase in the cooling requirement increases the pumping energy exponentially.

In [2], it is shown that the underlying causes of low delta-T syndrome can be optimized and resolved by designing a cooling plant in line with the international regulations, however, the rectification of some of the causes is not practical or possible. It is suggested that proper operation and maintenance of the cooling plant results in mitigating the low delta-T syndrome. In [3], it is suggested that by using variable speed chillers and implementing the load-based speed control, the DCP yields commercial benefits by consuming lower utility loads and reducing the drainage of electricity and chilled water. The conventional constant speed chillers are shown to be inefficient and not environmental-friendly. The causes of low Delta T syndrome have been studied in [4] and the control system has been identified as one of the main contributing factors. The low Delta T syndrome may occur when the control system and related sensing devices have not been selected and sized properly. The control system mainly consists of PLC with HMI and related sensors such as temperature sensor, pressure sensor, differential pressure sensor, flow sensor, and energy measurement. Temperature is one of the most important parameters in an ETS and contributes to its overall efficiency. In [5], a study related to problem detection and diagnostic approach to investigate the reasons for low delta-T syndrome in a sophisticated HVAC system is conducted and it is observed that improper set points of the sensors, inadequacy

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of control calibration and presence of uncontrolled process load in the control system are some of the major reasons for low Delta T syndrome. In order to prevent the low delta-T syndrome for chilled water systems, a study is performed in [6] to provide an online robust control technique. In addition to the traditional control strategies, a temperature set-point reset scheme is created with the goal of offering a trustworthy temperature set-point to increase the chilled water pumps' operational reliability. In order to diagnose the faults in the chilled water circuits of the buildings that cause the low delta T syndrome, a mathematical model is built in [7] and it is observed that the overall delta-T of the system is suggested to be lower than the delta-T of the separate coils. Under the conditions where the individual loads are involved, this phenomenon becomes very important.

The most widely used sensor for temperature measurement in an ETS is RTD sensor. This paper discusses the technical and commercial viability of thermistor as an alternative approach to RTD sensor for temperature measurement in an ETS and observes its impact on the delta T syndrome.

II. TEMPERATURE MEASUREMENT AND CONTROL IN ETS

A. *Background*

The DCP service provider maintains the chilled water supply at the contractually established low temperature. Users typically have to maintain the temperature of their returned chilled water at the level prescribed by the DCP service provider in order to maintain the differential temperature while improving the overall energy efficiency of the DCP plant [8]. The primary and secondary water temperatures in an ETS are expected to fluctuate depending on the ambient temperature. This control technique will keep interior temperatures at a tolerable level while lowering energy expenditures [8].

B. *Temperature Control Technique*

The representation of a typical ETS is illustrated in Figure 1. Installing partial redundancy in the ETS heat exchanger is a common approach, for instance, installing two heat exchangers with a 75% capacity is a general practice. The two heat exchangers operate in tandem to reach their maximum capacity, however, one of them may be shut down for maintenance while the other is active during times of low demand, preventing a disruption in service [8]. Generally, for a typical ETS, two PID loops are configured to control the district cooling return water temperature to maintain the design setpoint based on the signal from the temperature transmitters by modulating the temperature control valves. The control valves are configured in a one-third and two-third flow arrangement, respectively. If the process valve deviates from the set point, the smaller valve located in the bypass line operates first through the primary PID loop to achieve the set point. For example, when the smaller valve, opens up to approximately 70% of its capacity, then the set point is achieved, and the valve will close at approximately 90%. If the set point is not achieved and the smaller valve is 70% open, the bigger valve starts to operate through a secondary PID loop and reaches to 70% of its capacity and stops. If the setpoint is achieved, the bigger valve closes at 100% of its capacity and the smaller valve closes at 90% of its capacity. However, if the setpoint is not achieved with the smaller valve and bigger valve both opened at 70%, the smaller valve opens to 100% to achieve the setpoint. Once the setpoint is achieved, the bigger valve closes to 100% and the smaller valve closes to 90%. In case the setpoint is not achieved with the smaller valve being 100% opened and the bigger valve being 70% opened, the bigger valve again comes into operation and opens 100% to achieve the setpoint. Once the setpoint is reached, the bigger valve closes at 100% of its capacity and the smaller valve closes at 90% of its capacity, as illustrated in Figure 1.

The control valves are selected and sized to closely match the building's real thermal loads. Oversizing the valves results in reduction of their lifecycle. Control valve actuators are chosen to work well with the heat exchanger’s characteristics and are sized properly to ensure that the opening and closing of the valves are under the system's maximum pressure differential. Using two valves connected in parallel and functioning sequentially for higher flow rates are recommended. The two valves are sized to handle one-third and two-thirds of the total capacity, respectively, for best control in the majority of circumstances.

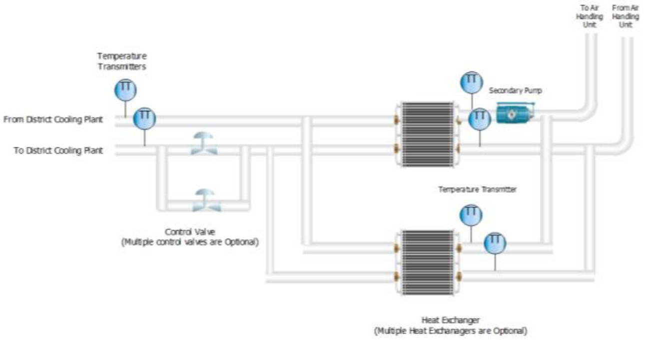

Figure 1- A typical ETS control system – Primary side and Secondary side

III. TEMPERATURE SENSOR OPTIONS FOR ETS

Various techniques are available to measure the temperature in an ETS. A sensor that changes the resistance with a change in the temperature is among the most basic and widely used temperature sensors. A simple ohmmeter can act as a thermometer by interpreting the resistance as a measurement of temperature in the arrangement as shown in Figure 2.

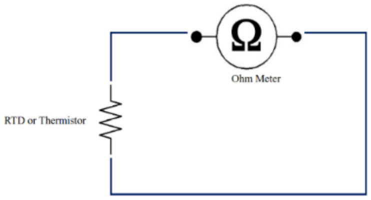

Figure 2. Both RTD and thermistor measure the temperature based on changes in the resistance.

A. *Resistance Temperature Detector*

When an RTD sensor is exposed to temperature, its resistance varies. The resistance of the sensor rises with the rise in the temperature. The corresponding impact of the temperature on resistance of certain metals is well known and is the basis of temperature measurement. Being a passive device, an RTD does not produce an output signal on its own. When the electrical current flows through the RTD strip, the voltage is induced through the RTD assembly, and an arrangement is designed using external electronic components to measure the sensor's resistance [9]. RTDs come in various wiring configurations, for example 2-wire, 3-wire, and 4-wire configurations, as shown in Figure 3.

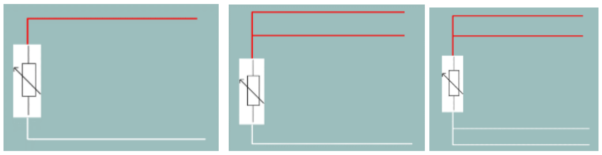

Figure 3. RTD 2-wire, 3-wire and 4-wire configurations with lead wire colors per IEC-60751

B. *Thermistor*

Thermistors are metal oxide-based devices whose resistance either rises with temperature (a positive temperature coefficient) or falls with temperature (a negative temperature coefficient). Individual sensors are carved from thin ceramic sheets to make up the majority of thermistors. The thermistors are completed by adding leads and either encasing them in glass or dipping them in epoxy. The most common thermistors come in glass bead, disc, and chip forms.

IV. DESIGN AND DEVELOPMENT OF THE ETS PROCESS SETUP

A prototype has been implemented to observe the impact of the thermistor as an alternative to the RTD sensor as temperature measurement device. The prototype consists of three layers in line with the ISA-95 pyramid [9].

A. *Network Topology*

The testing had been performed based on the topology, as shown in Figure 4. The engineering laptop shown in this figure is installed with PLC and HMI programming software and is used for engineering purposes.

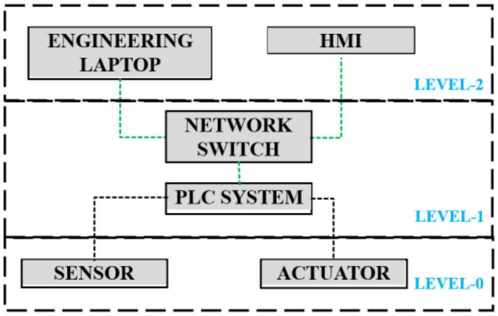

Figure 4. Network Topology for the setup

In line with the ISA-95 pyramid, the level-0 consists of sensing devices such as temperature, pressure and flow instruments that are installed in the chilled water supply and return pipelines and actuators such as valves and variable frequency drives. Level-1 contains a PLC system for sensing the process parameters and manipulating the actuators. The PLC system is a modular control system, with power supply, CPU, communication and I/O (input/output) modules in simplex configuration. Level-2 consists of a panel mount HMI for visualization, monitoring, and controlling of the ETS process.

The sensor and actuators are wired to the PLC system with signal cables to run 4 to 20 mA signals. There are four channels in each of the analog input modules selected for the ETS application. These modules are unipolar, non-isolated and with 12-bit resolution as mentioned in Figure 5.

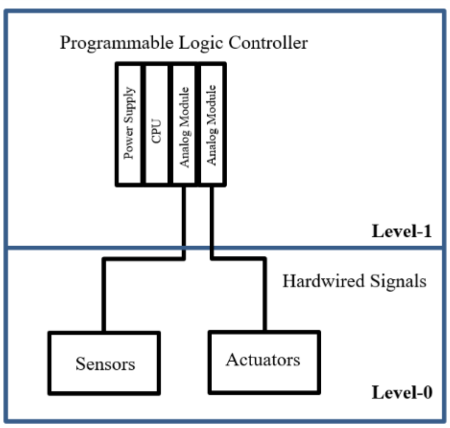

Figure 5. PLC system architecture

The PLC system supports a non-isolated USB 2.0 port, a non-isolated RS-232/RS-485 serial port and a 10/100 base-T Ethernet communication port with RJ-45 connector. The communication between PLC and HMI is established using Ethernet/IP communication protocol through RJ-45 port using an unmanaged network switch.

Connected Components Workbench software has been used for programming the PLC system. The software is based on IEC 61131-3 PLC programming standard and has the instruction set to perform the mathematical, Boolean, floating point and integer calculations. The functional blocks for the counters, timers and PID loops are also available to program the PLC system in line with the ETS application.

B. *Functional Description of ETS Process*

The functional process of a typical ETS system is described in the Piping and Instrumentation Diagram as illustrated in Figure 1. The process is controlled based on the returned temperature of the primary side, supply temperature of the secondary side and position feedback of control valves. ETS has been simulated based on two heat exchangers, and two control valves have been used to control the flow of chilled water. The control valves are sized for 30% and 70% of flow rate, respectively.

An ETS process is based on the open position feedback of the control valves. The position transmitter installed at the control valves helps to obtain the chilled water return flow rate. The smaller control valve at maximum open position allows 30% of flow rate. Similarly, the bigger control valve at maximum open position allows 70% of flow rate. The open position feedback of the control valves helps users to know the chilled water return flow rate. The simulated process is shown in Figure 6. The Control valve ‘CV2_PR’ is the smaller valve and ‘CV1_PR’ control valve is the bigger valve. The return temperature at primary side is ‘TT2’ and supply temperature at secondary side is ‘TT3’.

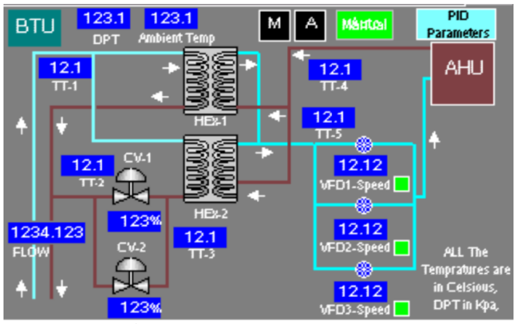

Figure 6. ETS Process Screen

C. *PID Loop Implementation*

A typical ETS process consists of multiple heat exchangers and the control valves are selected and sized accordingly. Based on the overall capacity of the ETS, the ETS process logic and set points are defined. The process variables sense the required chilled water load requirement, and the chilled water is supplied to heat exchangers to maintain the set point. If process values ‘TT2’ or ‘TT3’ deviate from set point (set point is adjustable from HMI based on the required load), ‘CV2’ operates first to achieve set point, until its open position feedback is 70%, then CV2 approaches to 90% (CVs minimum opening positions are operator adjustable from HMI).

If the set point is still not achieved due to additional load requirement and ‘CV2’ is 70% open, then ‘CV1’ comes into operation and opens up to 70% and continues to achieve setpoint. If the set point is reached, then CV1 closes at 100% and CV2 closes at 90%. Furthermore, due to new additional load requirement, if set point is still not achieved and ‘CV2’ is 70% open, and ‘CV1’ is 70%, then CV2 comes again in operation and opens 100% and continues to achieve set point. If the set point is realized, then CV1 closes at 100% and CV2_PR closes at 90%. If set point is not achieved due to the new additional load requirement and ‘CV2’ smaller valve is 100% open, and ‘CV1’ bigger valve is 70%, then CV1 comes again in operation and opens 100% and continues to achieve set point. If the set point is accomplished, then CV1 closes at 100% and CV2 closes at 90%, as illustrated in Figure 6.

V. FUNCTIONALITY COMPARISON BETWEEN RTD AND THERMISTOR

The setup mentioned in the previous section IV is used to take the measurements with RTD as a temperature sensor and then the process is repeated with thermistor. The impact of the readings on the Delta T syndrome is compared and the following observations are made in terms of range, sensitivity and response time, wire length, accuracy, stability, and transmitter output.

A. *Range*

The thermistor datasheet showed that they can be employed between -50°C and 150°C while the RTD based temperature sensors can operate between -260°C to 650°C, as illustrated in Figures 7 and 8 below. Since for an ETS application the design temperature ranges between 4°C and 15°C for a delta T of 9°C, it can be concluded that both RTD and thermistor are suitable for the application.

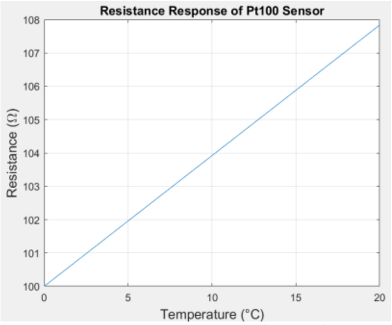

Figure 7. RTD (Pt-100) temperature change from 0 °C to 20 °C

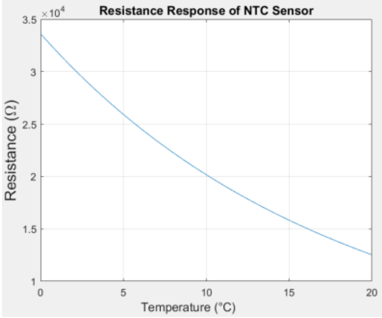

Figure 8. Thermistor temperature change from 0 °C to 20 °C

B. *Sensitivity and Response Time*

Thermistors and RTDs respond to temperature changes by changing their resistance in a predictable manner. The resistance of an RTD sensor changes with a small change in the sensing input as compared to the thermistors, which change resistance by tens of ohms per degree, as shown in Figures 9 and 10 below. It is observed that the thermistor shows higher sensitivity as compared to the RTD. The thermistors are noted to have a very high response time in the range of 0.2 seconds to 10 seconds. On the other hand, the response time of an RTD generally ranges from 2 to 50 seconds. Hence, the response time of a thermistor is proved to be far superior to RTD as mentioned in Figure 11.

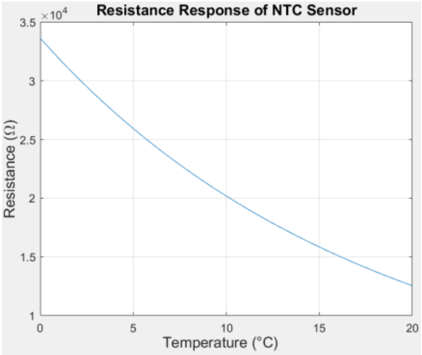

Figure 9. Thermistor Response Time from 0 °C to 20 °C

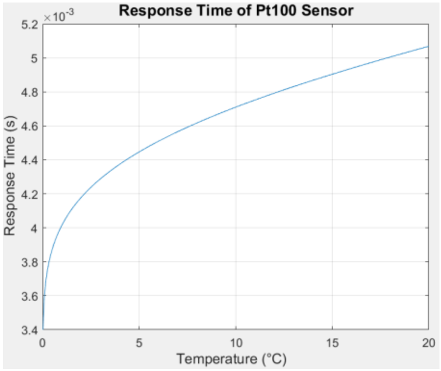

Figure 10. RTD Response Time from 0 °C to 20 °C

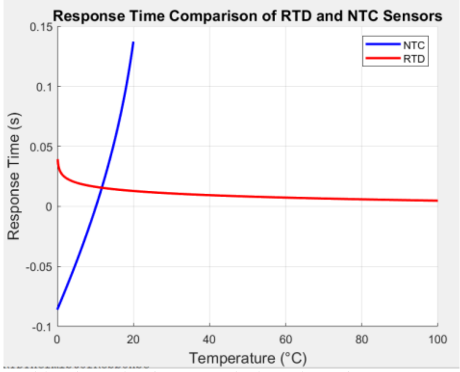

Figure 11. Combined graph of RTD and Thermistor for Response Time from 0 °C to 20 °C

C. *Wire Length*

It is noted that when the RTD wire length is increased more than 15 feet, there is a loss in the signal. However, the thermistors are tested up to the overall length of 500 feet and the extended cable length has no impact on the signal strength between the PLC and the sensor, as shown in Table 1. This observation shows that a transmitter is required to convert the measurement of an RTD sensor to 4 to 20 mA if the longer cable length is required between the PLC system and RTD sensor. Since the thermistors often have resistance values between 10,000 and 2252 ohms, the effect of cable length is typically insignificant. ETS room is usually a small room and hence both RTD and thermistor can be used, however, in case longer cable length is required, the thermistor offers superior performance as compared to RTD.

Table 1. Maximum observed wire length for RTD and thermistor

Sensor Type	**Wire length without transmitter at 20 Deg C**
RTD (Pt100)	12 feet
10K Thermistor	500 feet

D. *Accuracy*

It is observed that the error in the thermistor measurement is in the range of 0.08 to 0.9°C while the RTD is accurate within the range 0.5 to 1°C. The thermistors are made up of semiconductor material and have a negative temperature coefficient and can detect a very small change in the temperature. The RTD on the other hand is made up of metal and hence is less accurate as compared to the thermistor, as shown in Figures 12 and 13.

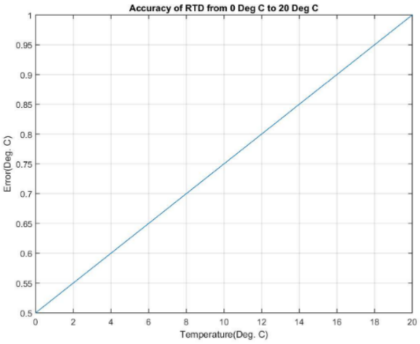

Figure 12. RTD Accuracy from 0 °C to 20 °C

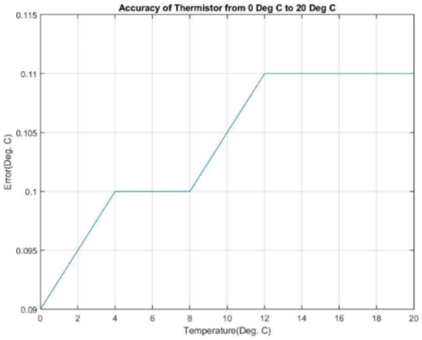

Figure 13. Thermistor Accuracy from 0 °C to 20 °C

E. *Stability*

Over a period, there is a drift in a sensor and its accuracy decreases and hence requires calibration. Such a change in the accuracy over a period is referred to as stability. In the case of a stable sensor, there is a very small drift in the output signal after installation, commissioning, and operation. The RTDs offer very good stability as low as 0.05°C/year. The thermistors are less stable when compared with the RTDs for higher temperature ranges. However, in case of lower temperature ranges that involve the temperature range of up to room temperature, the stability of the thermistors is comparable with RTDs. Typically, an ETS runs on temperatures that are lower than room temperature, hence, even though the RTD sensor is more stable as compared to the thermistor for the overall temperature range, the thermistor is as stable as RTD for lower design temperature ranges in an ETS application.

F. *Transmitter Output*

It is noted for our ETS simulation in the HMI (as shown in Figure 5) that both RTD and thermistor sensors provided robust signal on a hard-wired, 4 to 20 mA loop. However, the observations are not made with other protocols such as Profibus and left for future research. The temperature sensor is interfaced with the controller such as PLC or Direct Digital Controller for translating the analog measurement to digital signal and performing data manipulation. Typically, most controllers are capable of directly interfacing the RTDs and thermistors through special temperature measurement modules. However, the common practice is to use a local transmitter with inbuilt sensor where the transmitter converts the measured resistance value to 4 to 20 mA. In case of RTD sensor, the transmitter is required for longer cable length as observed in Table 1. The transmitter is then wired with the analog input module of the controller. The local transmitter provides additional information by superimposing the Highway Addressable Remote Transducer (HART) protocol on the 4 to 20 mA loop. The advanced ETS projects may specify digital communication protocols such as Profibus for temperature transmitters. In such cases, the controllers are required to have adequate communication modules or gateways to collect the data from the transmitters.

The RTD transmitters are available in the market with major communication options such as 4 to 20 mA, HART and Profibus. However, in case of thermistor, the option for selecting the transmitters is very limited. So, for the projects where advanced digital communication is specified, the thermistors could not be considered.

G. Commercial Impact

The RTD sensor costs around 2 to 3 times more than that of thermistor. In case of tight budgets, the thermistor offers a cost-effective alternative solution when compared with the RTD sensors. The lead time of RTD sensor is generally higher than thermistors and thermistors are a better option for tight project schedules.

H. Impact of Temperature Sensor Selection of Low Delta T Syndrome

It was discovered during the experiment that the identification and diagnosis of low delta T syndrome in ETS applications might be significantly impacted by the accuracy of temperature sensors. It was observed that erroneous temperature measurements resulted in false assumptions about the performance of the ETS, making it challenging to locate and address the root causes of low delta T syndrome. Inaccurate temperature data were simulated, and it was noted that when a temperature sensor reads a temperature that is too high or excessively low, it may suggest that the system is having difficulty because the delta T is low when, in reality, the issue was with the sensor.

In practice, choosing the wrong sensor can result in pointless system modifications or fixes that don't genuinely address the issue. On the other hand, it was discovered that a highly accurate and dependable temperature sensor aids in detecting the underlying cause of low delta T, such as a pump or heat exchanger issue, and empowers the technician to make the appropriate modifications to resolve the issue.

VI. CONCLUSION

The proper functioning of the control system and related process instruments plays an important role in avoiding the low delta T syndrome in an ETS. An improper selection of the controller and field instruments will result in higher water flow from the DCP to the ETS and push the pumps to consume more energy with adverse impact on the overall efficiency of a DCP and hence ETS. Since temperature measurement plays an important role in the proper function of the ETS, the selection of the temperature sensor should be considered in line with the guidelines of international and local standards.

When accuracy, longer cable length, response time, and sensitivity are the main factors for temperature sensor selection, it can be noted that the thermistor offers better results as compared to RTD. The selection between RTD and thermistor does not have any impact on the temperature range required to be measured for chilled water application. It has also been noted that if the stability and smaller drift are taken into consideration, the specifications of RTD and thermistor are comparable for an ETS application. The thermistors are made up of mixed metal oxides while the RTDs are constructed with pure metals such as platinum, hence the thermistors offer a cost-effective temperature measurement solution as compared to RTDs.

Based on the comparisons between the parameters of RTD and thermistors, it is observed that replacing the RTD with the thermistor gives improved results and does not impact the delta-T syndrome and hence, the thermistors offer a cost-effective alternative for an RTD. In this paper, the authors compared the specifications of RTD and thermistors and observed that the thermistor is an economical alternative to RTD sensor and does not impact the delta-T syndrome for an ETS. As future research, a broad study of RTDs, thermocouples, and thermistors will be performed and their impact on the Delta T syndrome will be investigated. Currently, the RTD sensors are used to measure the temperature for the TES thermal storage tanks in a DCP plant. The authors will also focus on the alternative temperature sensing devices such as thermistors or thermocouples and their impact on the efficiency on the TES tanks.

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