# Automated Bridge De-icer

# Final Project Report

**By**


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**URL: https://sites.google.com/site/automatedbridgedeicer/**

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## Letter of Transmittal

Dr. Pan Agathoklis
Professor of Electrical Engineering
University of Victoria

December 2, 2012

Dear Dr Agathoklis,

Please accept the attached ELEC 399 report entitled "Automated Bridge De-icer Final Project Report"

The attached report outlines the work completed throughout the fall 2012 semester for ELEC 399. During this course our project group was tasked with selecting and developing a product for our ELEC 399 design course. The project that we chose to design has the potential be utilized in ELEC 499.

While designing this project our group learned important criteria in 3 different areas. The first area was the process of selecting a heating method to melt ice that could form on the surface of a bridge. The second area was to find a way to control the heating elements to melt ice in an efficient manner. The final area was to design a power system capable of supplying power to the heating elements.

By dividing the work load among our group members, we were able to learn more about project management.

We would like to thank you for all your time and effort as our project supervisor.

Sincerely,
Coleton Denninger
David Turcios
Nathan Hardy
Tyler Jukes
Wesley Keim

## Summary

As the world changes and develops regulations for road safety become more and more of an amplified subject of debate among the public. Many fatal accidents are caused every year during the winter months by unsuspecting drivers caught off guard by ice covered bridge decks. This project will provide the ability to significantly reduce the chances of vehicle accidents and structural damage during the cold winter months on bridges. For this project many ideas came into consideration:

(1) Hydronic Systems which use a heated liquid circulated through embedded piping to heat the bridge surface.
(2) Resistive Element Systems which use an embedded coil in the concrete to produce heat by passing a current through it.
(3) Conductive Concrete Systems which use the conductive and resistive properties of the bridge deck itself to produce heat.

When comparing these technologies it was determined that *Conductive Concrete* technology provided the best combination of performance and reliability with comparatively low maintenance requirements.
Using an inexpensive microcontroller based control system and a power system that was designed by balancing safe voltage levels and desired power densities we were able to create a product that can effectively prevent the icing of a bridge deck.

Many fatal accidents are caused every year during the winter months by unsuspecting drivers caught off guard by ice covered bridge decks. Not only are these types of accidents a tragedy, they can become very expensive. This product can solve the risk of fatal accidents on icy bridge decks by effectively preventing the risk from being apparent in the first place.

## 1.0 Introduction

Road safety is a very important aspect in modern societies and become more and more of an amplified subject of debate among the public. Many fatal accidents are caused every year during the winter months by unsuspecting drivers caught off guard by ice covered bridge decks. This project will outlines a solution to significantly reduce the chances of vehicle accidents and structural damage during the cold winter months on bridges.

### 1.1 Problem

The most insidious type of road icing threat comes from bridges and overpasses. Those signs you always see *are* true. A bridge is exposed to air on all of its surfaces - on top, underneath and on its sides. By contrast, a normal road surface is only exposed to air on one side, its top surface. When temperatures drop, this means bridges will cool and accumulate snow and ice faster than roadways on solid ground, this effect is seen in the image below [6].


**Figure 1:** *Typical cycle for ice formation on a bridge*

An icy bridge's most dangerous threat is their element of surprise - they catch drivers off guard, who are travelling at full speed because the rest of the roads are either clear or just a little wet. The consequences of driving onto ice at highway speeds can be catastrophic, as the loss of control and impacts happen much faster than in most other conditions. Slides are often unrecoverable and chain-reaction type accidents are common, as additional vehicles will often lose control in the exact same location.

The goal of this project was to develop a product that can help prevent accidents on busy bridges prone to icy conditions. This product could ultimately eliminate the risk of accidents due to an icy bridge, which would not only save money to all parties involved, but could also save lives.

### 1.2 Scope

The content of the report is divided into three main sections, and will include: (1) Selection process for the de-icing system, (2) Implementation of the chosen system, and (3) Provision of further insight into complications that may be involved with the implementation of said system.
The report will begin by providing a brief description of existing approaches which are currently employed for the de-icing of concrete structures. It will then describe the reasoning that lead to the selection of our particular de-icing system, as well as, a description of the individual sub-systems that make up the whole.

The implementation portion of the report will provide thorough detail regarding the individual sub-systems of the de-icing system, which includes: (1) The heating system, (2) the control system, and (3) the power system. Upon completion of describing system implementation, the report will provide information pertaining to complications that may arise when deploying the automated bridge de-icer.

Complications involved with implementation includes: safety precautions, restraints encountered during the design process, and system limitations that may be encountered in practice. In addition to providing detailed installation and functional descriptions of the automated bridge de-icer, the report contains an Appendix section, where, one may locate information pertaining to component datasheets and important external resources.

### 1.3 Previous Designs

Ice removal systems for bridges have been explored in the past, however most systems were implemented to determine feasibility and were never intended for mainstream application. There are several different ice removal technologies that have been tried: (1) Heated liquid circulation, (2) Electrical coil heating, (3) Conductive concrete heating, (4) Chemical spray.

These systems are compared in more detail in *Section 2.1, Solutions Considered*. To get a better understanding of what's required for the design of an ice removal system as well as the challenges that have been encountered in the past research was done on real world implementations of the different methods. Interestingly, the vast majority applications in heated bridge technology have been implemented in the United States. Typically the control systems for existing heated bridges are based on environmental factors such as humidity, temperature and wind velocity. This is a method that has the potential to be improved in terms of energy efficiency, because heating is applied every time the temperature drops below freezing (for example) and can't check to see if there is actually snow or ice present. The following overviews are of commissioned projects in the United States.

### 1.3.1 Oregon Highland Interchange [1]

This is an overpass over US Highway 26 in Oregon that uses resistive coil heating capable of producing 323W/m$^2$. The heated section of the bridge is approximately 39m long and covers around 431m$^2$. The heater coils were installed on the bridge deck and a layer of microsilica concrete was then poured over top. Previsions were made to allow for thermal expansion.

This particular project also included heated approach roads in addition to the bridge itself. *Figure 2* below shows a plan view of the installation details for the resistive coils.

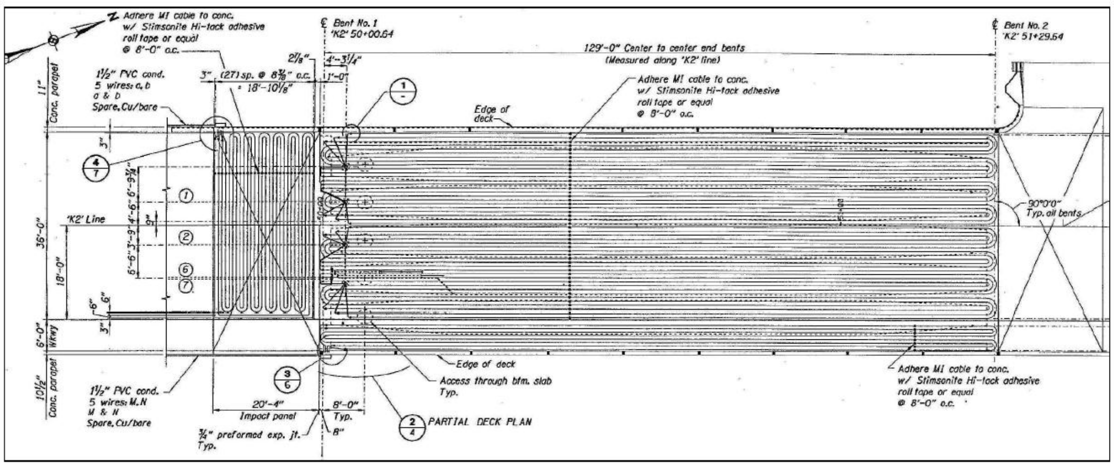


**Figure 2:** *Plan View of Highland Interchange Resistive Coil Installation Details [1]*

### 1.3.2 Oregon Silver Creek Bridge [1]

The Silver Creek Bridge is on a curve and is 274m long. A 32m curved section of the bridge is heated using a ground source heat pump to heat a propylene glycol mixture, which is then circulated through 5/8" embedded tubing in the bridge deck. The design heat input is 394W/m$^2$. Expansion allowances are extremely important with hydronic designs because piping is prone to leaking or breaking if the bridge moves, which would disable the system and require costly repairs. Another risk involved, especially when using ground water source wells, is the pipes freezing. This can also cause severe damage to inaccessible parts of the system.

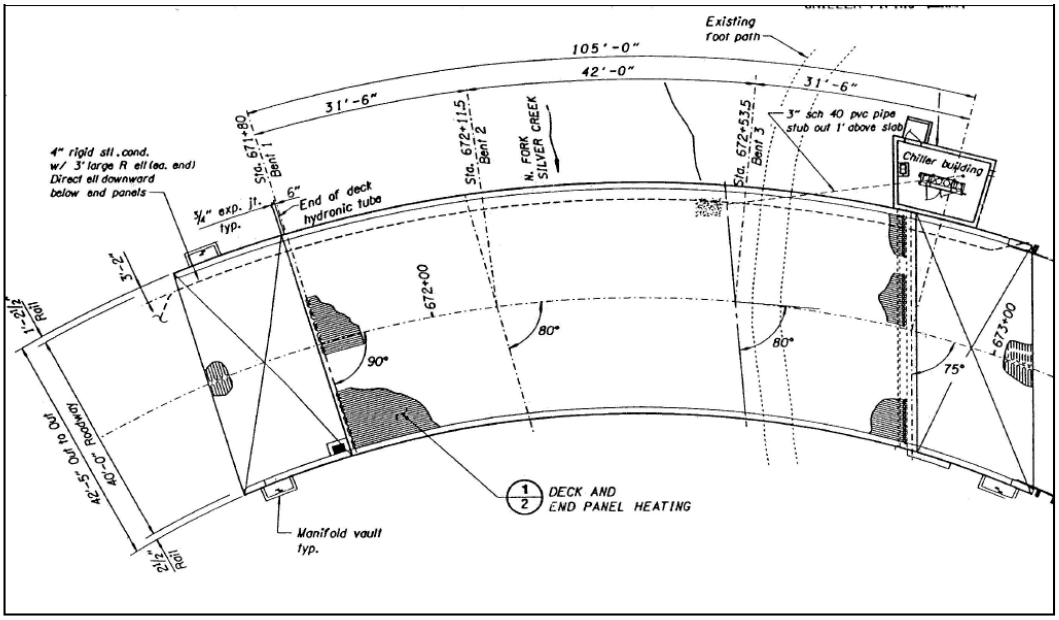


**Figure 3:** *Plan View of Silver Creek Bridge Heated Section [1]*

### 1.3.3 Nebraska Roca Spur Bridge [2]

The Roca Spur Bridge over the Salt Creek in Nebraska was the first heated deck bridge in the world to use conductive concrete as the heating method. The bridge was completed in 2002 and the concrete mix used was specially developed by the Nebraska Department of Roads for bridge deck heating applications. While this technology is still relatively new even today, conductive concrete mixes are now readily available. The heated section of the bridge is 35m long and 8.5m wide. The heated area needs to be broken up into individual slabs when using conductive concrete so that lower voltages can be used to obtain the proper current and heating values. In this case, 52 individual slabs were used (see Figure 3 below for the general conductive concrete slab layout). Each slab was energized by a 240V power supply.

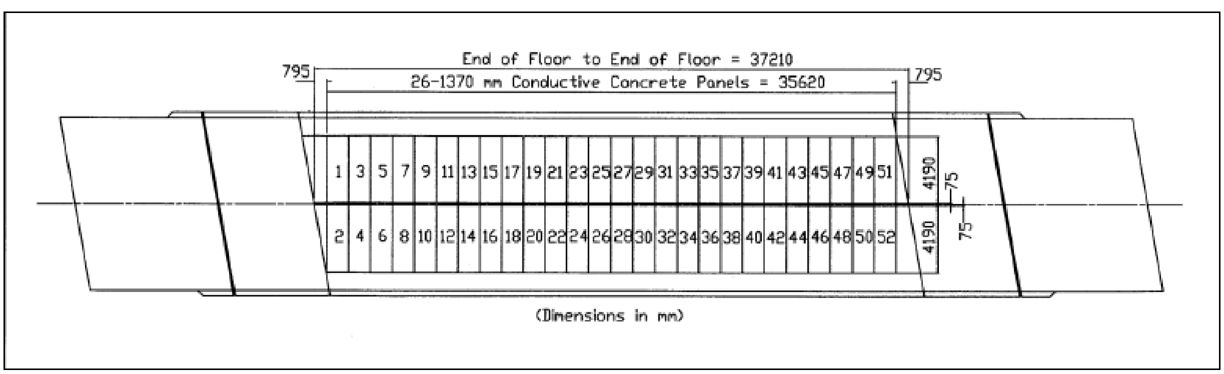


**Figure 4:** *General Layout of Conductive Concrete Slabs for the Roca Spur Bridge [2]*

This particular project achieved a high level of performance in addition to having several advantages over other methods in terms of maintenance and the construction process. For example, normal expansion joints can be used because the power connections are only connected to the deck itself and there is no piping or wiring going across the expansion joints. All the parts of the system are accessible for repairs and maintenance as well since the deck itself is the conduction medium. In addition, there is no risk of cables or piping being ripped out by snowplows or heavy trucks, or being corroded by salting trucks.

## 2.0 Solution

The design of this project was broken up into three categories: the heating, the controls, and the power. The design solutions chosen were evaluated according to their performance, cost, and simplicity.

### 2.1 De-Icing Solutions Considered

There are various methods and technologies that can be used in automatic de-icing applications. Here is a comparison of several systems that were considered for this project:

#### 2.1.1 Chemical De-icing spray system

There are several types of chemicals that can be sprayed on a surface to eliminate ice. In this scenario, ice detection instruments would determine if there is ice present, and then nozzles imbedded in the side structure of the bridge would spray the de-icing solution evenly on the bridge deck.

Pros

- Energy efficient. The system only requires power to run the intermittent pump/spray system and a small number of instruments.
- Fast de-icing operation.
- Can be retrofitted to an existing bridge.
- Most pieces are easily accessible for future work or repairs.

Cons

- Maintenance intensive. De-icing solution needs to be refilled, piping needs to be kept clean and clear.
- Long term use of chemical de-icing sprays is known to cause corrosion and structural damage, reducing the life span of the bridge and increasing maintenance costs.

#### 2.1.2 Heated Glycol Circulation (Hydronic)

This system requires piping to be embedded in the bridge deck. A heated storage tank would supply glycol to a pumping system which would circulate the glycol through the bridge deck. Although the pump system only needs to run when ice is present, the heating system needs to be on all the time to provide acceptable melting times (and to prevent pipe freezing if thermal energy is being extracted from a ground well). Geothermal energy sources can be used to reduce this requirement under the right conditions. Expansion allowances are extremely important with hydronic designs because piping is prone to leaking or breaking, which would disable the system and require costly repairs.

Pros

- Potentially more energy efficient.
- High heating performance.

Cons

- Heating system needs to be on constantly.
- Piping system is maintenance intensive.
- Some parts are not accessible for maintenance or repairs without ripping up the deck.
- Can’t be retrofitted to an existing bridge.

### 2.1.3 Heated Resistive Coil

This system uses an imbedded resistive coil in the bridge deck. An electric current is ran through the coil producing heat.

<u>Pros</u>

- Relatively maintenance free.
- Only turns on when ice is present.

<u>Cons</u>

- Large electrical power supply needed.
- Cannot be retrofitted to an existing bridge.

### 2.1.4 Conductive Concrete

The bridge deck itself can be constructed of conductive concrete slabs. When a voltage is applied to the concrete, heat is produced according to the resistivity of the concrete mix and the power supply used.

<u>Pros</u>

- Even heating across the surface.
- Only runs when ice is present.
- Can be retrofitted to an existing bridge.
- Relatively maintenance free.

<u>Cons</u>

- Large electrical power supply needed.

## 2.2 Solution that was selected

The two most important factors in the design of this project were reliability and performance. It was desired to achieve the highest performance while using a reliable technology that was relatively cost effective and low maintenance.

### 2.2.1 Heating

The technologies that were focused on for this project were Resistive Coil Heating and Conductive Concrete heating due to them being low maintenance and reliable over the long term. Hydronic systems simply require too much maintenance and are prone to failure.

To select a heating method, both systems were designed to compare performance and power requirements. *Section 2.2.1.1* and *Section 2.2.1.2* of this report describe the two designs and the parameters that were obtained. In the end it was determined that conductive concrete should be used for this design due to the higher power density (higher performance) obtained.

#### 2.2.1.1 Conductive Concrete

Traditionally concrete has used fly ash as an additive. A major source of fly ash is coal-fired generating stations, where it's removed from the boiler outlet air using bag-houses or electrostatic precipitators before the air is released up the stack. When the Clean Air Energy Act was passed in 1990, it mandated generating stations to significantly reduce the carbon emissions they release into the air. As a result, the air particulate removal systems at these generating stations began removing fly ash with much higher carbon based content than before. An indirect result of this high carbon content was that it produced highly conductive concrete when it's used as an additive. Other methods for conductive concrete are to add metal impurities. The specific mix of additives and metal impurities determines the resistivity properties (and therefore the heating properties) of the concrete as well as the workability of the material.

Conductive concrete has been used in applications that are safe for pedestrian use and has been deemed safe for direct contact up to 240V. This application has been designed to use a 208V 600A 3Ph power supply. This gives a maximum power available of 124.8kW (the bridge slabs are single phase but will use the line to line voltage). A rule of thumb for de-icing applications is that a system should deliver between 200-500W/m$^2$ to be effective. For this project, the goal is to achieve a power density of at least 300W/m$^2$.

Given the desired power density and the available power supply, the dimensions of a bridge are limited by these parameters to ensure acceptable performance. The average lane width on BC highways is 3.7m. Therefore a typical 2 lane highway bridge over a river would be approximately 8m wide. The power density $P_D$ is calculated as depicted in *Equation 1*, below.

$$P_D = \frac{P}{A} = \frac{P}{wl}$$

**Equation 1:** *Calculating power density of conductive concrete*

Therefore the maximum practical length of the bridge for this system can be determined as depicted in *Equation 2*, below.

$$l = \frac{124.8kW}{8m * 300W/m^2} = 52m$$

**Equation 2:** *Maximum practical length of bridge*

For even heating across the bridge deck, the heating layer should be broken up into smaller pieces. For simplicity the bridge was split in half so each piece would be 4m wide. The other dimension was fixed at 2m and the slab thickness will be 100mm. The bridge size for this design should not exceed 52m to maintain performance requirements, therefore a length of 50m will be focused on.

This means the bridge deck will be composed of 50 slabs (25 down each side). To select a possible concrete mixture, the resistivity was calculated for each slab as depicted in *Equation 3*, below.

$$P_{SLAB} = (310W/m^2)(8m^2) = 2480W$$

$$I_{SLAB} = \frac{2480W}{208V} = 11.92A$$

To achieve this current at this voltage each slab must have a resistance of:

$$R_{SLAB} = (208V)(11.92A) = 17.45\Omega$$

Using the designed slab cross sectional area described above, the concrete material used must have a resistivity parameter of:

$$\rho_{SLAB} = \frac{R_{SLAB} * Cross\ Section\ Area}{l} = \frac{17.45\Omega * 0.4m^2}{2m} = 3.49\Omega m$$

**Equation 3:** *Calculating resistivity of conductive concrete*

Refer to *Figure 4* below for sketch of the designed slab dimensions. There is a readily available conductive concrete mix called Conducrete that can provide this resistivity value.

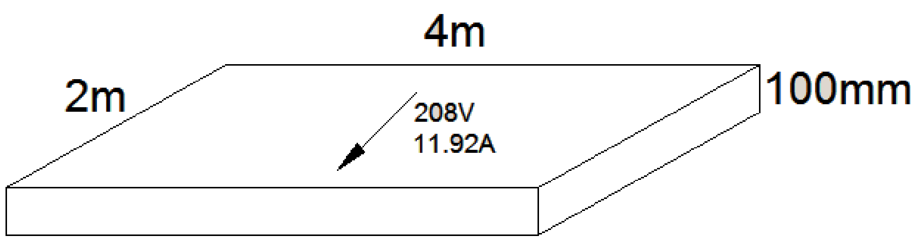


**Figure 5:** *Sketch of the Conductive Concrete Designed Dimensions*

*Figure 6*, below, shows the plan view of the overall bridge deck with 50 heated slabs.

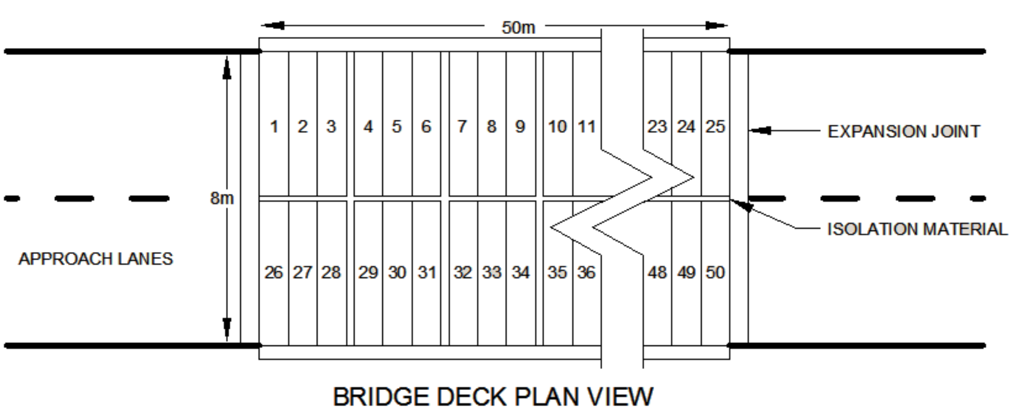


**Figure 6:** *Conductive Concrete Bridge Deck Plan View*

#### 2.2.1.2 Embedded Heating Elements

While researching information on the implementation of embedded heating elements we found an American company that manufactures mineral insulated cables. These cables can be laid out along the bridge prior to paving and work in much the same manner as a resistive element on a stove.

The company that manufactures the cable is called *Tyco Thermal Controls*, and the datasheet for the particular heating cable selected for the system provided the information depicted in *Table 1*, below.

**Table 1:** *Rated values for SUB10 cable from Tyco Thermal Controls*

| | |
|---|---|
| **Length (m)** | *218.5* |
| **Power (W)** | *13.0 x $10^3$* |
| **Voltage (V)** | *208* |
| **Resistance (Ω)** | *3.4* |

In order to maximize the power delivered to the bridge, we found that it would be best to employ a matrix-style configuration when implementing a system consisting of MI cables. This conclusion was made due to the following reasons:

(1) In order to achieve successful de-icing of the bridge we must apply a minimum power density of 300Wm2. Each cable outputs 13kW of power and, a modular approach is the only means of achieving this magnitude of power density.

(2) Employing a matrix, or modular, approach to heating the bridge allows us to reduce the total power consumed, as it enables the ability to heat only certain portions of the bridge at a time.

Implementation of the matrix-style configuration would occur in the manner depicted in *Figure 6*, below.

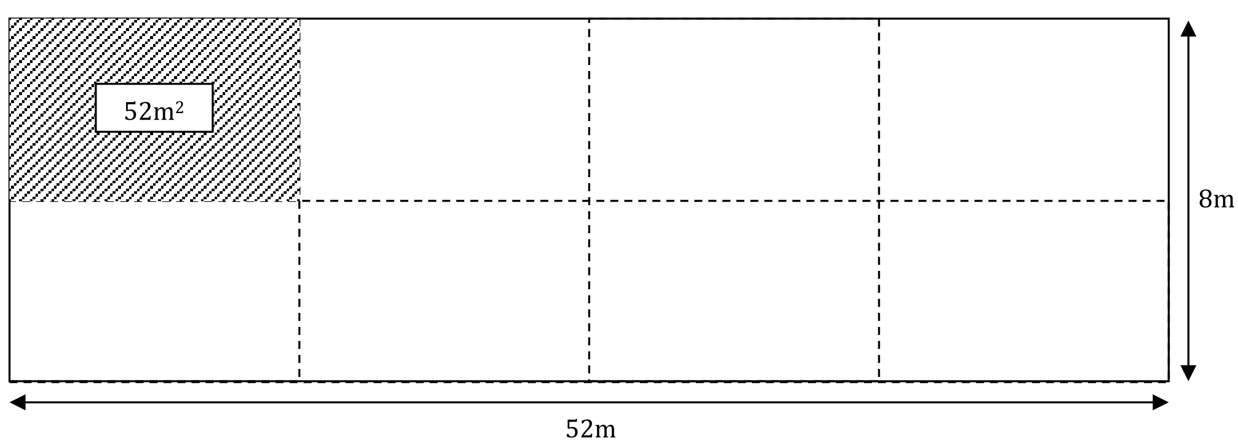


**Figure 7:** *Sample implementation of embedded heating elements*

Employing the modular configuration means that a total of eight cables of *218.5m* in length will be used, and, each cable will have to be carefully coiled to fit into the *52m²* partition. Application of this configuration allows us to calculate the power density of the heating system as depicted in *Equation 4*, below.

$$\frac{P}{m^2} = \frac{13kW}{52m^2} \cong 250\,\frac{W}{m^2}$$

**Equation 4:** *Power density obtained when using embedded heating elements*

The total power consumed by the system can be calculated as depicted in *Equation 5*, below.

$$P_{total} = 8P_{cable} = (8)(13kW) = 104kW$$

**Equation 5:** *Total power consumed when employing embedded heating elements*

As one can see in the calculations, above, the total power consumed by the system yields a relatively moderate value; however, the power density obtained by the system comes short of the $300\frac{W}{m^2}$ required to perform optimal de-icing. Therefore, this allows us to conclude that a heating system composed of embedded heating elements may not be the optimum choice in our case.

### 2.2.2 Controls

A control system, by definition, is a device or set of devices to manage, command, direct, or regulate the behavior of other devices or systems. The ideology of the control system used in this project consists of peripheral sensors, algorithm methodology for decision making, and the ability to directly control the operation of an independent power system external to the control system. The system consists of a weather station and the bridge control system.

Using a weather station allows the control system to accurately control when such conditions for the formation of ice are present. The weather system consists of three different sensors; a temperature sensor (LM32AH from Texas Instruments), a barometric pressure sensor (BMP085 from BOSCH Sensortec), and a humidity sensor (HIH-5030-001 from Honeywell Instruments and Control) as well as a PSoC (CY8C3865LTI-062 from Cypress Semiconductor) microcontroller. The PSoC will read the data from the sensors, and, based on the results, will make calculated decisions.

Using the barometric pressure sensor allows us to accurately tell at which temperature water forms into ice, and, employing the humidity sensor allows us to determine the extent of the amount of ice that will be formed. Taking temperature measurements allows for the on-off control of the bridge de-icing system via the PSoC, which sends information to the microcontroller.

The microcontroller (PIC18F13K22-E/P from Microchip) will handle all of the switching involved with the on-off control of the bridge heating system. Notified by the weather station (PSoC) the bridge microcontroller will receive the calculated temperature and level of humidity and turn on the power to the conductive concrete, which depends on if conditions for ice are present. As the surface temperature of the bridge increases, the microcontroller will monitor it via thermistors (KT103J2 by US Sensor).

Employing a logical algorithm allows the microcontroller to turn on when heating is required, and turn off when the average surface temperature of the bridge exceeds the determined temperature for the formation of ice by a temperature as determine by the humidity. A table outlining the turn off temperature with respect to relative humidity can be seen below in *Table 2*. The controller will then wait until the bridge cools, and will turn back on once the average surface temperature of the bridge drops below this calculated temperature for the formation of ice.

**Table 2: Turn off Time with respect to Relative Humidity**

| Relative Humidity | Turn off Temperature |
|---|---|
| *0-15%* | *$2^oC$ + Calculated Icy Conditions Temperature* |
| *16-40%* | *$3^oC$ + Calculated Icy Conditions Temperature* |
| *41-60%* | *$4^oC$ + Calculated Icy Conditions Temperature* |
| *60-100%* | *$6^oC$ + Calculated Icy Conditions Temperature* |

The bridge control will use a *polling* methodology to gather temperature information from the bridge. It will poll every *30 minutes* to gather temperature information from, not only but the bridge, but the updated temperature and humidity information from the weather system as well.

### 2.2.3 Power

The definition of a power system is an electrical system that generates, transmits, transforms, and distributes electrical energy. The most important design criteria of any power system is to ensure power is supplied to all loads in a safe and efficient manner. The main purpose of the power system that was designed for this project revolves around transforming and distributing electrical energy to various loads. The largest loads for this project would be the heating sections of the bridge. The design of the power system can be broken into two sections. The first is the supply of power and the second is the control of the power system.

The design for supplying power in this project was a design that involved 3 sections of equipment. The first section was the connection to the main power grid. The second section was to transform the voltage to a safe and practical level. The third and last section was to distribute the power to each section of the bridge. The style in which the power is distributed will be discussed in the power system implementation (Section 3.3). These three sections each have a different protection scheme between them to ensure that no equipment is damaged during the operation of the bridge.

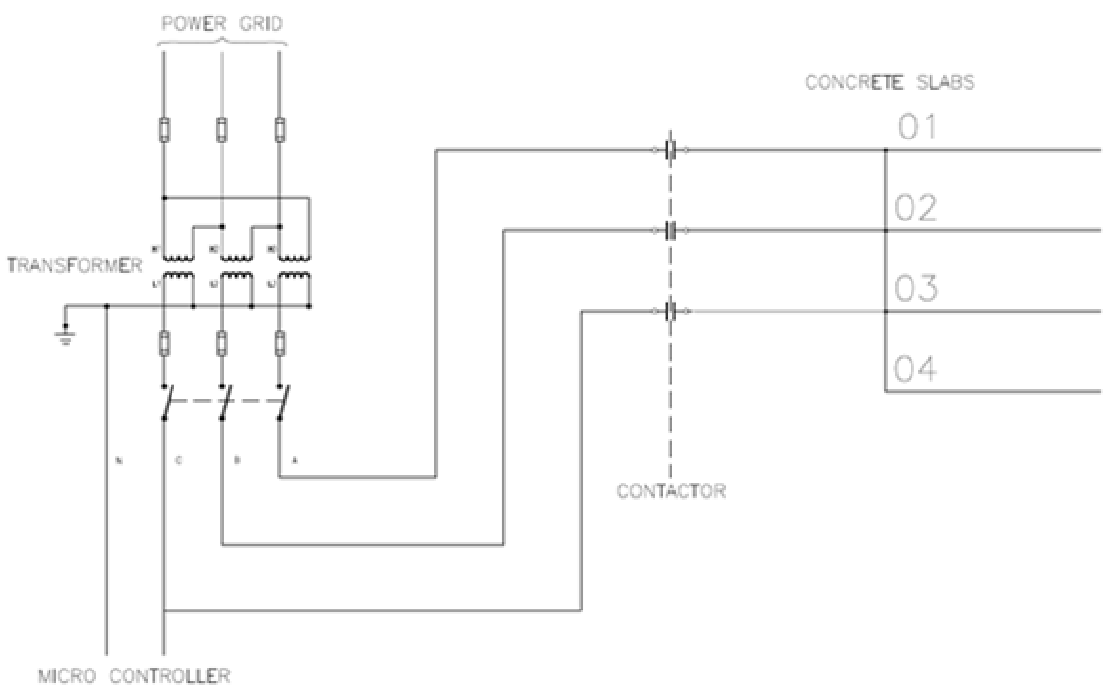


**Figure 8:** *Schematic of power system employed for bridge de-icer*

The design for controlling the distribution of power in this project is in 3 sections. The first section is the bridge control microcontroller. The bridge control microcontroller will output a control signal to multiple relays. These relays represent the second section of controlling the power system. The third section is the contactors that are controlled by the relays in the second section. The contactors will directly control the flow of power to the concrete slabs.

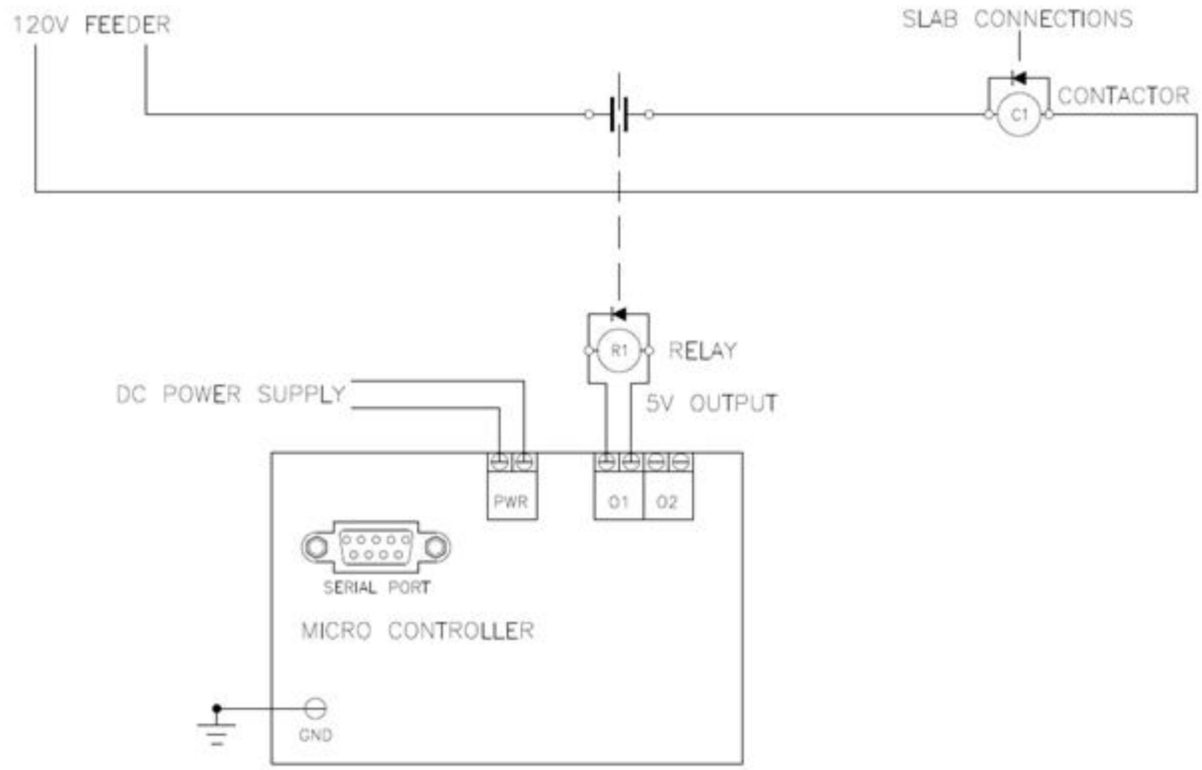


**Figure 9:** *Connecting power system to control system for bridge de-icer*

## 3.0 Implementation

After finding the solutions for the design of the project it was then necessary to find a way to implement these solutions. The three sections below discuss the implementations for the heating, the control, and the power.

### 3.1 Heating System

The best heating system for this project was determined to be a bridge deck consisting of 50 slabs of conductive concrete with dimensions 4m X 2m X 100mm as designed in Section 2.2.1.1. To ensure the heating system operates as designed, an insulating material should be placed to separate the 2 lanes from each other and also break the slabs up into groups of 3. This accomplishes two things:

(1) Dividing the 2 lanes ensures that the loads do not operate in parallel if one section is not energized, which would reduce the effectiveness of the system by causing stray currents and floating voltages in the de-energized sections.
(2) Dividing the slabs into groups of 3 allows the phasing to be connected to minimize load imbalance as described in the power systems section.

The control and power cables running from the control cabinet to the bridge should not cross the expansion joints at either end of the bridge. This reduces the likelihood of them being damaged by thermal expansion of the bridge or by highway vehicles such as snow plows or salting trucks. Although step potential calculations were not completed for this project, testing was completed during the construction of the Roca Spur bridge and found that the step potential at 240V was well within safe limits. Given that the system voltage for this project is significantly less (208V) it's safe to assume that step potential in this case is not an issue. As a precaution, a thin layer of non-conductive concrete could be applied over top of the heating surface to reduce step potential significantly. This would also provide a protective barrier to the heating surface.

### 3.2 Control System

Both Microcontrollers (PsoC from Cypress semiconductors and PIC from Microchip) support the $I_2C$ and SPI communication interfaces, which is ideal for this project. Due to the minimal setup time for $I_2C$, and the fact that the barometric pressure sensor can only communicate via $I_2C$, $I_2C$ was the preferred method of communication for this project. Each sensor is monitored in a different fashion, which really opens this project up in terms of diversity.

The PSoC will be handling the inputs from the TI temperature sensor, the barometric pressure sensor, and the humidity sensor. The temperature sensor will communicate via an analog voltage signal which will be handled via an internal ADC. The digital signal can then be converted from a digital bit sequence to a temperature. The barometric pressure sensor will communicate via $I_2C$, which is fully supported on the PSoC. When the PSoC receives the $I_2C$ data as a 16-bit data stream it will convert it into a pressure reading in kPa. Then using the pressure vs. temperature state change data gathered from the state change diagram located in as *Figure 16* in *Appendix B* will enable the PSoC to calculate an adjusted temperature. This temperature will be a more accurate reading of when the change from liquid $H_2O$ to solid $H_20$ will happen. The humidity sensor is added to the weather system to be able to determine the magnitude of the amount of ice will form due to the general water content of the air. It, like the temperature sensor, has a linear output voltage that will be handled by the PSoC's internal ADC, and conditioned in a similar way as the temperature sensor. The humidity reading will be sent with the adjusted temperature to the bridge control microcontroller via the $I_2C$ communications interface. *Figure 14* in *Appendix B* shows a typical wiring configuration for peripheral sensors using a PSoC.

The temperature sensor for the weather station is the simplest to implement. We chose to use the LM35 Precision Centigrade Temperature Sensor from Texas Instruments. The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. This package operates from 4 to 30 volts, which means we can use the 5V regulated voltage that is tapped from the power system. This temperature sensor provides a linear +10.0 mV/°C scale factor, with a ±0.5°C accuracy guarantee-able at +25°C. This package is rated from a full -55 to +150°C range which makes it suitable for remote locations as well as urban locations. The PSoC will receive the linear voltage via one of its general purpose I/O and internally convert the analog signal to a digital signal.

The barometric temperature sensor for the weather station uses the $I_2C$ communication interface to communicate its information. Its $I_2C$ bus is used to control the sensor, to read calibration data from the $E_2PROM$ and to read the measurement data when the A/D conversion is complete. The chip comes with preloaded calibration data, so depending on the temperature of the chip it can still give an accurate barometric pressure reading. Although the ranges of barometric pressure won't vary much in urban locations (with respect to the temperature at which state change of $H_20$ will happen) it could have an effect in remote locations that are at a large differential altitude from sea level. The sensor will communicate its pressure measurement to the PSoC, who will then handle the data. The sensor runs with a typical supply voltage of 1.8 to 3.6V range. Although we cannot directly connect this to our 5V power bus, we can use a lower voltage zener diode in parallel with the input to create a sufficient input voltage. *Figure 15* in *Appendix B* shows a typical wiring configuration with a microcontroller.

The humidity sensor is a relative humidity sensor, which uses a laser-trimmed, thermoset polymer, capacitive sensing element with on-chip integrated signal conditioning. This sensor provides direct input to a controller or other device which is made possible by this sensor's near linear voltage output. The PSoC will receive the linear voltage via one of its general purpose I/O and internally convert the analog signal to a digital signal. This sensor uses a supply voltage of 5V, which makes it possible to connect it directly to our 5V power bus.

The bridge control microcontroller will be receiving data from the PSoC as well as analog values from bridge temperature sensors. The microcontroller will also be controlling the high power relays that allow the power to flow to the bridge segments. Using the $I_2C$ communication interface, the microcontroller will receive a temperature value, and a humidity value. Thermistors will be embedded in all pieces of the bridge. The microcontroller will convert the analog voltages provided by the thermistors to a temperature using its onboard ADC registers. The thermistors will be embedded in each cement segment of the bridge, providing the microcontroller with the approximate surface temperature for the bridge segment. Using these values, the microcontroller will use a logical algorithm to determine the best time to turn off and on the bridge relays (cooling or heating the bridge). The 50 meter bridge used as an example in this report is comprised of 50 conductive concrete segments. A single bridge control microcontroller will be responsible for 4 bridge segments. Therefore to control the entire bridge 13 bridge control microcontrollers are distributed along its length. Each microcontroller monitors 4 temperature sensors (one temperature sensor per bridge segment). Since one contactor will controls 2 bridge segments, the microcontroller will control two contactors in order to control 4 bridge segments. The diagram in *Figure 9*, below, illustrates the control system with a single microcontroller. (See also *Appendix B*)

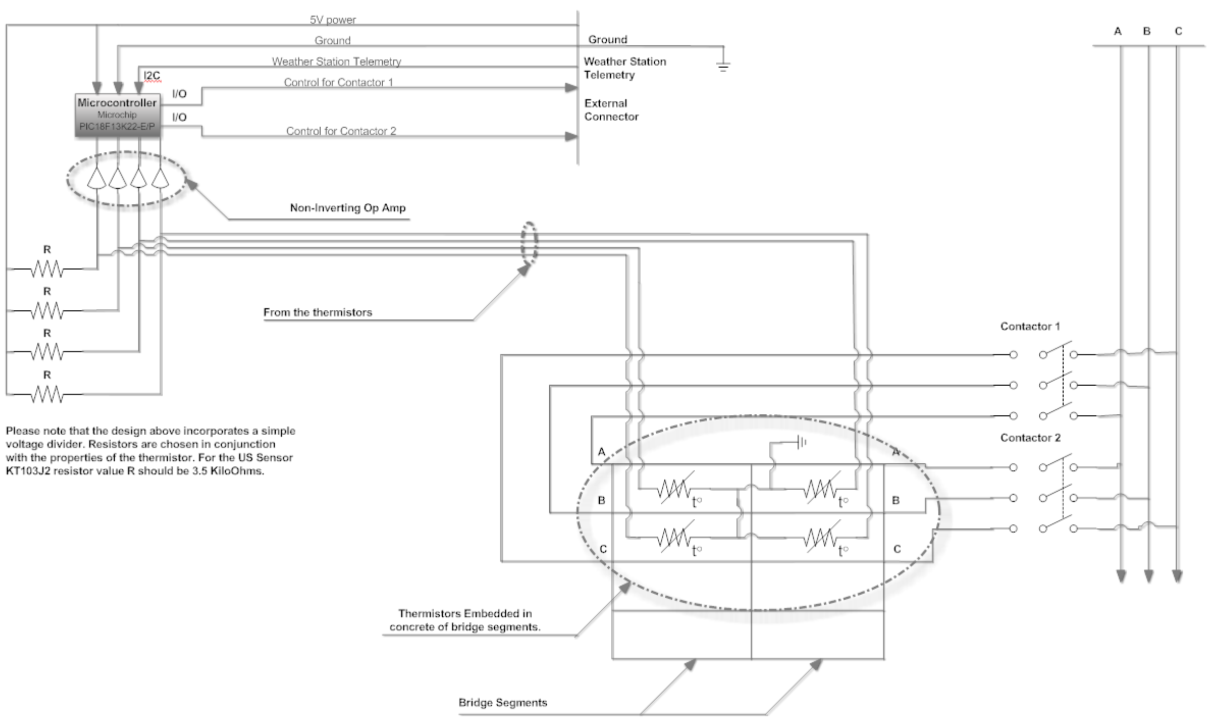


**Figure 10:** *Implementation of control system for bridge de-icer*

The thermistors embedded in the bridge will be monitoring the temperature in each piece of the bridge. As the surface temperature of the bridge increases, or decreases, the resistance of the thermistor will vary with a resistance tolerance of ±0.2°C. By applying a constant current across the thermistor the varying voltage can be monitored via the bridge microcontrollers ADC. This will allow us to accurately satisfy the second condition of when to turn off/on the power to the bridge.

As a whole, this system will be constantly be polling for new information. This will allow the controller to compensate for varying weather conditions. If there are conditions for the formation of ice, the bridge control system will tell the relays to activate, supplying power to the bridge. If the surface temperature of the bridge is a sufficient value, the power to the bridge will be turned off until its surface drops below an acceptable level determined by the weather station. Although the decisions this control system makes seem simple, the algorithms that make these decisions are very sophisticated. The flowchart depicted in *Figure 10*, on the following page, illustrates the operation of the microcontroller. (See also *Appendix B*)

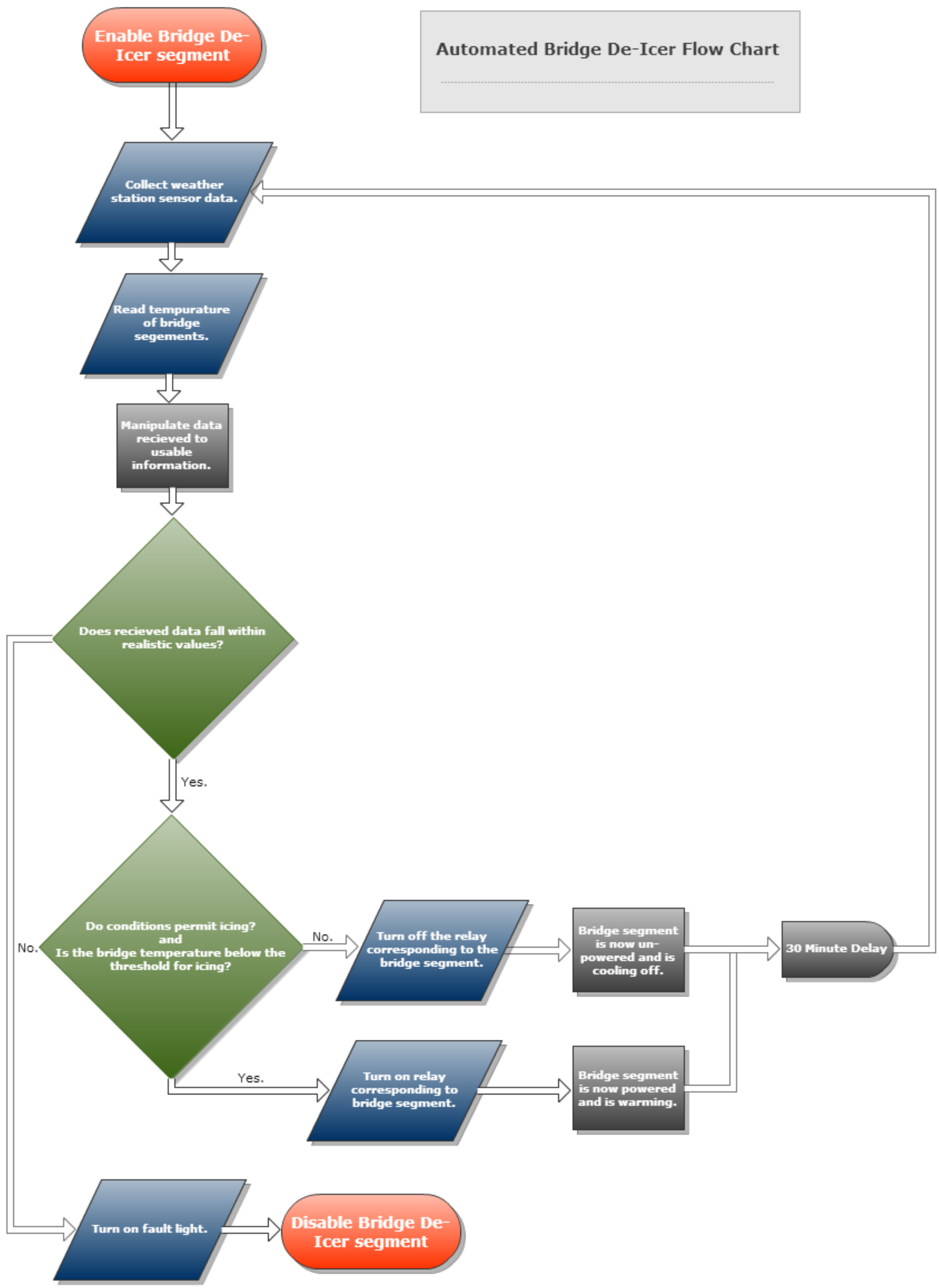


**Figure 11:** *Flow chart depicting operation of the microcontroller*

### 3.3 Power System

The overall layout of the power system implemented for the bridge de-icer will be covered starting with the main power grid connections to the concrete slab connections. The grid voltage was assumed to be 4160V for this implementation. The concrete slab voltage was 208V in this case. All conductors in this implementation will be sized for 90 $^{o}$C. The total demand of the 50 concrete slabs is estimated to be a maximum of 124.8KVA. The first piece of equipment to be discussed is the fuses between the main grid connection and the transformer.

The first equipment encountered when tracing the connection from the power grid to the concrete slabs is the fuses upstream of the transformer. The maximum current for the primary side of the transformer is 26A(This will be proven later). The fuses used in this location were rated for 5.5 kV and rated for 30A (model name: Ferraz Schawmut A055C 30E). These fuses satisfy the requirements of the primary side of the transformer as seen later when selecting conductors for the transformer.

The fuses upstream of the primary windings have two purposes. The first purpose of the fuses is to protect the transformer from any damage if there is a fault in the power grid. The second purpose of the fuses is they can be used as an isolation point to ensure that any maintenance can be conducted with a guarantee of isolation. The next piece of equipment downstream of the fuses is the transformer.

The transformer used in this design is a Delta-Wye connected transformer. The reasoning for picking this transformer as opposed to a secondary delta connection is because some of the equipment used for controlling the power system require 120V (a phase to neutral connection) and the slabs require 208V (a line to line connection). The parts of the control system that require the 120V are the contactors and the DC source used to supply the controls system.

The transformer used for this implementation is the MV3S150SB made by Hammond Power Solutions. This transformer is rated for 150 KVA and can supply 208 / 120V from 4160V. The maximum power the concrete slabs require is 124.8 kVA. A good design practice when sizing transformers is to oversize the transformer by 125%. *Equation 6*, below, outlines the sizing needed.

$$124.8kVA * 125\% = 156kVA$$

**Equation 6:** *Loading calculations for power system*

*Equation 6*, above, indicates that the transformer would need to have a rating of 156 kVA. A transformer with a rating of 150 kVA should be able to satisfy this design criterion. The current calculations for the primary connections and the secondary connections are as follows.

$$I_{Primary} = \frac{S_{total}}{\sqrt{3} * V_{LL}} = \frac{150kVA}{\sqrt{3} * 4160V} = 20.8A$$

$$I_{Secondary} = \frac{S_{total}}{\sqrt{3} * V_{LL}} = \frac{150kVA}{\sqrt{3} * 208V} = 416.35A$$

**Equation 7:** *Current calculations for power system*

As seen in *Equation 6* and *Equation 7*, on the previous page, the primary current is going to be 20.8 A for a maximum load of 150 kVA. The secondary current is going to be 416.35 A for a maximum load of 150 kVA. Just like the transformer, the current values are multiplied by 125% to ensure no damage can take place. The calculations depicted in *Equation 8*, below, outline the new current values.

$$I_{Primary\ rated} = 20.8 * 1.25 = 26A$$

$$I_{Secondary\ rated} = 416.35 * 1.25 = 520A$$

**Equation 8:** *125% current calculations for power system*

The new primary current value is 26 A. The conductor size for the primary side of the transformer is going to be #12 wire [3] which is rated for 30 A. The new secondary current value is 520 A.

The secondary conductors are going to need to be two 4 aught conductors (2*0000) in parallel per phase. These parallel 0000 conductors will allow a combined ampacity of 520A per phase. Both the primary and secondary conductors should be capable of safely supplying power to the entire bridge while all loads are activated.

The 3 pole disconnect acts as a way of disconnecting the secondary windings of the transformer. The disconnect chosen for this bridge also includes fuses for situations where faults may occur. The disconnect chosen was the "Square D D326NTR" which is made by Schneider Electric. This disconnect is rated for 240V and 600A. The fuses which are also shown on the power systems schematic are located within the disconnect and are also rated for 600 A. The last piece of equipment needed before the concrete slabs are the contactors. The contacts used in this project provide control over which sections of the bridge are activated. The 3 pole contactors used for this implementation are rated for 30 A and 208 V. Each contactor controls 2 slabs through 3 connections. This means there is 25 contactors for the 50 slabs of concrete. Each of these contactors are controlled by a relay.

The relays that were chosen for this implementation are known as "Releco IRC Series CSS-AC" which is made by Releco Comat. Each relay controls a single contactor. This means that each relay controls 2 slabs of concrete. The last connection is the connection between the relay and a bridge control microcontroller. One microcontroller is responsible for controlling 2 relays. For more details please refer to the controls section. The last consideration for the implementation of the bridge de-icer is the balancing of power consumption between the three phases.

The orientation of the loads is very important when designing a power system. The 50 concrete slabs in this project need to be connected in a way that allows the system to distribute the current evenly. The best way to achieve this is to look at a small sample of the bridge and then apply it to the bridge entirely.

The best sample would be to look at a 6 sections of the bridge. These 6 sections would involve 9 different connections to the 3 phases with different currents. The schematic diagram depicted in *Figure 11*, below, outlines this concept.

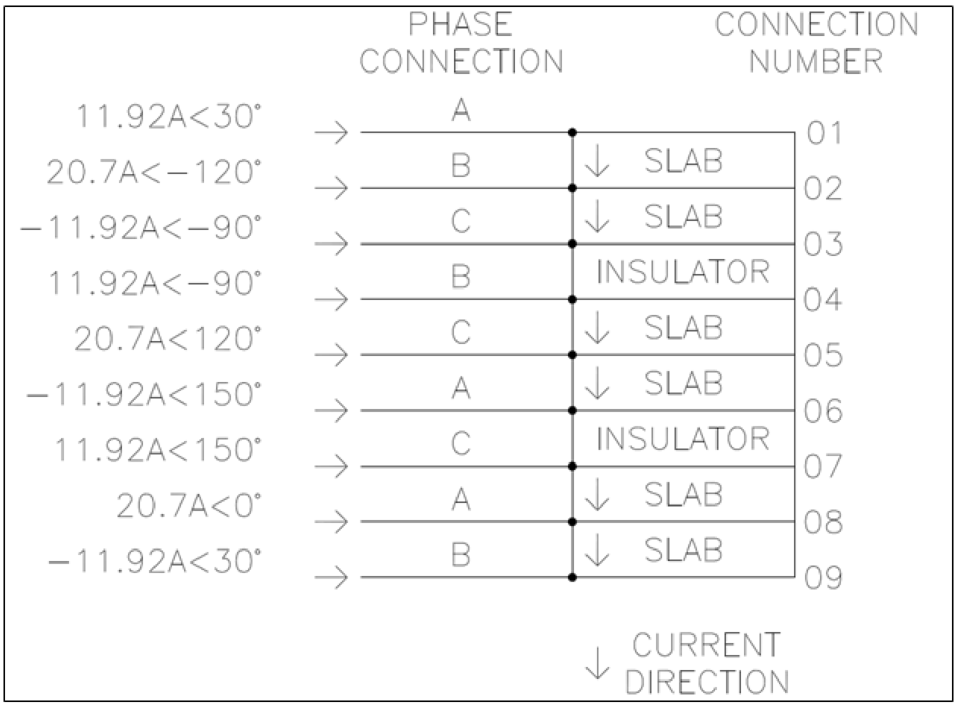


**Figure 12:** *Schematic diagram for connection of concrete slabs*

The sums of the currents outlined in *Figure 11*, above, can be seen in *Equation 9*, below.

$$I_A = I_1 + I_6 + I_8 = 11.92A < 30° - 11.92 < 150° + 20.7A < 0° = 41.35A < 0°$$
$$I_B = I_2 + I_4 + I_9 = 20.7A < -120° + 11.92 < -90° - 11.92A < 30° = 41.35A < -120°$$
$$I_C = I_3 + I_5 + I_7 = -11.92A < -90° + 20.7 < 120° + 11.92A < 150° = 41.35A < 120°$$

**Equation 9:** *Current sums for power system*

The bridge in its entirety has 50 slabs. This means that the bridge will need 75 connections. 48 slabs can be connected using the same configuration throughout the bridge. Because the last 2 slabs are not located side by side they will require 4 connections instead of 3. This means the true total number of connections is 76. The remaining 2 slabs will be connected as follows.

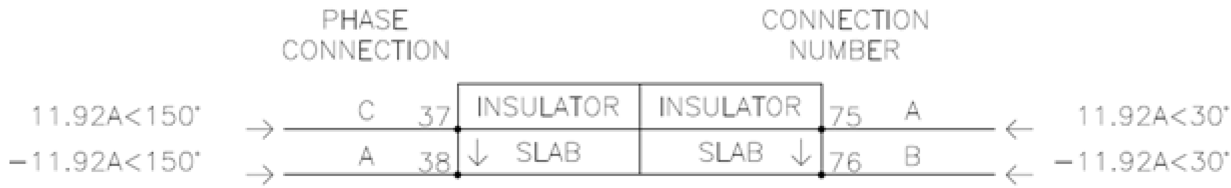


**Figure 13:** *Schematic diagram for connection of remaining concrete slabs*

This means that the bridge will have the current totals depicted in *Equation 10*, below.

$$I_{A\ TOTAL} = I_A * 8 + I_{38} + I_{75} = 41.35A < 0° * 8 - 11.92A < 150° + 11.92A < 30° = 351.41 < 0°$$
$$I_{B\ TOTAL} = I_B * 8 + I_{76} = 41.35A < -120° * 8 - 11.92A < 30° = 341.14A < -121.0°$$
$$I_{C\ TOTAL} = I_A * 8 + I_{37} = 41.35A < 120° * 8 + 11.92A < 150° = 341.14A < 121.0°$$
$$I_{TOTAL} = I_{A\ TOTAL} + I_{B\ TOTAL} + I_{C\ TOTAL} = 351.41 < 0° + 341.14A < -121.0° + 341.14A < 121.0°$$
$$I_{TOTAL\ FULL\ LOAD} = 0.01423 < 0°$$

**Equation 10:** *Current totals for power system*

The total current outlined in *Equation 10*, above, shows how the system has an imbalance of 0.01423 A which is 0.0027% of the rated current for the secondary conductors. This design is more than satisfactory.
The systems layout does have the potential to be imbalanced if the same 2 sections come online using the same phase configuration through the entire bridge. The worst case scenario for the system causes a maximum current imbalance of 2.93 A. This imbalance is 0.5% of the rated current for the secondary winding conductors. This means that there is no need to include a neutral conductor for the concrete slabs. For more details please refer to *Appendix C*.

### 3.4 Cost Analysis

A cost analysis was done on the equipment pertaining to the scope and a Bill of Material is located in Appendix A. The objective of this cost analysis was to get a rough estimate for the main parts of the system and is not intended to be a comprehensive project budget. There are several costs that are not included in this analysis. Namely:

(1) Construction Costs: Labor, construction equipment and extra engineering costs associated with the physical bridge construction were not accounted for.
(2) Excluded Material Costs: Due to fluctuating and application specific prices, power cabling costs were not included.

The vast majority of the cost for this scope is associated with the power system. The transformer feeding the system makes up 45% of the total. The cost for the transformer was made somewhat higher by using a lower secondary voltage since the conductors increase in size. However this also made the remaining power system components less expensive. The entire power system accounted for approximately 96% of the total equipment cost.

The control system chosen for this project was made to be extremely inexpensive using simple off the shelf parts that are easy to obtain. The entire control system bill of material accounted for only 3.5% of the total equipment cost.

To get a more detailed idea of how much a similar project would cost in total, the Roca Spur bridge discussed in *Section 1.3.3* can be looked at as an example since the bridges are very similar in size. The total construction cost for this particular project was cited as $193,175 [2]. The Roca Spur bridge used a much more expensive control system but most of the other parts are comparable and therefore if this project were to actually be built, this would be a good estimate for the total costs

## 4.0 Critical Discussion

This section of the report discusses considerations and complications that may arise with the implementation of the bridge de-icer system. A critical analysis is done of the heating, control, and power solutions used.

### 4.1 Heating System

The initial step in the design of the heating system was to determine what a practical power source could be. A lower voltage was chosen to minimize the safety issues that could become a factor with higher voltages. With a lower voltage, the amount of current required to achieve the desired power level increases and therefore the size of the equipment (transformer, cables, contactors etc.) increases as well as the cost, so there was also a practical current level that we wanted to stay below as well. The decision was made to use a standard power source of 208V and 600A. Once that was determined then the rest of the system could be designed to get maximum heating performance from the power that was available. Overall, there is high confidence that system specified would operate as intended. It was unexpected, however, that the size of the bridge would be so limited. 50m x 8m is much smaller than was originally desired. This means that our design does not scale up for a larger bridge without re-designing large pieces of the power and heating system. If this system were required for a larger bridge, it would be inevitable that a higher voltage would be needed to produce an effective power density (600V is the next common standard in Canada, but 480V could also be investigated if parts were source from the U.S). Another solution could be to revisit the Resistive Element concept if higher voltages are necessary because there is not the potential for direct human contact with electricity.

It would be interesting to re-visit this project with a different end goal. The project could be centered around designing a retrofit system specifically for an existing bridge that is known to be problematic for traffic in the winter months.

### 4.2 Control System

When designing the control system it was necessary to determine what kind of controller to use. The two control options that were considered was PLC's and microcontrollers. In similar projects PLC's have often been used (References 1 and 2).

PLC's are often used because of their capability to handle automation and multiple inputs. For this project a different route was taken by using microcontrollers as control for the bridge. A PLC with the 50 inputs and 50 outputs required to run this particular bridge costs much more than the comparable microcontroller. Another point where the microcontroller bests the PLC is the simplicity of its implementation.

One disadvantage in using microcontrollers is that there are no single microcontrollers produced with the mass number of inputs and outputs required to control the bridge. A way to work around this is to simply use more than one controller. This allows for greater versatility and expandability in our control system by making the control system modular. Finally, by dividing the control of the bridge into small manageable tasks shared over many microcontrollers, design of the control system became much simpler.
To de-ice the bridge we must first know whether the bridge is capable of icing or not. One solution discussed to detect ice upon the bridge was a thermal camera. A thermal camera would provide the control system with detailed readings on icing conditions for different areas of the bridge.

Unfortunately the processing required to implement the thermal camera was beyond the computational capabilities of a microcontroller. A simpler and cheaper solution was devised through the use of a PsoC microcontroller.

The PsoC microcontroller takes readings of the current humidity, temperature, and barometric sensor to determine the temperature required to prevent icing. This temperature is then directly used by other, cheaper, microcontrollers to control the heating and cooling of the bridge. An advantage to this solution is only one device for the entire bridge does the work of interpreting and correlating the information from the weather sensors. This allowed for cheaper microcontrollers to be used throughout the rest of the control system, reducing the overall cost.

### 4.3 Power System

One of the major design considerations for the power system in this project included the different styles in which the loads could be supplied power. The main goal in any power system is to make the loads evenly distributed. This project was no exception. There were a couple of different options for supplying power to the bridge sections. Some of the options that were discussed would make the system unbalanced. An unbalanced system would cause more current to be present in one of the 3 phases. The conductors would need to be sized larger because of the heat caused by the increase in current. This makes the cost of the project increase. This cost is completely unnecessary because the system could be balanced by changing the orientation of the loads. This in turn would make the conductor size decrease. The connection system implemented to provide power in our implementation gave a system that was the most stable.

## 5.0 Conclusion

Bridge icing is a widespread threat to motorists in areas all around the world. Being exposed to air on all sides (and added moisture from rivers in some cases), a bridge deck may be covered in snow and ice while the approaching roadway may be dry or simply wet (since it is insulated on one side by the ground). Many fatal accidents are caused every year during the winter months by unsuspecting drivers caught off guard by ice covered bridge decks.

The primary purpose of this project was to reduce or eliminate this danger by designing an automated system to de-ice a bridge deck or prevent ice from forming at all. Several de-icing technologies were considered:

(1) *Hydronic Systems* which use a heated liquid circulated through embedded piping to heat the bridge surface.
(2) *Resistive Element Systems* which use an embedded coil in the concrete to produce heat by passing a current through it.
(3) *Conductive Concrete Systems* which use the conductive and resistive properties of the bridge deck itself to produce heat.

When comparing these technologies it was determined that Conductive Concrete technology provided the best combination of performance and reliability with comparatively low maintenance requirements.
For this heating method, control and power systems were designed to achieve maximum performance and practicality. A cost effective micro-processor based control systems was sourced and block diagrams were created to describe the operation of heating the bridge based on environmental conditions. The power system was designed by balancing safe voltage levels and desired power densities that ensure ice is able to be eliminated in a timely manner.

This project allowed the exploration of some newer technologies for de-icing applications. A practical bridge de-icer could be created using the many of the same design techniques used in this project. As the electrical properties of conductive concrete are improved and perfected, it is likely that more of these projects will be built in the future to help reduce traffic accidents and make roadways safer.

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## Appendix A (Cost Analysis)

POWER SYSTEM

| Item Description | Rating | Manufacturer | Model No. | Supplier | Qty | Cost PU | Cost |
|---|---|---|---|---|---|---|---|
| TX primary fuse | 5.5kV, 30E Rated Fuse | Ferraz Schawmut | A055C 30E | Mersen | 3 | $411.30 | $1,233.90 |
| Transformer | 4160V-208/120V, 150kVA | Hammond | MV3S150SB | Hammond | 1 | $7,864.00 | $7,864.00 |
| TX secondary fused disconnect | 240V/600A | Square D | D326NTR | Civic Solar | 1 | $1,829.18 | $1,829.18 |
| TX secondary fuses (for disconnect) | 208V/600A | Edison | - | Automation Direct | 3 | $53.00 | $159.00 |
| Power block lugs | 4/0 - #8AWG | Square D | - | EECOL | 6 | $49.75 | $298.50 |
| Power Contactors | 208V, 30A, 3P | Siemens | 42BF35AFNC | Westway Electric | 25 | $189.47 | $4,736.75 |
| Interposing Control Relays | 5VDC In/250VAC out - 3A max | Releco | IRC Series CSS-AC | Turck | 25 | $9.40 | $235.00 |
| Configurable DC Power supply | 120V-12/5VDC - 5A | Arrow | NET2 AC-DC | Arrow | 1 | $500.45 | $500.45 |
| | | | | | | SUBTOTAL | $16,856.78 |

CONTROL SYSTEM

| Item Description | Rating | Manufacturer | Model No. | Supplier | Qty | Cost PU | Cost |
|---|---|---|---|---|---|---|---|
| Temp Sensor - WS | 5Vdc | Texas Instruments | LM32AH | Texas Instruments | 1 | $22.60 | $22.60 |
| Microchip - Bridge Logic | 5Vdc | Microchip | PIC18F13K22-E/P | Microchip | 13 | $2.10 | $27.30 |
| PSoC - Weather station | 5Vcd | Cypress Semiconductor | CY8C3865LTI-062 | Cypress Semiconductor | 1 | $3.25 | $3.25 |
| Humidity Sensor | 5Vdc | Honeywell | HIH-5030-001 | Honeywell | 1 | $4.05 | $4.05 |
| Barometric Pressure Sensor | 1.8-3.6 Vdc | BOSCH Sensortec | BMP085 | BOSCH Sensortec | 1 | $8.19 | $8.19 |
| Temp Sensor - BS | 30mW max | US Sensor | KT103J2 | US Sensor | 50 | $10.73 | $536.50 |
| LED - BS | 2V | Lumex | SSI-LXH600ID-150 | Lumex | 13 | $1.15 | $14.95 |
| | | | | | | SUBTOTAL | $616.84 |

**TOTAL** **$17,473.62**

# Appendix B (Control System)

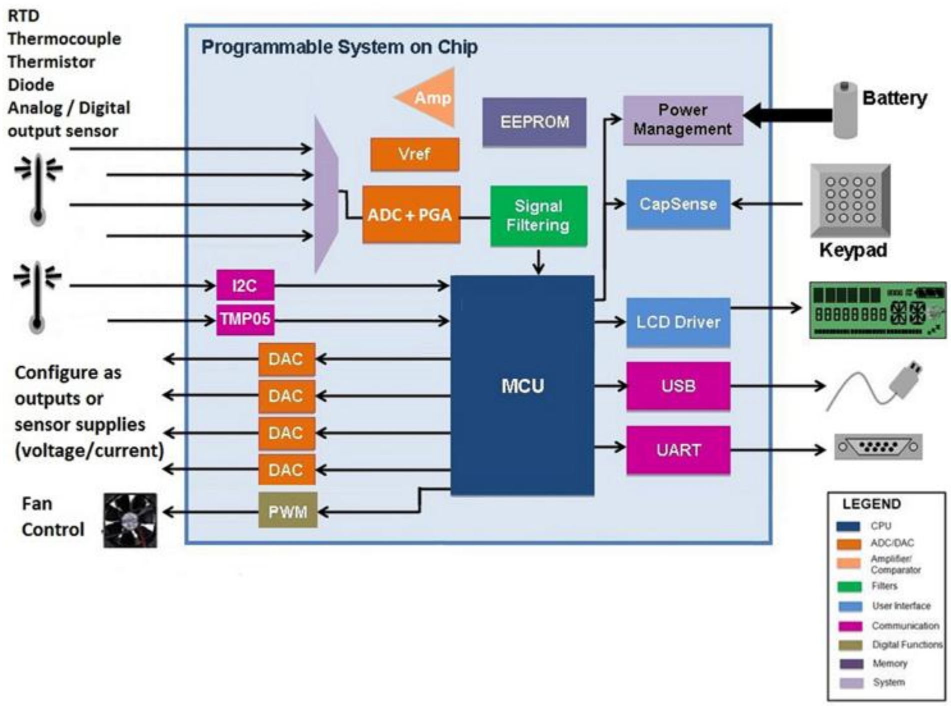


**Figure 14:** *PSOC temperature sensing and control block diagram*

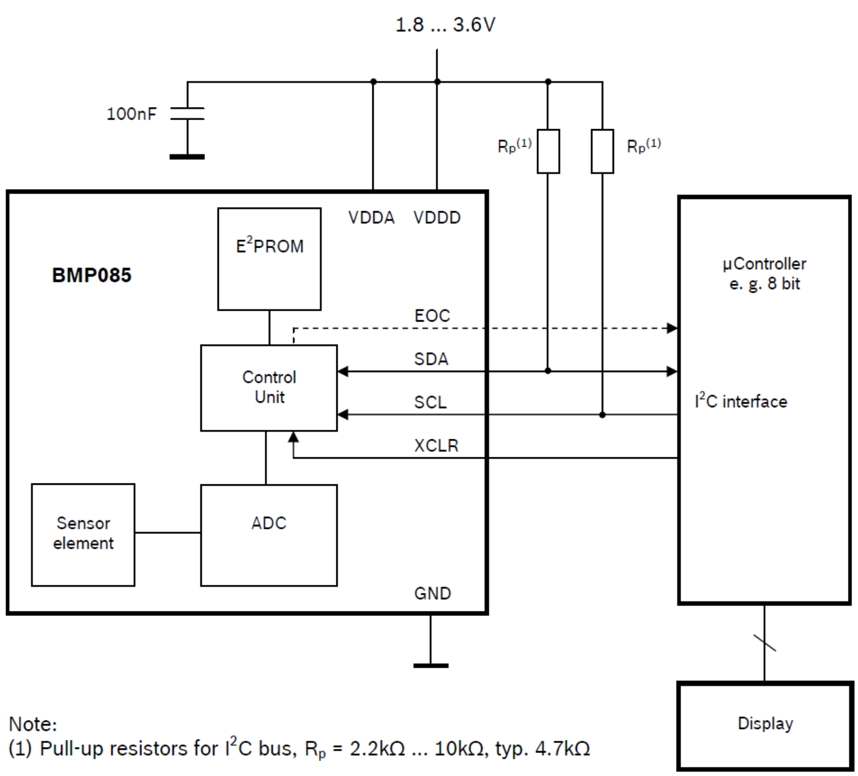


**Figure 15:** *Barometric pressure sensor typical connection diagram*

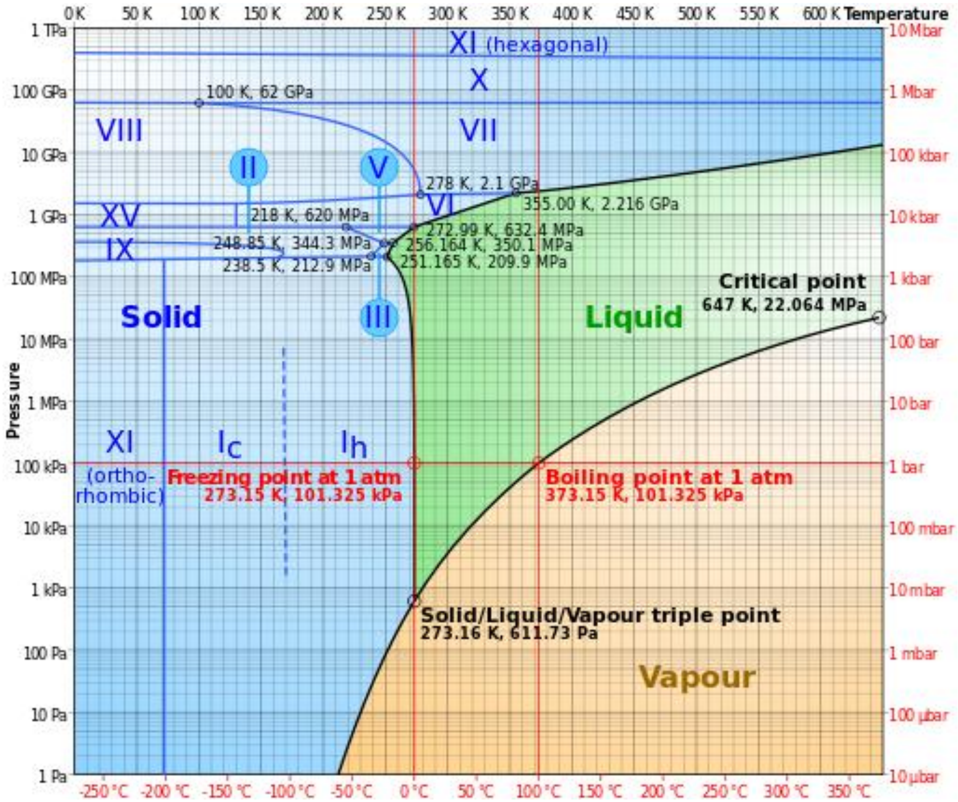


**Figure 16:** *$H_2O$ state change diagram*

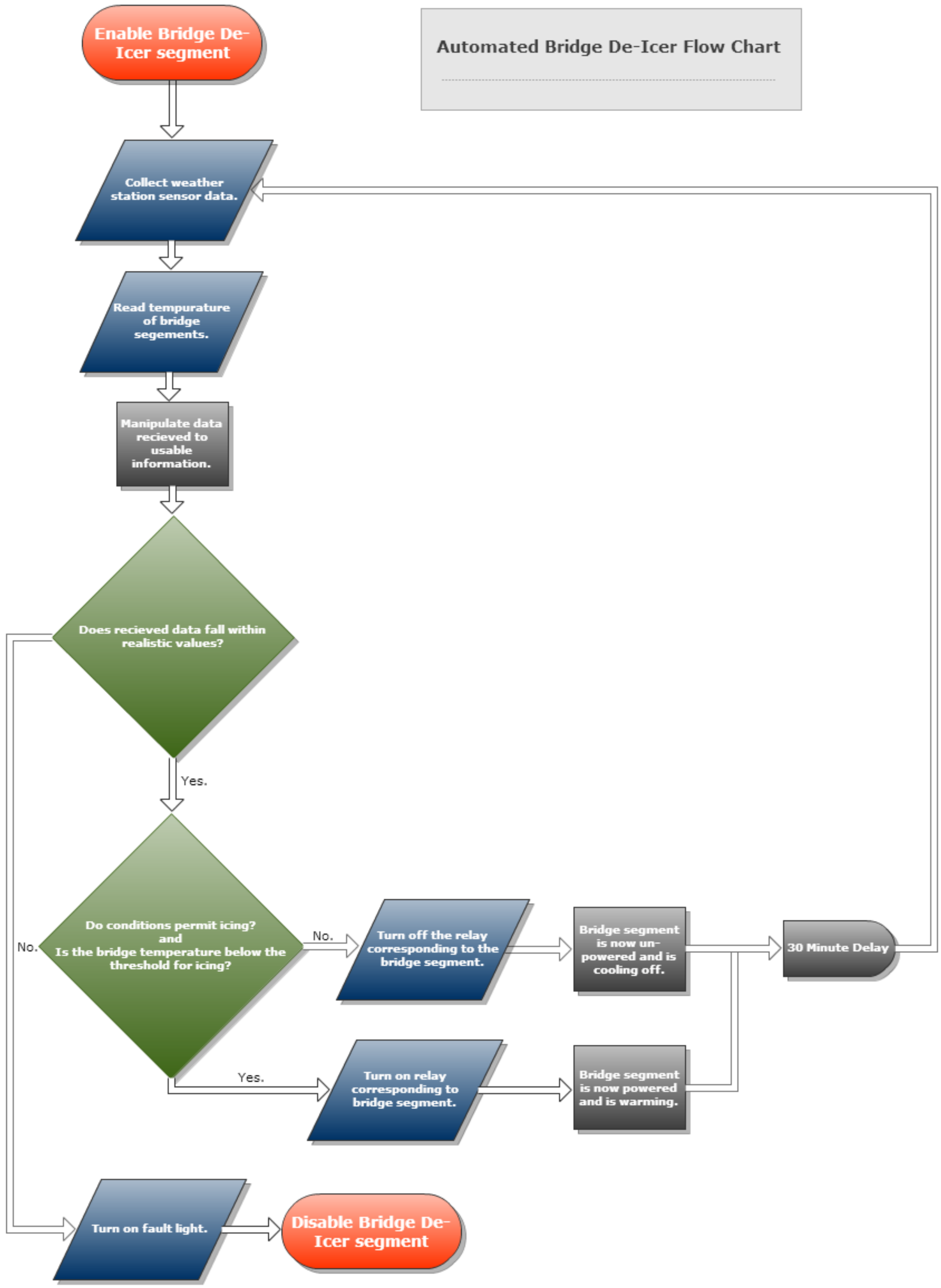


**Figure 17:** *Control system logic algorithm flow-chart*

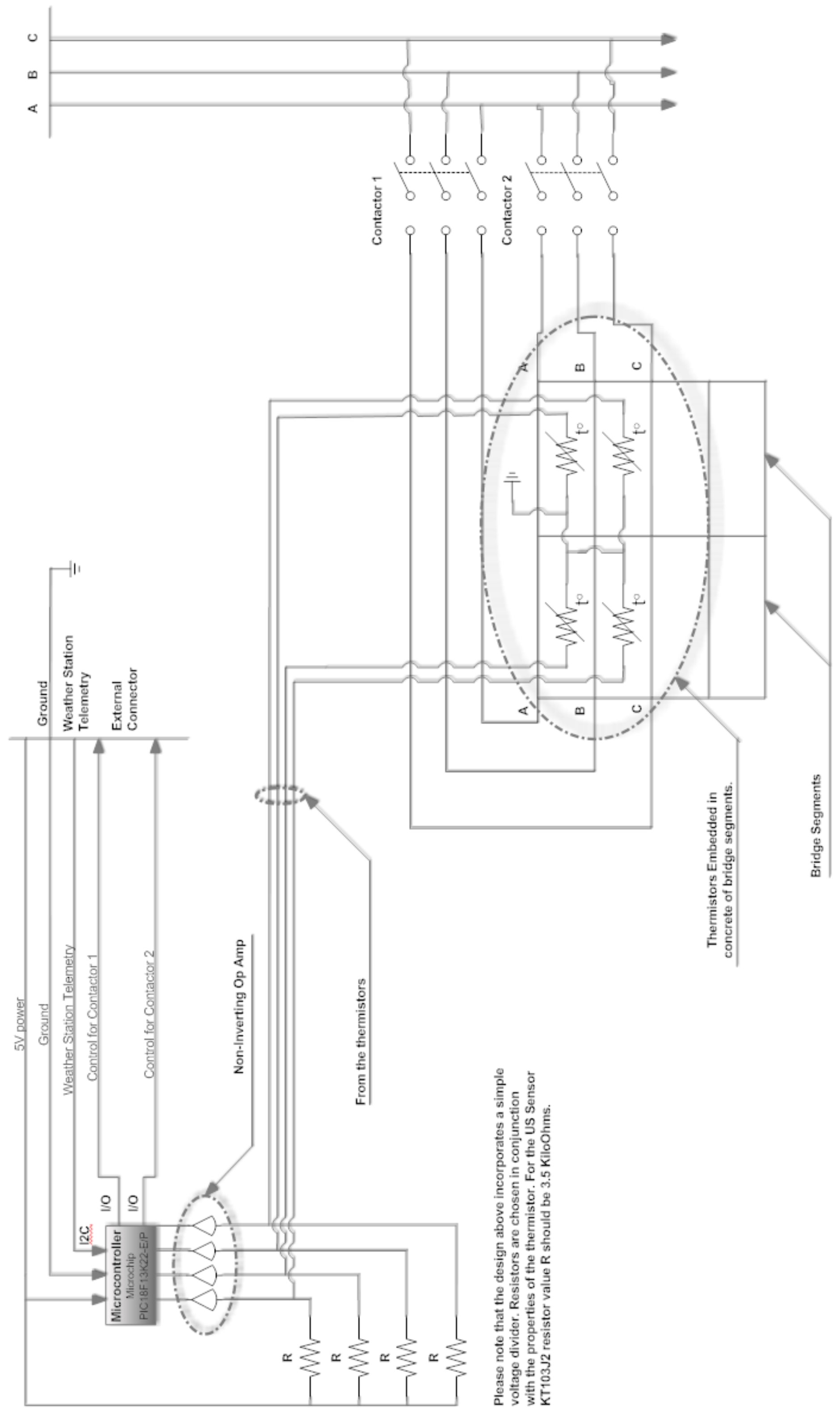


**Figure 18:** *Diagram for control of bridge segment*

## Appendix C (Power System)