DIGITAL SYSTEMS AND MICROPROCESSOR
MCTE 2332

DIGITAL LOGIC DESIGN PROJECT: ALARM SYSTEM IN A NUCLEAR POWER PLANT

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1.0 GOAL OF PROJECT

The objectives of designing this project include:

- Implementing logic gates and its working principles in the industry or everyday life
- Implementing comparators in the design of digital logic circuits and understanding the mechanism
- Relating real life and what was learned in the course by designing a working system that can bring benefits to the society
- Using the knowledge of the industry and making researches based on what is known to implement the learning objectives of this course
- Understanding how sensors work and implementing it in a logic circuit

2.0 DESIGN PROCESS

To implement the knowledge of digital logic design into the real world, one must have a good understanding of the course and a basic grasp of what is happening in the industry, or everyday life. Technological advancements have made humans' lives easier since the start of time, not to mention the contributions of digital systems itself to the betterment of mankind. Be it using a simple circuit for a doorbell, using a calculator, or even a fire alarm system in a building, one can create a digital system that can be beneficial to others with a basic understanding of the course. With that said, I chose to implement digital logic design in a basic alarm system in a nuclear power plant, or more specifically, the nuclear reactor. It's vital to comprehend what is actually happening inside a nuclear reactor to design a working system which can be used for the plant.

Nuclear reactors are the most essential part of a nuclear power plant. You can also describe it as being the heart of the plant itself. The reactors contain and control nuclear chain reactions that will produce heat through a process called fission. The heat that is produced from the fission reaction is used to make steam that spins a turbine, which in turns create electricity. Nuclear power is one of the largest sources of carbon-free electricity available, which is very important in this day and age where sustainable resources is needed more than ever.

Like all the other industries, the nuclear industry is not immune from accidents, in fact there are three major accidents that have occurred in the past – Three Mile Island, Chernobyl, and Fukushima. Nevertheless, evidence over six decades proved that nuclear power is safe, as the risk of accidents in the plants is low and declining. The design and operation of nuclear power plants aims to minimize the likelihood of accidents, and to avoid major human consequences when they occur. The safety elements focus on unintended conditions or events that can lead to radiological releases from authorized activities. This stems from intrinsic problems or hazards, which are mainly happening inside the reactor.

The biggest potential hazard that can occur inside a nuclear power plant is a nuclear meltdown, which is what was happening in Chernobyl, Ukraine. The plant experienced fires, explosions, and radiation leakage, resulting fatalities from acute radiation syndrome and fatal cancers and birth defects in the following years. These events were caused by design flaws and operator errors, which need to be highly considered in maintaining a safe system.

Inside the core of a nuclear reactor are thousands of long, thin fuel rods made of zirconium alloy which contains uranium. Fresh water flows round the fuel rods to keep it from overheating and also to produce steam from the turbine. As the fission reaction proceeds, the uranium fuel gets used up and there comes a point when the fuel becomes inefficient. When that happens, these spent *fuel rods* are taken out of the reactor, and the plant operators will use *control rods* to turn of the fission reaction. Another aspect of the design that needs to be taken into consideration is the core temperature of the nuclear reactor. The *core temperature* needs to be maintained as a high temperature which exceeds the intended safe level can result in a nuclear meltdown, which is what we want to avoid. Nuclear power plants are usually built close to huge bodies of water, for the sake of cooling. Other than that, they also have a *cooling system* themselves in order to prevent a nuclear meltdown. A minor cooling system malfunction can lead to series of events that cause a partial meltdown. This was what happened in Three Mile Island, Harrisburg.

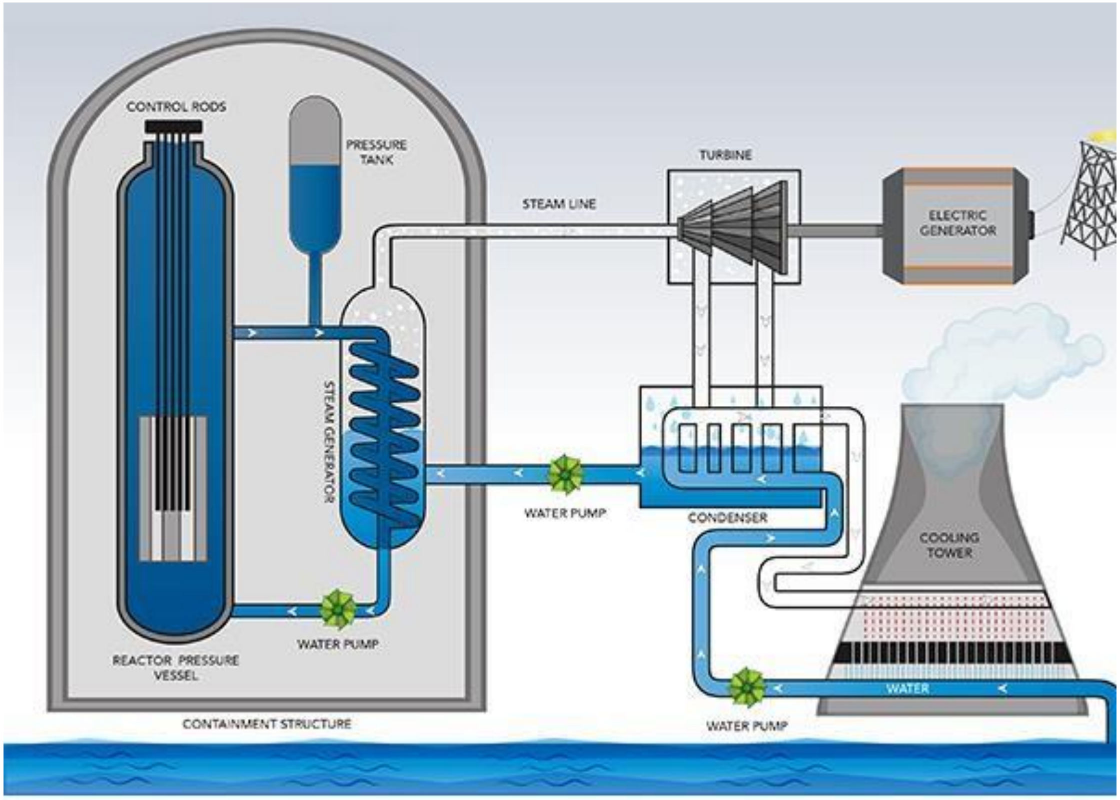


Diagram 1: Nuclear Power Plant

Based on how a nuclear meltdown occurs and the safety precautions to keep the plant intact, some conditions are established and a digital logic circuit is designed based on this. A serious of sensors will be installed throughout the plant that will monitor the conditions that are set – *core temperature* (high or normal), *fuel rods placement* (up or down), *control rods placement* (up or down), and *cooling system status* (working or failed). If the core temperature is high AND the fuel rods are down AND the control rods are up, OR if the cooling system fails then an alarm will be activated.

How these *sensors* work is that it will return a value of either *5V or 0V* to a comparator. If the fuel rods are placed up, the sensors return a value of 5V and vice versa, if the control rods are placed up, the sensors return a value of 5V and vice versa, and if the cooling system is working, the sensors return a 5V value. Because 5V is higher than 0V, the comparators will have an output value of 1 when the sensors return a 5V value. In the case of core temperature of the reactor, a *temperature transducer* is used to convert the thermal quantity into an electrical signal. The output voltage of this electrical circuit represents the real core temperature, and it will be an input to a comparator. A temperature reference voltage is used as a reference and is also an input to the comparator. The comparator output will be high when the temperature voltage exceeds the voltage of temperature reference.

The outputs to these comparators will be the inputs to two logic gates, based on the conditions set to trigger the alarm to be turned on (high = 1). The core temperature, fuel rods, and control rods are ANDed together and will be the input to an OR gate. Another input to the OR gate is simply the output of the comparator from the sensor of the cooling system. The output of the OR gate is the alarm.

3.0 DETAILED DESIGN

The conditions for the logic circuit for the alarm to be activated:

- If the core temperature is high AND the fuel rods are down AND the control rods are up
- OR if the cooling system fails

Let the core temperature be represented by T, fuel rods placement by F, control rods by R, cooling system status as C and the alarm by A.

The voltage of the real core temperature is denoted by V_T, and the temperature reference voltage by V_{TR}.

A Boolean expression can be created from the conditions above, which in turn gives us the design of the logic circuit:

- $A = \bar{C} + (T\,\bar{F}\,R)$

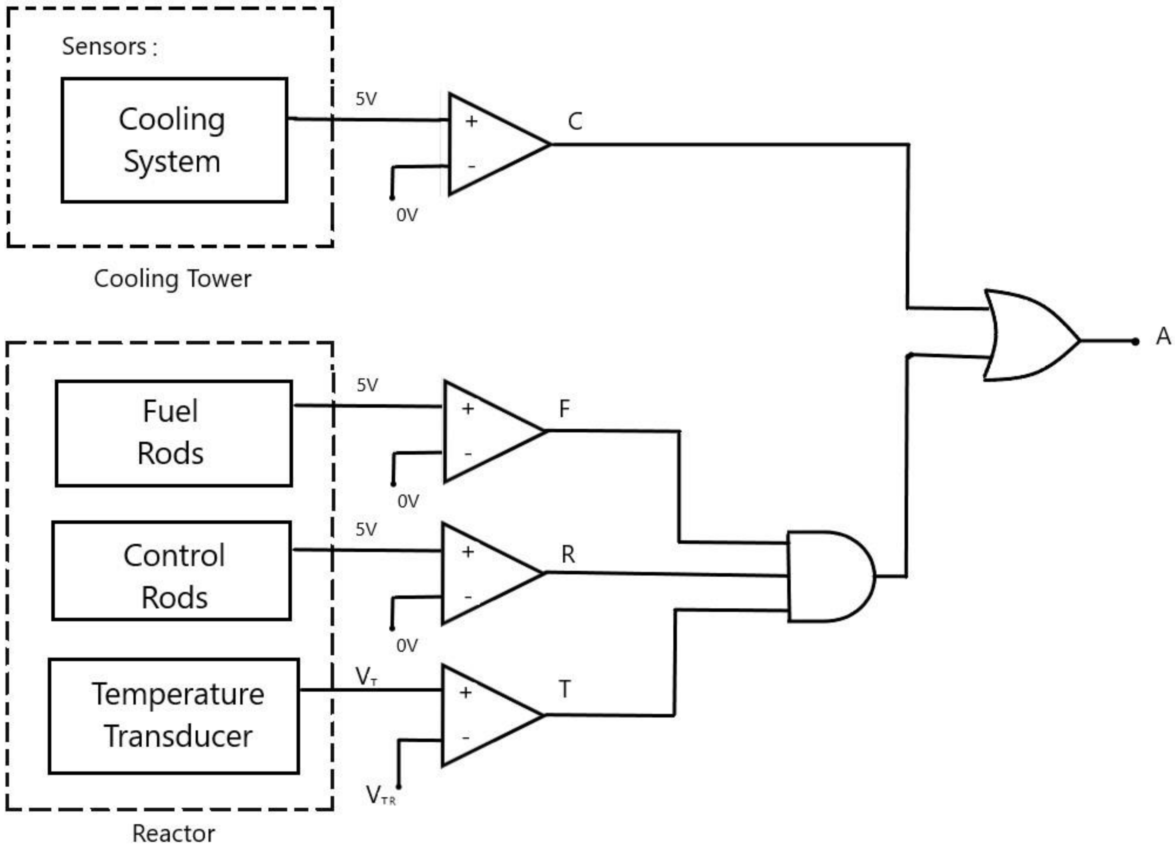


Diagram 2: Logic Circuit of Alarm System

A truth table is built from the conditions established:

INPUTS				OUTPUT
C	**T**	**F**	**R**	**A**
0	0	0	0	1
0	0	0	1	1
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	0
1	1	0	0	0
1	1	0	1	1
1	1	1	0	0
1	1	1	1	0

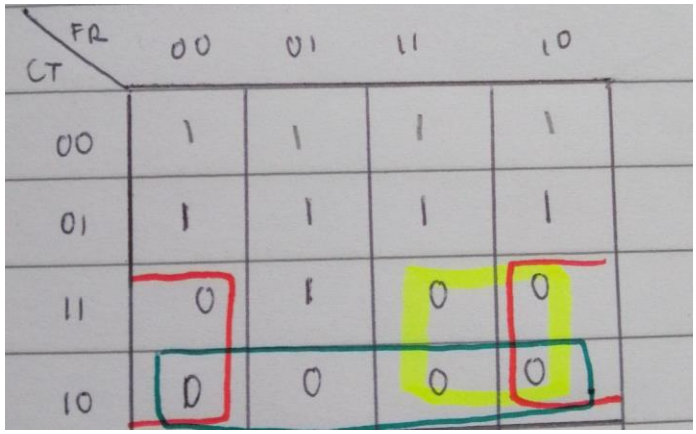
Table 1: Truth Table

From the truth table, we can find the minterms (SOP, Sum of Products) and maxterms (Product of Sums):

$$A = f(C, T, F, R) = \Sigma m(0, 1, 2, 3, 4, 5, 6, 7, 13)$$

$$\Pi M(8, 9, 10, 11, 12, 14, 15)$$

From the minterms and maxterms, we can build a K-Map and find the minimum POS expression:



From the K-Map, the POS expression is:

$A = (\bar{C} + R)(\bar{C} + \bar{F})(\bar{C} + T)$

Applying rule number 12 of the Basic 12 Rules of Boolean Algebra, the minimum POS expression is:

$A = \bar{C} + (T\,\bar{F}\,R)$ which is the same as the Boolean expression constructed from the conditions.

4.0 DESIGN VERIFICATION

For the design verification, we will use Logisim to construct a logic circuit.

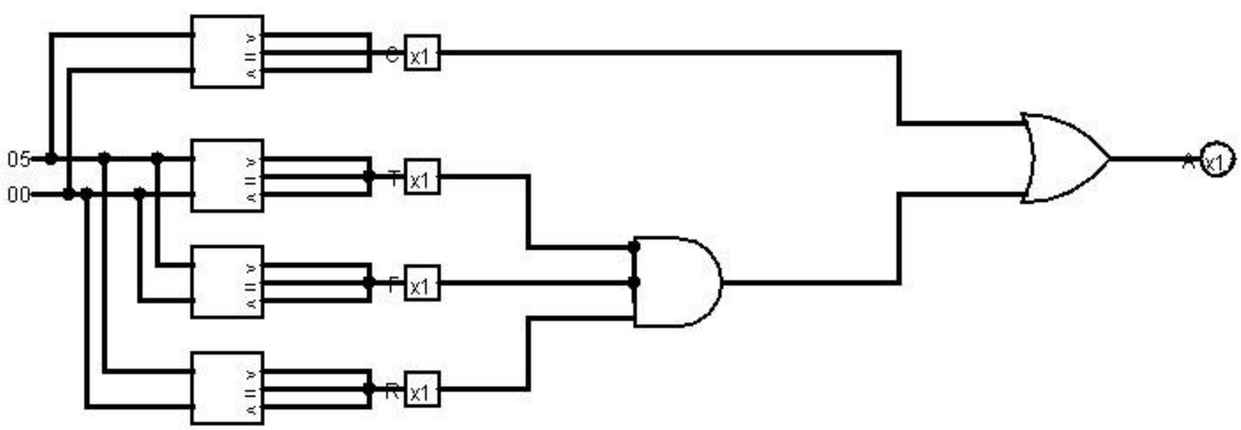


Figure 3.1: Logic Circuit built using Logisim

We can analyze the circuit using Logisim and the truth table, K-Map, and Boolean expression will be built based on this.

C	T	F	R	A
0	0	0	0	1
0	0	0	1	1
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	0
1	1	0	0	0
1	1	0	1	1
1	1	1	0	0
1	1	1	1	0

Diagram 3.2: Truth table from Logisim

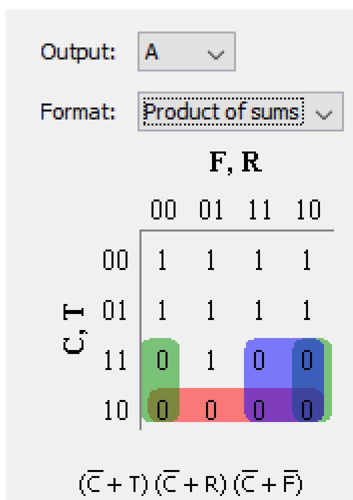


Diagram 3.3: K-Map from Logisim

Seeing that the truth table, K-Map and the POS expression of the circuit constructed using Logisim are the same as the ones that are built beforehand, it’s safe to say that the design is verified.

5.0 CONCLUSION

For this project, we have successfully implemented the knowledge of Digital Logic Design into the industry by building a working alarm system that can prevent potential hazards in a nuclear power plant from causing any major accidents. The use of AND and OR gates, as well as comparators are used in the design. We also understood how a sensor work and how it can be used to detect the conditions established and how it returns a value to the comparator. From the logic circuit, we also constructed the truth table, K-Map and the minimum POS expression which are then verified using Logisim.