INTELLIGENT RAILWAY SIGNALING FAILURE ALERT SYSTEM

M.A Nadeera Sugandi

159289J

Degree of Master of Science in Industrial Automation

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

April 2021

INTELLIGENT RAILWAY SIGNALING FAILURE ALERT SYSTEM

M.A Nadeera Sugandi

159289J

Dissertation submitted in partial fulfilment of the requirements for the degree Master of Science in Industrial Automation

Department of Electrical Engineering

University of Moratuwa
Sri Lanka

April 2021

DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature: Date:

M.A Nadeera Sugandi

The above candidate has carried out research for the Masters under our supervision.

Signature of the supervisor: Date:

Prof. Buddhika Jayasekara

ABSTRACT

One of the key factor for the development of the country is the efficiency of the transport system. In Sri Lanka, 20 percent of the passengers travel by the train. The demand for the rail transportation systems have been increased by the increment of rail transportation facilities and the population. Recently rail transport was introduced to Sri Lanka in 1864 to transport goods, but currently popular for the passenger transportation.

The railway signaling system is used to cater the traffic issues by utilizing the limited resources such as trains and tracks. The loss due to the failure of the signal system is substantial, as this result in the loss of human lives and human hours in addition to the loss of damages to properties. For the reliable signaling system main input is train detection.

Currently Sri Lanka Railway hasn't got a proper Failure diagnosis and maintenance reporting system. Therefore, it is essential to have a system to ensure that railway signals are reliable and safe.

The research is based on an intelligent fault detection method on railway signal color light signals. Before commencing the research, several literature surveys had been done on railway signalling and railway fault diagnosis methods, railway signal maintenance and signal fault detecting mechanism. Moreover attention was placed on other industrial intelligent fault diagnosis methods. A brief go through on signal aspect circuits, circuit relays and relay theories, would help find out the most suitable method for fault detection.

To carry on the research many color light signals inputs, outputs were obtained and surveys were done on different signal lamps, signal poles, signal aspect faults and faulty ranges in each red, amber, green circuits were identified. Mainly research was done by a case study, from the three signal aspect pole 263 where located in Colombo- Fort yard. All the data of case study 263, three signal aspect pole's data was recorded manually and the current and voltage reading fault ranges in each red , amber, green circuit's electric components were observed. Considering observed data and survey data model is implemented for the case study.

The Model is implemented with three input subsystems and six outputs. The proposed model uses a fuzzy system and the model is design by MATLAB Simulink system. Fuzzy system is developed using the “mamdani” technique.

The system is tested with actual readings for different faulty modes and justified that model output result and actual readings are accurate. The final develop model shows that the proposed method has the capacity to find faults in each Red, Amber and Green color light circuits.

Key words: Fault detection, fault diagnosis, fuzzy logic, Signal aspect, Signal aspect pole, MATLAB, Railway

DEDICATION

I dedicate my M.Sc. research dissertation to my beloved parents for their guidance given throughout my life.

ACKNOWLEDGEMENT

I would like to give my sincere gratitude to my project supervisor Prof. Buddhika Jayasekara for his continuous guidance and support and the motivation throughout the research to develop the result in to a fruitful outcome.

Support I received from my office environment is great and never forgotten.

I would like to thank the Chief Engineer Signal and Telecommunication sub department, Mr J.I.D Jayasundara. Special thanks to Deputy Chief Engineer Signal and Telecommunication Mr V.C.D Jayasekara who given me continuous guidance to success this research.

I would like to sincerely thank for the kind cooperation of Signal Supervisor Mr T.L Padmarajan and all my friends who helped me and encouraged me this programme by extending their support.

Finally, my special thanks to my beloved parents and family members for supporting me during the research period.

M.A.Nadeera Sugandi

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

LSTM	Long Short-Term Memory
GSM	Global System For Mobile Communication
GPS	Global Positioning System
RE	Red Lamp
DE	Amber Lamp
HE	Green Lamp
RECR	Red Bulb Checking Relay
HDECR	Amber Green Checking Relay
EMF	Electromotive Force
CLS	Color Light Signal
CO	Call On

CHAPTER 1

INTRODUCTION

1.1 General and Background

Most of industrial systems are needed to be monitored continuously to detect failures and good quality of service, especially in the railway industries. Rail infrastructure companies are faced with many challenges in maintaining full operations throughout their networks. Achieving maximum service availability for train operators while ensuring passenger safe is crucial for the betterment of the design and maintenance of the rail infrastructure. Maintaining traction, signaling systems and the power networks that supply railway services, are core in achieving this both in terms of user satisfaction and economic impact.

1.2 Railway Signaling System

In the railway system, the railway signaling system is the essential system that is responsible for the safe operations in trains. Signals are line sight pieces of equipment that tells train drivers when it is safe to proceed to the next destination. In Sri Lanka there are more than 20,000 of signals across the whole network, including two color line signal aspects, three color line aspects, gate signals, banners, as well as semaphore arm signals. (Figure 1, Railway Signals).

A complete Signaling system compromises with many parts with electrical and mechanical components. All over the world railway signaling systems are designed as failsafe to avoid train accidents due to railway signal equipment failure. That guarantees the passenger is safe whenever. Therefore, it will not affect the safety but due to that train delays may occur if the system becomes faulty or fail operations of controllers.

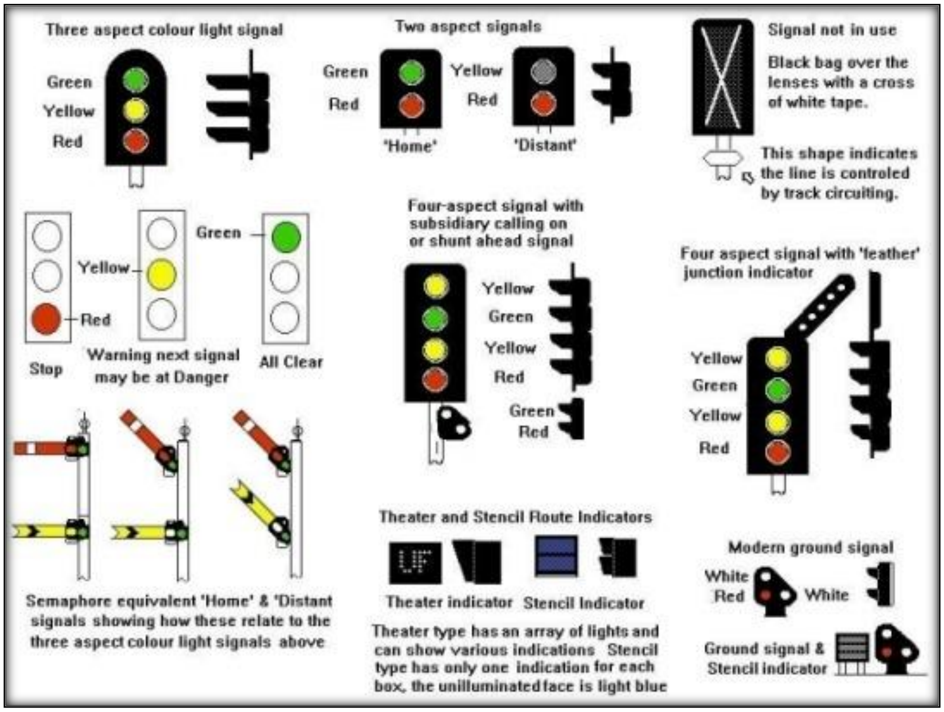


Figure 1 : Railway Signals [18]

There are so many faults and failures can happen in a railway signaling system, some of them are:

- Equipment's faults – These are faults due to equipment failure. They are the most common type of signaling faults such as relays, bulb fusing, point machine faults. Probably they not directly unsafe but can be indirectly result in an unsafe condition.
- Cable faults – cable faults are also common in signaling failures.
- Design faults- these type failures not detected when designing and testing, those can happen when doing actual process.
- Faults due to error by maintenance personnel when replacing or resetting faulty equipment.

When such an event has happened the failure area will be informed by train controller or the station master to the signaling maintenance staff, then the rectification team is sent to the failure location, and identifies the problem. Once they are done they can repair or replace the equipment. After testing the replaced equipment the area is cleared and confirmed that problem is rectified and the signal system is tested to be working properly. Then the maintenance team handover the signal operation control back to the controller.

1.2.1 Sri Lanka Railways Signaling Maintenance & Rectification Mechanism

In Sri Lanka Railways, from railway stations and running trains information is passes through copper medium. Once the train departures the station, there is no communication between the running train and the station or controller. All commands for the equipment's are given by the control panel which is located in the central monitoring place or local panel which is located in stations. (Figure 02, Basic structure of Railway signaling process).

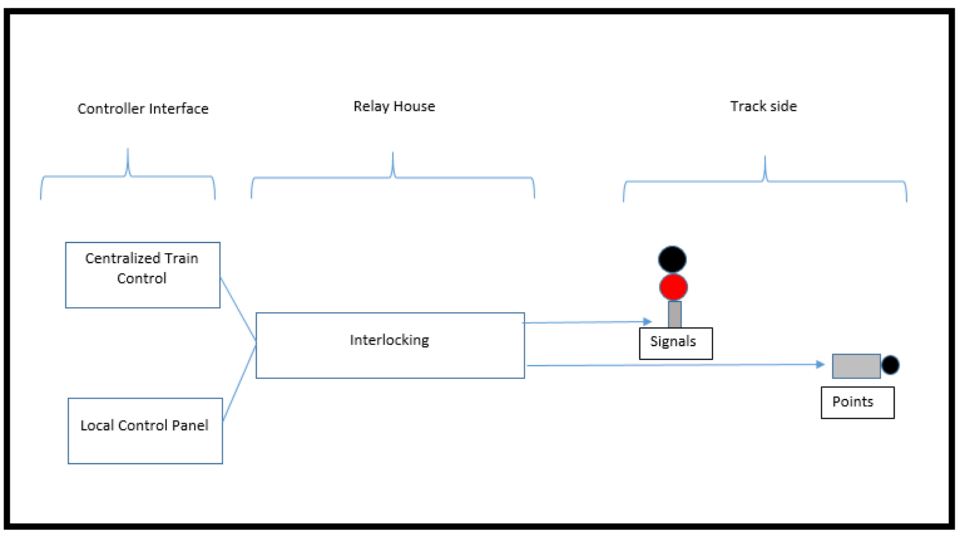


Figure 2: Basic Structure of Railway Signaling Process

The interlocking section is the most important part of the railway signal body. Its function is maintaining record of the position of every train in the control area and to maintain real time records of the status of all signaling outputs. (Position of points or aspects display by signals)

It is also used to process the controller's input request to set a particular route or swing a set of points. If these requests are safe at a given circumstance it controls signaling outputs work according to the controller's request. (Figure 03, Sri Lanka railway interlocking relay house)

Figure 3 : Sri Lanka Railway Interlocking Relay House

Sri Lanka Railways signal system is usually inspected by Signal Inspectors manually to ensure the safety and the availability within maintenance. Signal inspectors recording signal data during the inspection runs and identify anomalies. But in some cases, whenever a failure has happened signal inspectors cannot get the failure information properly.

Therefore, when failures occurred or in any emergencies in between stations, immediate information cannot be reported and a particular problem will increase with valuable time lost. So, it is necessary to have an intelligent based signaling failure alert system.

1.2.2 Typical Signal Circuit used in Sri Lanka Railway

Before installing a signal system to a station, signal expertise designing a track plan and interlocking table according to signal operations in station. (Figure 04, Colombo Fort yard track plan)

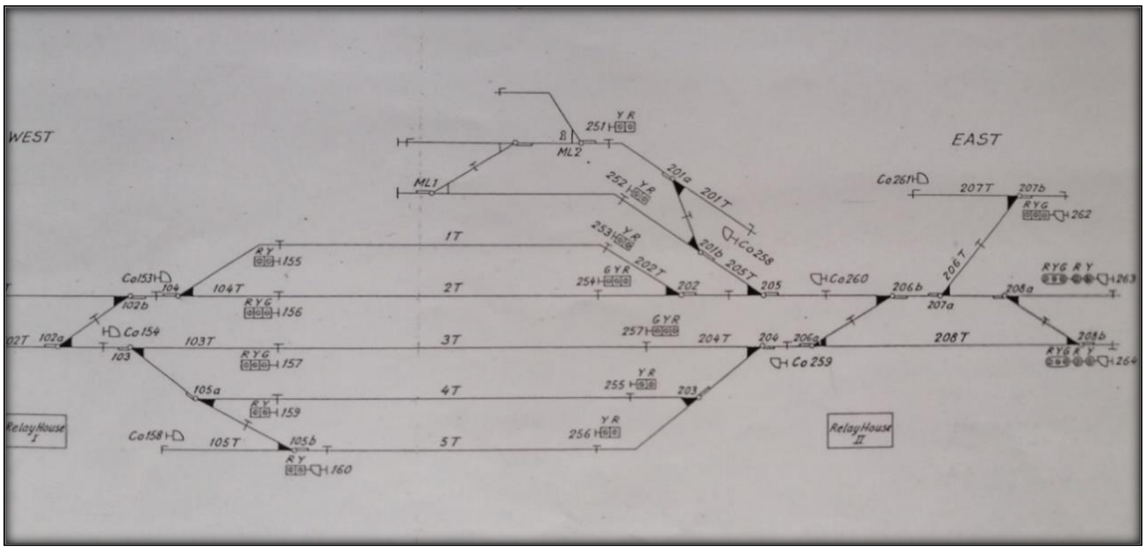


Figure 4: Colombo Fort Yard Track Plan. [5]

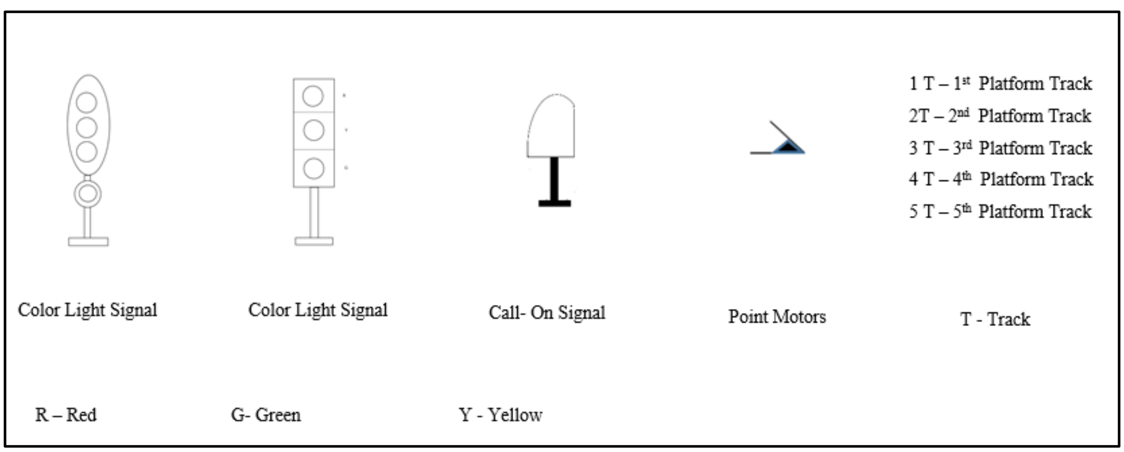


Figure 5: Symbols of Yard Track Plan Signal Process

When a particular Signal is requested to be cleared to the destination, a certain preparation of route will be taken place.

If all prerequisites and expected route preparation is made, then the signal will be cleared and respective aspect (Red, Green, Amber) will be shown to the driver (refer figure 04), Fort 263 signal extract the interlocking table to the route preparation.

Route	Points required in normal position	Pre required position	Track circuit to be free	Other signal to be locked
CLS 263- P1	207, 208, 206 104,202	202	206T, 205T 104T, 202 T	CO 260 , CLS 151

Table 1: Fort 263 Signal Extract

P1 – Point Motor 1, CO- Call on Signal , CLS – Colour Light Signal

1.2.2.1 Signal Aspect Proceed Green

1. Set the Route

This checks the possibility of clearing the requested route. It checks and secures that no conflicts and obstructions are presented. If the route is possible then the plant automatically drives the changing of switches (points) to the required position.

2. Locking the Signal

If the route is correctly set, then the desired signal gets locked through de- energizing its locking relay. This de-energizing path closes through a checking circuit of the route.

3. Locking the Route

This step gets a confirmation from field the ensuring that the route is properly set and safe. Then locks the route by de-energizing some relays called “Locking Relays”.
If this step is successfully completed it gives rise to energize the signal relay (HDR) which is responsible for lighting the correct aspect.

Suppose controller wants to give commands to proceed up to track 1 (P1) (refer figure 06) from signal 263. Point motors 207 and 208 should be in normal position and that no route has already been established from signal 263. Track circuit 206T must also be free. Further the signal CO 260 shall show the stop aspect, and track circuit 205T should be free. Track circuit 104T and 202T need to be free, secondly, the signals 151 is at stop aspect in addition.

The establishment of a route means that it is locked. For this locking to be accomplished a number of conditions must be fulfilled as earlier described. One of them is that the point on the route must be in their proper positions, which is affected automatically by the operation of the route levers. Before a route is locked, a check, called train route selection is done by closing a circuit through contacts on a train route control relay for that route and through contacts on the point detection relays on to the locking relays which locks the route.

The feed for the track circuits is in the form of DC (approx. 6V) from a rectifier which in turn is fed from a 110 Volt AC transformer. The feed is so arranged that two track adjustment circuits separated in feeding since the voltages from the respective rectifiers may affect another Signal cannot show proceed aspect until a signal relay HDR has operated, Figure 06 illustrates the signal aspect circuit. RE is Red Light, HE is Amber Light and DE is Green Light. Since the signal relays are normally in released position (this is to assure “fail safe”) and their back contacts are in the circuit for ‘STOP” the signals, normally red aspect.

1.2.3 Signal Aspect Circuit

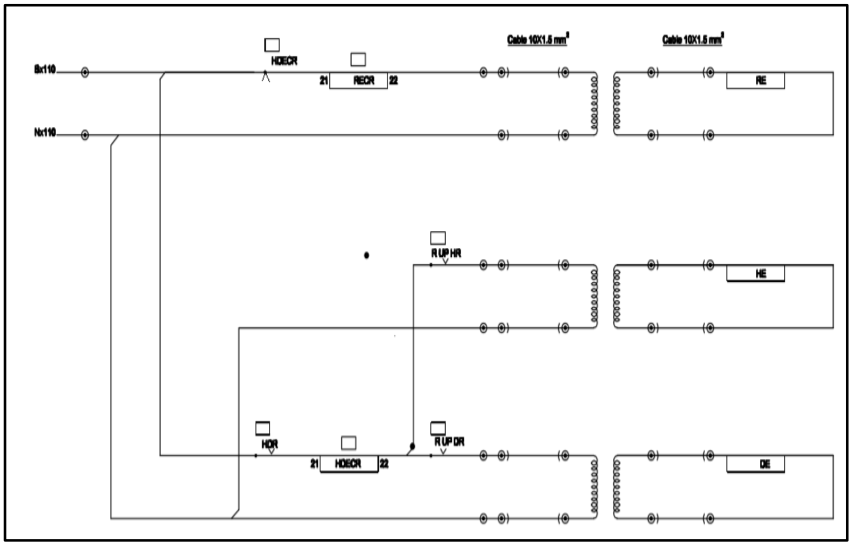


Figure 6: Signal Aspect Circuit

The signal lighting circuits contain light checking relays ECR. These relays operate according to the signal aspect shown. As an example, Amber Green lamp light in the signal. The respective light checking relay HDECR is operated, and if the red lamp lights a light checking relay called RECR is operated. The checking relays are used for disconnection of unwanted aspects in their own signals, for selection of the aspects in the signal to the rear which are dependent on the signal ahead, and also for indications.

Route from signal 263 to Track 01,

A route from signal 263 to track 01 has the signal aspects: Red, Amber, and Green (Figure 4). It will be seen from the signal relay circuits (Figure 06). When this route is established. Lamp RE (red) is continuously energized in series with light checking relay RECR. The light checking relay HDECR for HE (Amber) and DE (Green) is released, furthermore, since the signal relay HDR has not operated. This means that the Lamp RE is energized via a back contact on this relay in series with the light checking relay

RECR. HDR is not operated means that signal permission is not given by the interlocking plant.

1.2.4 Relay Theory

Normally each relay has one or two coils. The coil is made up of a large number of turns of small gauge sizes copper wire. Bellow figure 7, illustrates a relay structure when coil energized.

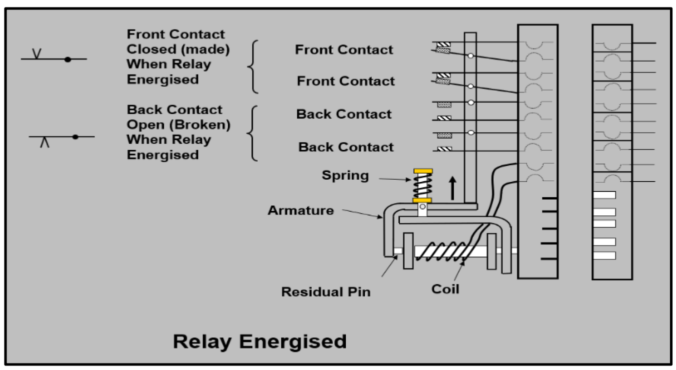


Figure 7: Coil Energized

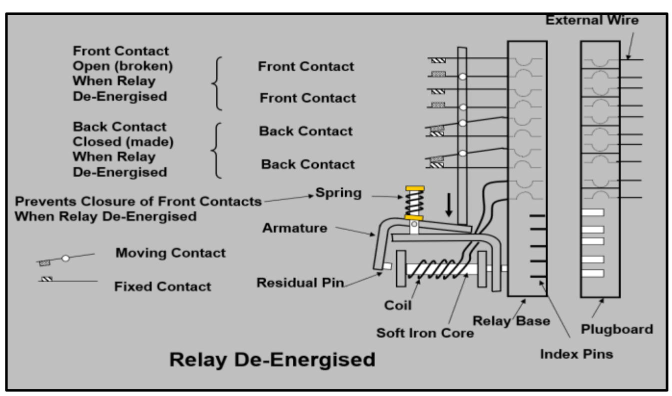


Figure 8: Coil De-Energized

1.2.4.1 Characteristic of Electromagnetic Relay

1) Force attraction
2) Effects of air gap
3) Effect of the hysteresis
4) Transient condition

In this research the most important characteristic is the transient condition of the relay. The relay takes some time to steady the current in a relay, when the voltages are applied or disconnected from the coils. This is called as the transient condition.

The current in the relay is stabilized after some time. It occurs, when the voltage is applied from the coil or disconnected from the coil. When the voltages applied into the coils, the magnetic flux is increases on the coil and starts to produce the back EMF that resists the applied voltage and interrupts the growth of current. The escalation and decay of flux depend with the inductance and the resistance in circuit. This relationship is called as the time constant. When the relay is de-energized, the Value of "L" is small.

Both the flux of the relay and the back EMF is increased, when the movement of the armature occurs. Then the current continuously grow along a new curve related to the take up along with the inductance, until it gets the final results (E/R) as shown figure 09.

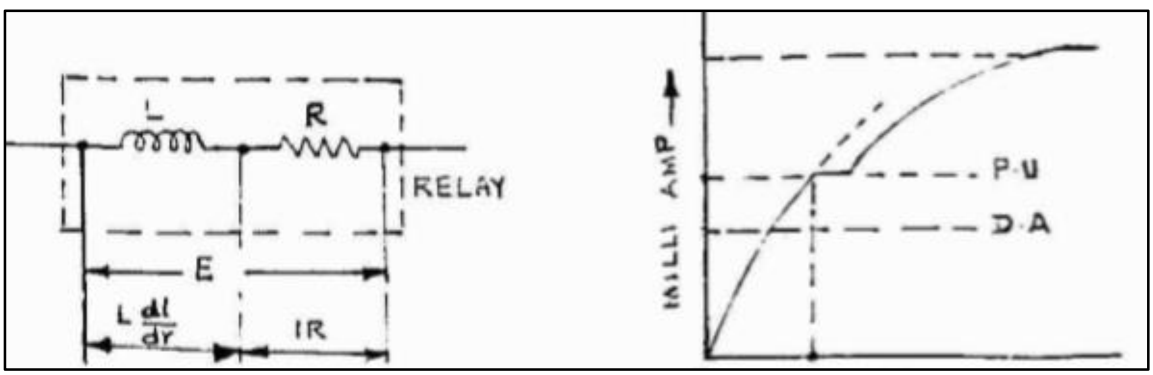


Figure 9: The Increase in Flux Increased the Back EMF [5]

When the relay supply disconnects the current, is immediately reduced to zero, but the flux decay constantly, slowly receives to the eddy currents and produced in the core by the speedy flux change, which contributes to maintain the flux. The drop away time on disconnection is negligible. (Figure 10, the drop away time on disconnection.).

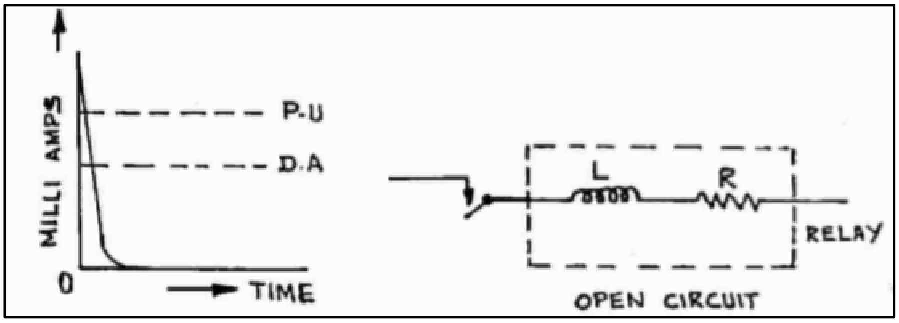


Figure 10: The Drop Away Time on Disconnection. [5]

When the current is reduced, the relay releases. This relay releasing time is much longer than the relay disconnection time. The rate of rise or fall of current during the transient conditions also depend on exterior circuit values, because inductance and resistance apply to the whole circuit. The eddy current production in the core is in a higher rate than the flux decay. Hence the actual relay release time will be a little longer than it takes the current to fall to the release.

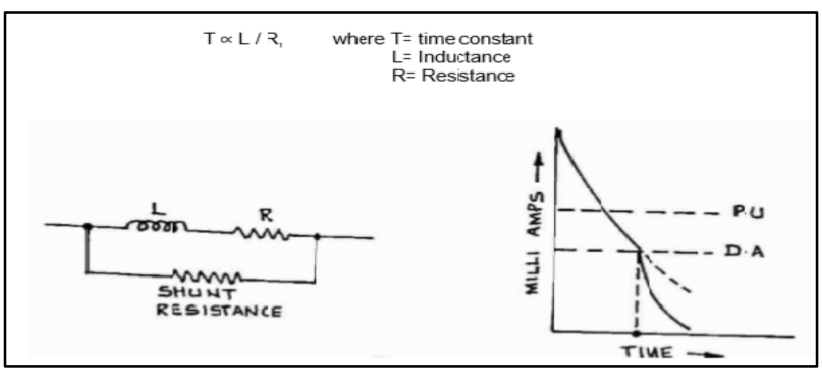


Figure 11: The Graph of Release Time of Relay. [5]

1.3 Research Initiating Statements

Currently, the Sri Lanka Railway has no proper Failure alert system and maintenance system. There were thousands of failures in the signal and telecommunication systems of Sri Lanka Railway. Most of these failures were caused by relays in signal circuits. According to an analysis by the signal department in the year 2017, the train delays caused by signal failures were approximately seven signal breakdowns per day causing an average delay of 30 minutes a day. [14]

When some relays are faulty, the signal output will be malfunctioned rapid. In this case, to find faults in relays, maintenance personal has to check relays along the signal circuits one by one. Due to that Failure, Rectification is delaying, which not only long delay in train operations but also causes to country economy. Some failures are not recording. Maintenance programmes are not going properly, therefore my approach of this research is to implement an intelligent based railway signalling failure alert system.

1.4 Objective

The main objective of this research is to design an intelligent based railway signalling failure alert system by designing a fuzzy logic controller. System can find the faulty relay in the signalling circuit. Hence, the maintenance staff does not need to check relays, one by one therefore we can increase efficiency of SLR signalling system and railway service by implementing actual intelligent base failure alert system. The implementation of the intelligent failure alert system shall maintain effective management of railway signalling maintenance mechanism and thus reduces train delays as well as improvement of the nation’s economy from efficient train service.

1.5 Methodology

I. Study the current maintenance mechanism and failure finding mechanism.
   Study the signaling circuits and feed voltages and currents to each relay in aspect signaling circuits used by Sri Lanka Railway department.

II. Literature survey on fault diagnosis methods and current circuit diagram of signal aspect.
   Do a literature survey on intelligent based railway signaling fault diagnosis systems and find the best method for intelligent system.

III. Taking physical measurements.
   Measures the relay voltages and currents when working condition and failure condition in different stations. Identify the faulty ranges.

IV. Calculate the Transfer functions for the signal aspect system for the Red Lamp, Green Lamp and Amber Lamp.
   Calculate transfer functions for red lamp, green Lamp, amber lamp faulty condition.

V. Design a model of intelligent based railway signaling failure alert system for the signal aspect circuit.
   Using MATLAB Simulink design fuzzy logic based signaling failure identifying system.

1.6 Justification of Methodology

1.6.1 Alternative Approaches for Failure Monitoring

1.6.1.1 Taking Manual Measurements, (Enhanced With Rewarding Support)

The present practice of SLR is using simple electronic measuring equipment's to measure voltages and current reading in circuits. An enhancement of the practice could also be proposed to deliver failure monitoring system. The reading could be recorded in a soft form (Which is not practicing now) and an analyzing tool can be used to predict the failure. But the system could suffer fallowing draw backs.

- Disturbing the circuit when measuring signal equipment's readings.
- Measuring frequency is very law, once a week is the shortest.
- Skilled Manpower required.
- Maintenance interval required.

Above is a cumbersome procedure and needs to be interacted with the central controller all the time which may interrupt the operating procedures too.

1.6.1.2 Deploying a Simple Circuit to Record Measurements

- Using a simple electrical circuit (Testing circuit) at relay house.

Further to the manual system explained in 1.5.1.1, a self-recording system with simple measuring arrangements could also deployed. Here following basic theorems can be used in analyzing and obtaining measurements.

- Kirchhoff's law
- Voltage divider

Since above will need be automated or unattended, the precision and the flexibility of readings could be suffered. For an example the manual measurements can be done by interrupting circuits at tester's discretion. But in deploying simple circuits this flexibility of disturbing the circuits will be an issue where series measurements (current readings) need to be recorded.

On the other hand since the research is on safety circuits, intervening of foreign circuits in to the safety signaling circuits will not be allowed as they might degraded the safety level. Hence the self-deploying of simple test circuits will have its own restrictions.

Considered to Current SLR failure monitoring practice or Signal equipment voltage and current readings according to 1.5.1.1, over the manual measuring mechanism with proposed fuzzy Logic control failure alert system has many advantages.

- No need to disturb the circuits

hence will not affected to daily train routines and signal circuits can be used long period without any failures, cause while testing some unknown failures damages can be happened.

- Without skill manpower system can monitor failures.
- The monitoring frequency is high.
- System is real time.
- Can be implemented to use for points motors monitoring, track circuit monitoring etc. using the same method failure alert fuzzy logic controller.

As mentioned in 1.5.1.2 monitoring method voltage and currents are impossible to obtain. Need to use separate equipment such as meters sensors or manpower to observe readings. When testing circuit is faulty wrong information can be logged.

Therefore Fuzzy logic Signaling failure alert system would be a better solution for fault finding and observing the current situation of Railway Signal circuits

CHAPTER 2

LITERATURE SURVEY

2.1 Researches Based on Rail Way Fault Diagnosis and Intelligent Control System

According to the railway signal faults diagnosis, there are few researches have done. But most of them are done for railway track circuit's failures, railway level crossing circuits' failures, and point machines failures.

Fault Detection and Diagnosis for Railway Track circuit using Neuro-Fuzzy. (Chen.Robers.C and Weston.P, 2008) [7], this research considered railway track circuit. "Track circuit" is one of important electrical device used in railways to find the occupancy or absence of a train on rail tracks used to inform control relevant signals. Track circuit is a fail to safe device, if any fault in the track circuit should result in the color signal started show as danger "RED".

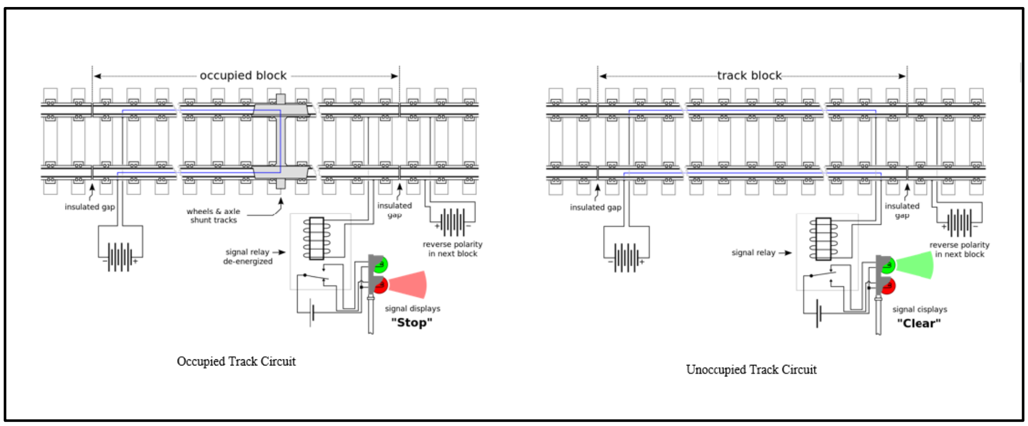


Figure 12: The Basic Track Circuit

Source: https://en.wikipedia.org/wiki/Track_circuit

In this research, track circuit is constructed in a lab. The model is modified with a tuning unit capacitor and two track ends with termination bond.

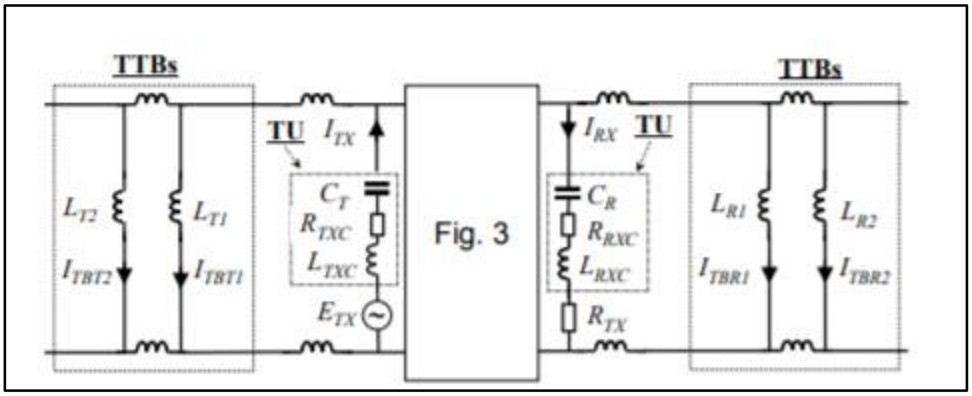


Figure 13: Track Circuit Termination Model with Tuning Unit Capacitors [7]

Lab based track circuit tested with track circuit failures, such as track termination bond failures, transmitter receiver failures, cable connection, and tuning unit failures. This modified lab-based track circuit has been tested and trained with Neuro- Fuzzy Artificial intelligent technology. System inputs are voltages and currents of track circuit. Finally research showed that the incorporation of neural network with fuzzy is more accurate [7].

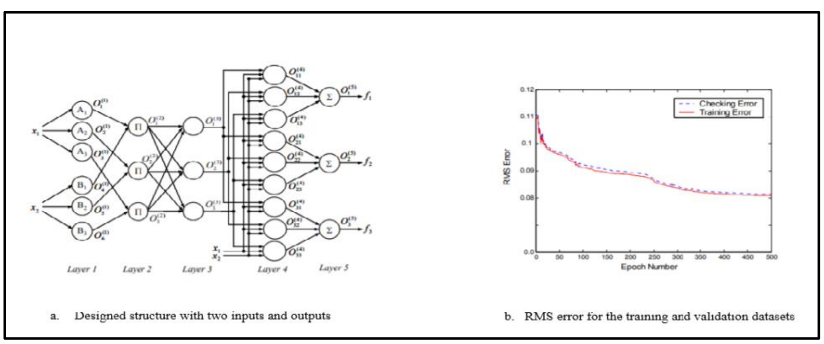


Figure 14: Designed Structure and Training and Validation of “Fault detection and diagnosis for railway track circuit using Neuro-Fuzzy” Research [7]

Railway track circuit fault diagnosis using recurrent neural networks, (Tim de Bruin, Kim Verbert and Robert Babuska), this research is also very similar to earlier mentioned research and research is addresses the issues of fault identification and isolation in railway track circuit. Generative model is developed by researchers, basing on assumption and approximate understanding of the system and the results of the faults considered, also randomly selected set of measurement data used from actual track circuits.

The model is tested with variation of the current over time I (t) during a train passing the track circuit. Research described the need of the long-short term memory (LSTM) recurrent neural network and proposed to do tasks based on the repeatedly measurements signals. And trained the data to modified model to find faults in railway track circuit [11].

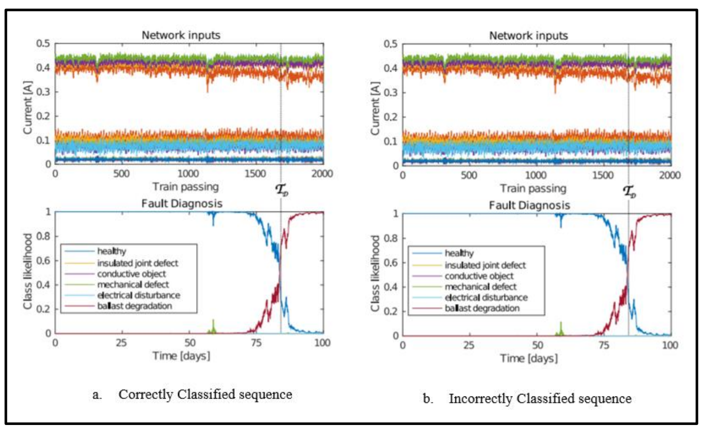


Figure 15: Results of Railway Track Circuit Fault Diagnosis Using Recurrent Neural Networks [11]

However the research has identified incorrect results due to train speed. Train speed is drawn from normal distributions that are fault dependent. Research identified, in combination with the natural variations of the current measurements, causes some error results [11].

Research of Intelligent railway cross level gates and signalling system using fuzzy logic controller (Olaniyi O. M, Abdullahi, I. M and Maliki, D Lasore T.M, 2016) [6] focused current manually operated gates at the railways level crossings of developing countries. The main objective of this study is effective control of accidents through closure and gates opening at the level crossing by the use of motors.

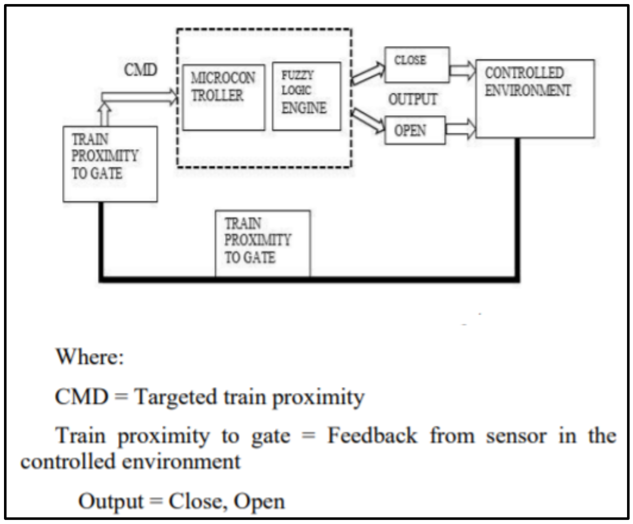


Figure 16: Fuzzy Logic Controller for the Gate Control Intelligent System [6]

Response in gate control's evaluation done by modelled, which is the behavior of DC motor output was modelled. The motor included the armature, inductor powered by applied voltage (Va). When applied voltage applied to the motor, Torque and back Electro Motive Force, armature current are generated.

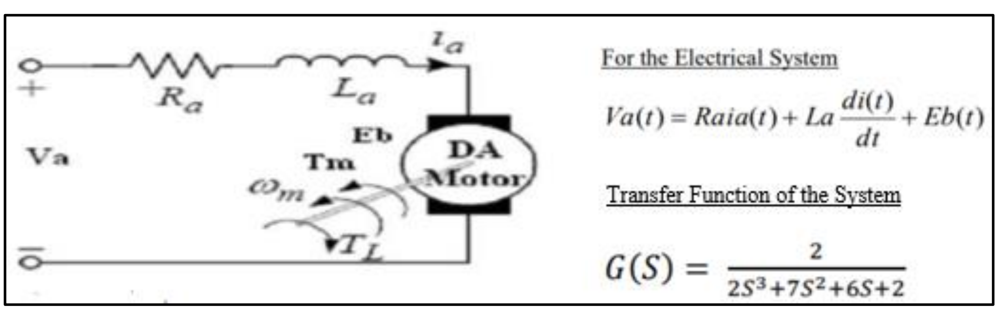


Figure 17: Modelling diagram of gate control of the intelligent Railway System [6]

The model was developed using Mamdani's Fuzzy Inference system modelled and simulated in MATLAB 2013a using Mamdani fuzzy logic control technique. (Figure 19: Gate Control Membership Function). A 3x3 matrix of nine rules consequently developed to the output of the gate control to (S) slow, Speed, (M) moderate and (F) fast. (Figure 18: Linguistic rules and Fuzzy Rule Matrix**).**

Rule No	Rule statement
Rule 1	If the Speed is low and the distance is very far, gate operation is slow
Rule 2	If the Speed is average and the distance is very far, gate operation is slow
Rule 3	If the Speed is high and the distance is very far, gate operation is fast
Rule 4	If the Speed is low and the distance is far, gate operation is slow
Rule 5	If the Speed is average and the distance is far, gate operation is moderate
Rule 6	If the Speed is high and the distance is far, gate operation is fast

Distance \ Speed	L	A	H
V.F	1 S	2 S	3 M
F	4 S	5 F	6 F
N	7 F	8 F	9 F

Figure 18: Linguistic Rules and Fuzzy Rule Matrix [6]

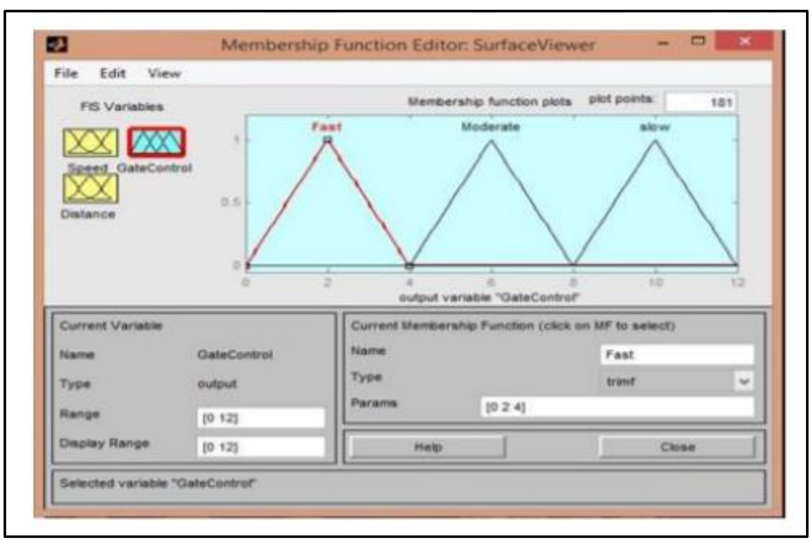


Figure 19: Gate Control Membership Function [6]

In the developed model, the Passive Infrared Sensors detect both the arrival and departure of a train and sends signal to the Atmega 2560 microcontroller which gives commands to the Buzzers, LCD and LED's to display safety control measures to all road users and the Servo Motor to open or close the gates at the railway level crossing.

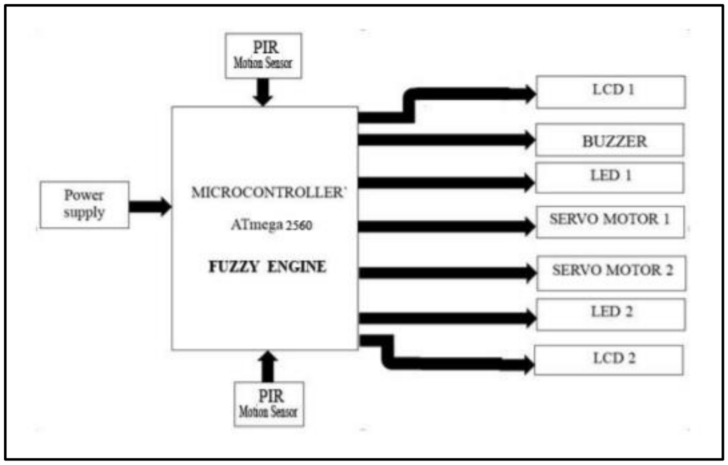


Figure 20: Overall Intelligent Railway Cross Level Gates and Signaling System [6]

The system gate controller has a high response with time with fuzzy logic controller without fuzzy logic controller law response. Research showed system response without Fuzzy Logic Controller makes the performance of the system unstable [6].

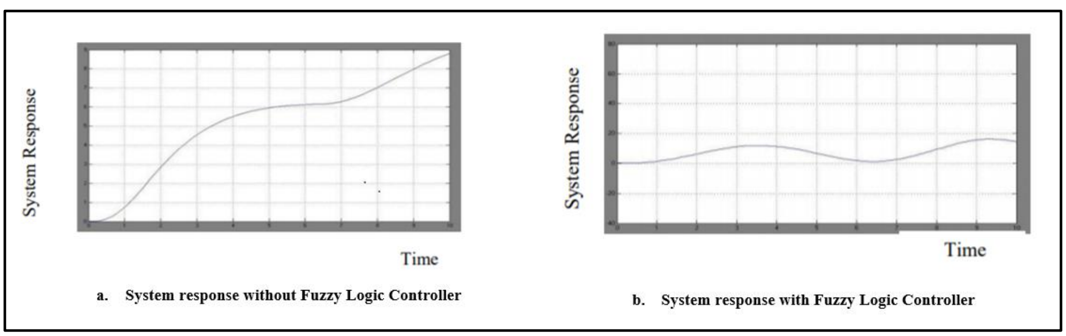


Figure 21: Intelligent Railway Cross Level Gates and Signaling System Response With and Without Fuzzy Logic Controller [6]

Automated Railway Track Fault Detection System Using Robot (Mansi R.Sarwan, Ankita S.Sonawane, Prof.Parneet chowdhary and Prof.S.M.More 2018), this research focused to develop the economical and user friendly technology to find out problems with the rail tracks and cracks in the rails due varies situations.

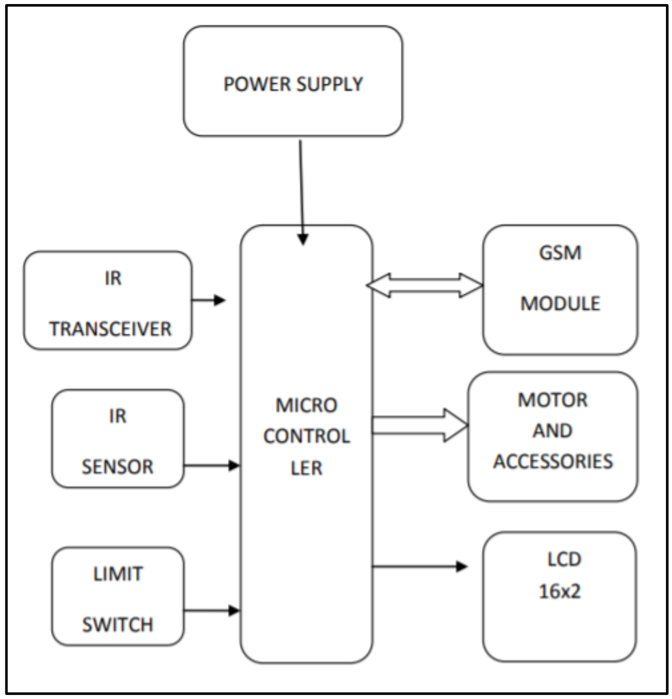


Figure 22: Block Diagram of Automated Railway Track Fault Detection System Using Robot

Research has designed a model of an automatically detecting system which is implemented with using different sensors. IR sensors are used to find the cracks and damages of tracks. Ultrasonic sensors are used to detect any obstacle presented in the track. TRI axis sensor is used to find the slope of track. GPS and GSM systems are used to locate the fault and send information. Motors are used to drive the system. Researches presented that the system properly detects the cracks or deformities on the track which when rectified in time will reduce train accidents.

2.2 Summary of Literature Review

The approaches reviewed different railway signal failures and there is no similar method with this research study Railway signal failure alert system for signal aspect circuits. This section shows research can benefit for the Railway failure alert system. Research can be considered as an effective approach achieving railway signal aspect fault finding.

Despite the approaches mentioned above have come up with satisfied results. But those researches have not considered about railway standards. When considering it is a must to work with railway SIL "Safety Integrity Level" (SIL) standards .SIL functions for railway applications. Safety Integrity Level (SIL) is a standard of the relative risk-depletion sustained by a safety function. Some studies modified signal circuits without considering about Railway SIL standards. As shown in Table 2, Research approach meets the effective, easy, real time and Signal aspect faulty finding system. Also this system Fuzzy Logic method easily can be modified for other signal failures. Not only that, the system found faults without disturbing the whole railway services, summarily the earlier discussed approaches haven't yet evolved to a sufficient state.

2.2.1 Advantages of the Proposed System

- Real time monitoring in Railway signal system.
- Time save for finding faulty.
- Not affected to Railway Safety Integrity Level (SIL) Standards.
- Can be applied for other signal failure finding.
- Less Manpower

Table 2: Comparison of Researches Based On Rail Way Fault Diagnosis and Intelligent Control System

Reference	Approach Name	Faulty Considered	Method Used	Considered about Railway standards	Tested with Actual network	Method can use for other signal Failures
[7]	Fault Detection and Diagnosis for Railway Track Circuit	Track Circuit	Neuro- Fuzzy AI Technology	Not considered	Only Tested with lab based model	No
[11]	Railway track circuit fault Diagnosis using recurrent neural networks	Track Circuit	recurrent neural networks	Not considered	Tested with actual data	No
[6]	Intelligent Railway cross level gates and signalling system using fuzzy Logic control technique	Level crossing gates	Fuzzy logic technology	Not considered	Tested with actual data	No
[8]	Automated Railway Track Fault Detection System Using Robot	Railway Track	Used Microcontroller	Not considered	Only Tested with lab based model	No

CHAPTER 3

SYSTEM MATHEMATICAL MODEL

3.1 Case Study 263 Experimental Data

The main focus of case study is diagnosis of failure in railway signal aspect red, amber, green circuits in one unit. As mentioned in chapter one this research, we are considering only one circuit of signal aspect pole 263 of circuit side only with respect to the signal aspect circuit relays in interlocking.

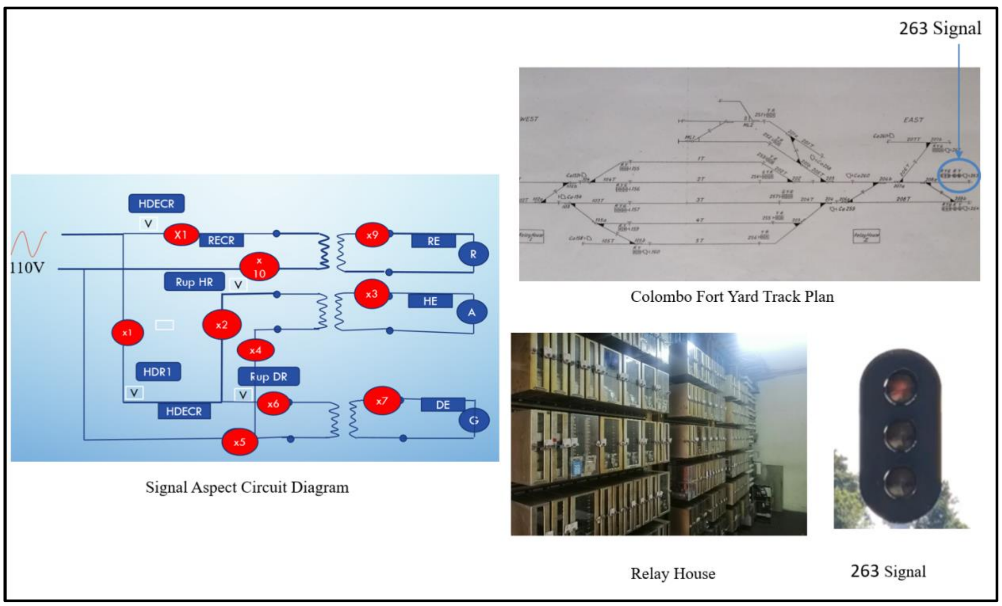


Figure 23: Case Study of Signal Pole 263

RE- Red Lamp   RECR- Red Lamp Checking Relay   Rup HR- Amber Lamp Contact up

DE- Green Lamp   HDECR- Amber Green Checking Relay

HE-Amber Lamp   HDR- Amber Green Relay

Measuring Points- x1, x2, x3, x4, x5, x6, x7, x8, x9, x10

The proposed method is based on the voltage and current observation. Because the system inputs are only current and voltage, each components of circuit of signal aspect current and voltage values are observed, Chapter 01 already discussed how current pass to red, green, amber signal Lamps. The fuzzy Logic control of this system is shown figure 24.

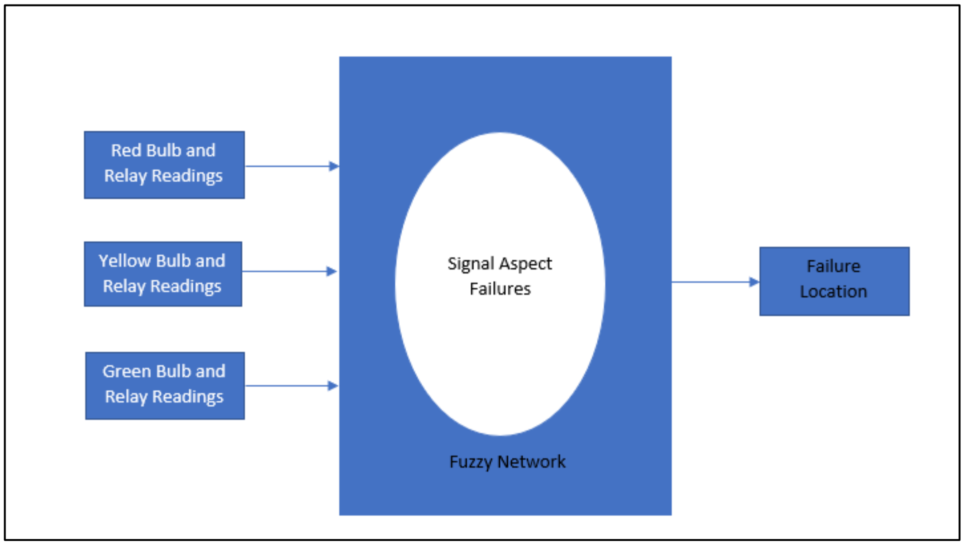


Figure 24: Fuzzy Logic Control of Intelligent Based Railway Signaling Failure Alert System

The readings of each red lamp, green lamp, and amber lamp voltages and currents are manually taken.

Figure 25: Observing Data

In this research, behavior of signal aspect was modeled and calculated transfer function for red, amber, and green Lamps from mathematical modelling equivalent circuits. (Figure 26, the equivalent circuit of signal aspect circuit)

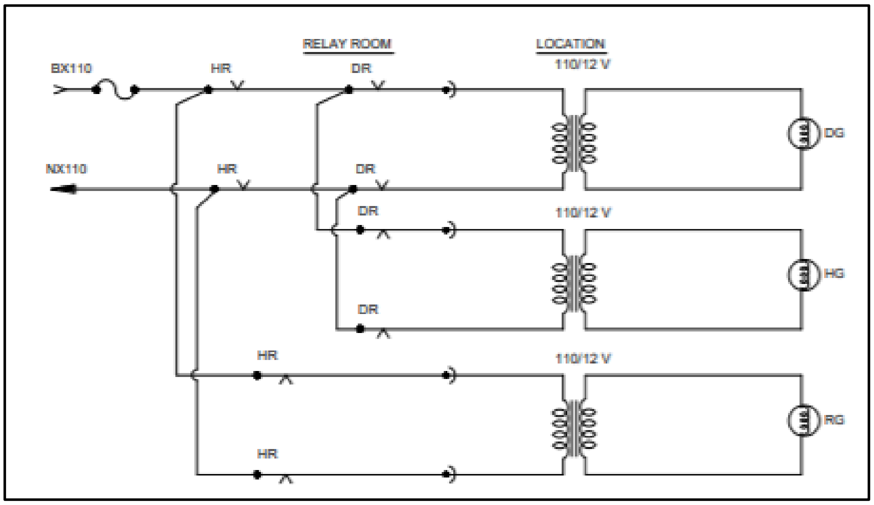


Figure 26: The Equivalent Circuit of Signal Aspect Circuit

To work properly voltage should be equal in both sides. According to this system we considered about the moments of faults can be happened. We considered voltage references and current references.

Figure 27: Three Aspect Signal [13]

Reading of each red lamp, amber lamp, green Lamp voltages and currents manually taken, in this research and behavior of signal aspect was modeled and calculated transfer function for Red, Amber, and Green Lamps from mathematical modelling equivalent circuits. Figure 28. Shows equivalent circuit of signal aspect circuit.

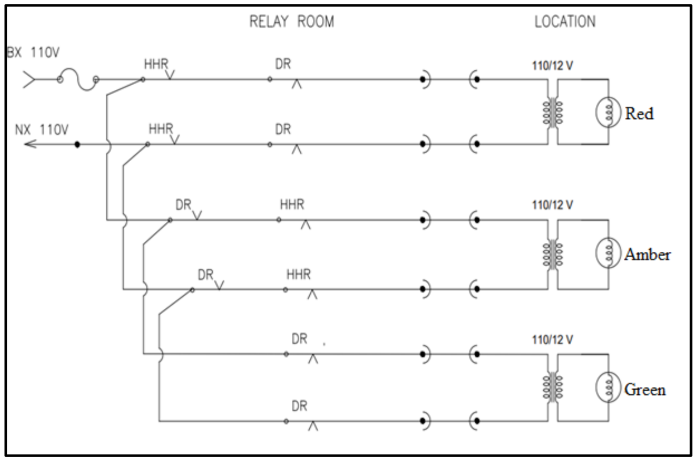


Figure 28: Three Aspect Control Signal [13]

To work properly voltages should be equal in both sides. According to this system we considered about the moments of faults can be happened. We considered voltage references and current references.

Therefore, Apply KVL for the common circuit Diagram.

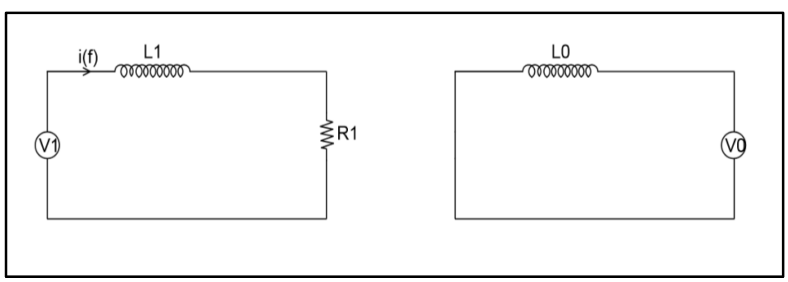


Figure 29: Common Circuit Diagram

Current is change with Time

L.H.S

$V1-0 = L\ di/dt + I\ R1$ —— (1)

R.H.S

$v(0) = L(s)$ —— (2)

Let L=1H

From Laplace Transformation

$$V1(s)/I(S) = (L1S + R1)$$

From given data reference [2]

Lin and Rin are fixed value

Lin = 0.150H, and Rin = 40 Ω.

$$V(s)/I(s) = 40\Omega$$

Thus V(s) = 110 V AC

$$I(s) = 6A$$

Proceed current = 6A

From (1) & (2)

$$V0(s)/Vi(s) = Ls/(R + LS)$$

$$V0(s)/Vi(s) = 1/(40 + 0.150S)$$

We can get Transfer function of this system is

$$T.F = 1/(40 + 0.150S)$$

Using MATLAB, we can test this system is not a failure one. Using MATLAB, we can draw bode plot. (Figure 32, Mat lab Plot) shows that system hasn't any failure.

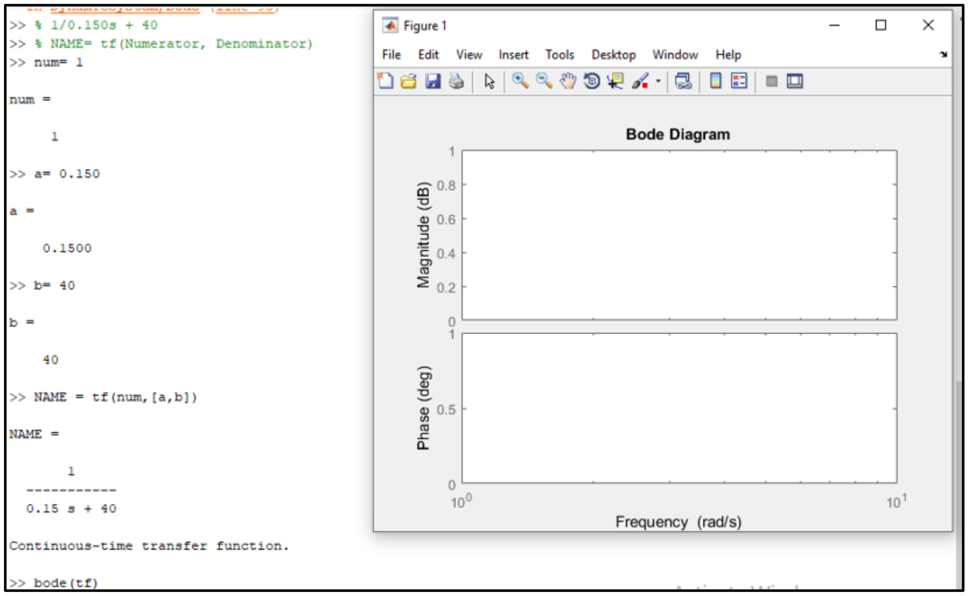


Figure 30: Mat Lab Plot

3.1.1 Red Bulb

Apply KVL

$$V1(t) - 0 = IR + Ldi/dt$$

$$V1(t) - iR = Ldi/dt$$

$$dt/L = di/(vi(t) - iR)$$

Current is changing with Time

$$\int_0^t \frac{1}{L} dt = \int_0^i \frac{1}{vi(t) - iR}$$

$$\frac{t}{L} = \int_0^i \frac{1}{u}\left(\frac{-du}{R}\right)$$

$$\frac{t}{L} = -\frac{1}{R}\int u.du$$

$Let \quad v(t) - iR = U$
$\therefore \quad du/dt = -R$
$\therefore di = du/R$

$$\frac{t}{L} = -\frac{1}{R} ln|u|_0^i$$

$$\frac{\mathrm{Rt}}{\mathrm{L}} = \ln|\mathrm{v(t)} - \mathrm{iR}|_0^{\mathrm{v}}$$

$$-\frac{\mathrm{Rt}}{\mathrm{L}} = \frac{\mathrm{v(t)} - \mathrm{IR}}{\mathrm{v(t)}}$$

$$\mathrm{e}^{-\frac{\mathrm{Rt}}{\mathrm{L}}} = \mathrm{e}^{\ln\left|\frac{\mathrm{v(t)}-\mathrm{iR}}{\mathrm{v(t)}}\right|}$$

$$\therefore\ \mathrm{e}^{-\frac{\mathrm{Rt}}{\mathrm{L}}} = \frac{\mathrm{v(t)} - \mathrm{iR}}{\mathrm{v(t)}}$$

Therefore $$\mathrm{i} = \frac{\mathrm{v(t)}}{\mathrm{R}}\left[\mathrm{e}^{-\frac{\mathrm{Rt}}{\mathrm{L}}} - 1\right] \qquad (3)$$

Red Lamp circuit has 1.68 Ω we take it as R4 therefore AMBER and GREEN bulb circuits has 20% of resistance than Red Lamp .and the inductance is increasing with distance 3.6%.

Red Lamp circuit resistance R_4 =. 1.68Ω

AMBER circuit Resistance = 1.68Ω x 20% +1.68Ω

= 0.336Ω +1.68Ω

= 2.016Ω

Relay Inductance value is same for all Lamps and we know that the real Inductance is 1.5mH Therefore L_5 = 1.5mH x 36% + 1.5mH = 2.04 m

3.1.2 Amber Bulb

When Amber light working

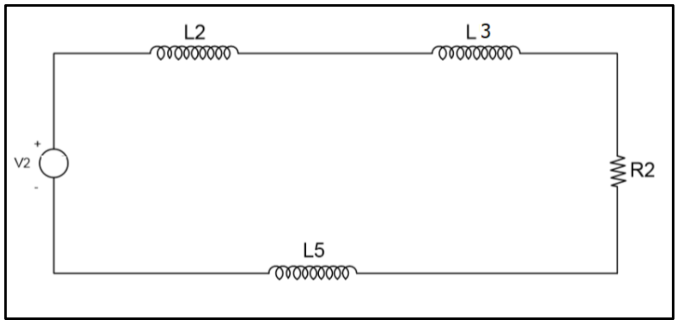


Figure 31: The Equivalent Circuit for Amber Light

Apply KVL for Amber light.

$$V2(t) - 0 = iR2 + L2di/dt + L3di/dt + L5di/dt \quad (4)$$

$$V2(t) - iR2 = \frac{di}{dt}[L2 + L3 + L5]$$

$$\frac{dt}{L2 + L3 + L5} = \left(\frac{1}{V2(t) - iR2}\right) di$$

Inductor value is change with Time and voltage is change with current.

Therefore

Let $v_2(t)$ $iR_2 = U$ $\therefore$ du/dt

$$\int_0^t \frac{1}{L2+L3+L5}\,dt = \int_0^i \left(\frac{1}{V2(t) - iR2}\right) di$$

$$\left(\frac{t}{L_2+L_3+L_5}\right)_0^t = \int_0^i \left(\frac{1}{u}\right).\left(-\frac{1}{R}\right).du$$

$$= -\frac{1}{R_2}\ln|U|_0^i$$

$$= -\frac{1}{R_2}\left|V2(t) - iR2\right|_0^i$$

$$-\left(\frac{\mathrm{R_2 t}}{\mathrm{L_2 + L_3 + L_5}}\right) = \frac{\mathrm{V_2(t) - i\,R_2}}{\mathrm{V_2(t)}}$$

$$\mathrm{e}^{-\left(\frac{\mathrm{R_2 t}}{\mathrm{L_2+L_3+L_5}}\right)} \qquad = \mathrm{e}^{\ln\frac{\mathrm{V_2(t) - i\,R_2}}{\mathrm{V_2(t)}}}$$

$$V(\mathrm{t})\left[\mathrm{e}^{-\left(\frac{\mathrm{R_2 t}}{\mathrm{L_2+L_3+L_5}}\right)}\right] = -\mathrm{i\,R_2}$$

$$\therefore i = \frac{V_2(t)}{R_2}\left[1 - e^{-\left(\frac{R_2 t}{L_2+L_3+L_5}\right)}\right]$$

We know R2= 40Ω, L_2=L_3=L_5 = 0.150H, V2 = 230V from this equation we can find theoretical required current to work without any failure.

Laplace T.F for Amber Lamp

$$\frac{\mathrm{V_2(t)}}{\mathrm{I(t)}} = \frac{\mathrm{R_2}}{1 - \mathrm{e}^{-\left(\frac{\mathrm{R_2 t}}{\mathrm{L_2+L_3+L_5}}\right)}}$$

Red Lamp circuit has 1.68 Ω we take it as R4 therefore AMBER and GREEN bulb circuits has 20% of resistance than Red Lamp .and the inductance is increasing with distance 36%.

Red Lamp circuit resistance R_4 =. 1.68Ω

AMBER circuit Resistance = 1.68Ω x 20% +1.68Ω

= 0.336Ω +1.68Ω

= 2.016Ω

Relay Inductance value is same for all Lamps and we know that the real Inductance is 1.5mH

Therefore L_5 = 1.5mH x 36% + 1.5mH = 2.04 mH

3.1.3 Green Light

When Green light working

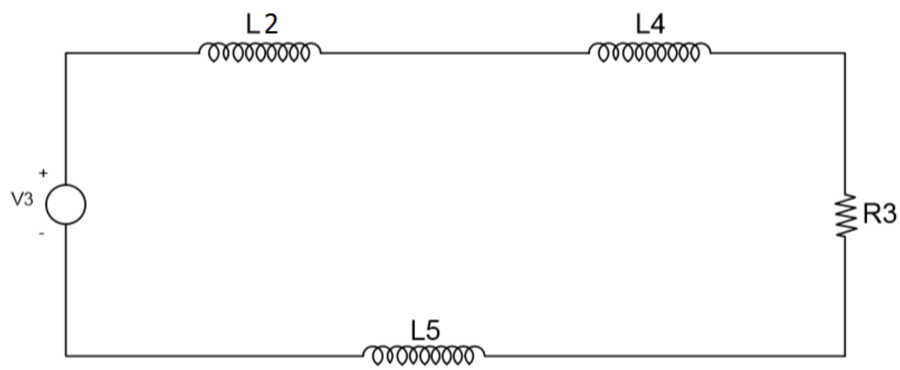


Figure 32: The Equivalent Circuit for Green Light

Above figure shows the equivalent circuit for Green light

Apply KVL for Amber light.

$$V3(t) - 0 = iR3 + L2di/dt + L4di/dt + L5di/dt \qquad (5)$$

$$V2(t) - iR3 = \frac{di}{dt}[L2 + L4 + L5]$$

$$\frac{dt}{L2 + L4 + L5} = \left(\frac{1}{V3(t) - iR3}\right) di$$

Inductor value is change with Time and voltage is change with current.

Therefore

$$\int_0^t \frac{1}{L2+L4+L5}\, dt = \int_0^i \left(\frac{1}{V3(t) - iR3}\right) di$$

$$\left(\frac{t}{L_2+L_4+L_5}\right)_0^t = \int_0^i \left(\frac{1}{u}\right).\left(-\frac{1}{R}\right).du$$

$$\text{Let} \quad v_3(t) - iR_3 = U$$

$$\therefore \quad du/dt = -R_3$$

$$\therefore di = -\frac{1}{R_3}$$

$$= -\frac{1}{R_3}\ \ln|U|_0^i$$

$$= -\frac{1}{R_3}|V3(t) - iR3|_0^i$$

$$-\left(\frac{R_2 t}{L_2 + L_4 + L_5}\right) = \frac{V_3(t) - i\,R_3}{V_3(t)}$$

$$e^{-\left(\frac{R_2 t}{L_2+L_4+L_5}\right)} = e^{\ln\frac{V_3(t)-i\,R_3}{V_3(t)}}$$

$$V_3(t)\left[e^{-\left(\frac{R_3 t}{L_2+L_4+L_5}\right)}\right] = -\,i\,R_3$$

$$\therefore i = \frac{V_3(t)}{R_3}\left[1 - e^{-\left(\frac{R_3 t}{L_2+L_4+L_5}\right)}\right]$$

We know R2= 40Ω, L_2=L_4=L_5 = 0.150H, V3 = 230V from this equation we can find theoretical required current to work without any failure.

Laplace T.F for Green Lamp

$$\frac{V_3(t)}{I(t)} = \frac{R_3}{1 - e^{-\left(\frac{R_3 t}{L_2+L_4+L_5}\right)}}$$

According to Railway theories there is voltage drop to Amber and green lights. For 1m grid resistance is 0.016Ω. From theories voltage drop is 3.16% from red light voltage required if the signal pole is 600m - 800m far to the relay house. There is a voltage drop for Amber Lamp than Red Lamp.

3.1.4 Amber Bulb Rule Base

We found Red Lamp Voltage Range 3.059V Therefore Amber Bulb voltage ranges taken by calculating.

Amber Lamp voltage drop = 3.059 x 3.16/100

= 0.0966V

Therefore, calculate voltage Range starting value is

= 3.059 – 0.0966V

= 2.9624V

3.1.5 Green Bulb Rule base

As mentioned, Amber fuzzy controller designed there is a voltage drop of 1/3 from Amber Lamp voltage drop as per railway circuit theories.

We found Amber Lamp Voltage Range 2.962V Therefore Green Bulb voltage ranges taken by calculating.

Green Lamp voltage drop percentage = 3.16 % x 1/3 = 1.05%

Green lamp voltage drops 2.9624 x 0.105% = 0.0311

Therefore, Actual voltage range = 2.9624V – 0.0311V = 2.9313V

3.2 Justification of Fuzzy Values with Observed Data of Case Study – Signal Pole 263

We have observed many readings of three aspect signals and found there is voltage different in green, amber and red bulbs when working.

Lamp circuit	Voltage (AC)	Current (AC)
Red Circuit	21 V	139 mA
Amber Circuit	21.12 V	138.5 mA
Green Circuit	21.54 V	138.64 mA

Table 3: Case Study 263 Signal Minimum Voltages and Currents for Threes Aspect Work

Calculated data in section 3.1.4 and 3.1.5 data are approximately equal with the observed data. Therefore justified as given fuzzy values are correct. This voltage different can be happened due to length of cables, Cable diameter, loads which working with circuits, bulb lumens.

- Length of cables , diameter of cables

Wire is a resistor and drops some voltage. Therefore, it produces a certain amount of heat. When the wire is long, voltage drop high. When the current is high through the wire, voltage drop along the wire is high. When the wire is thin, voltage drop is high.

Formula for the single phase voltage drop

$$\text{Voltage Drop} = \frac{2\ K\ L\ I}{K\ CM\ I\ L}$$

I = Current

L = Length

K = Constant (Copper media)

KCMIL = Area of conductor in thousand circular mils

- Bulb Lumens

The output of the bulb light is vastly sensitive to voltage. Also, the brightness of the bulb is vastly nonlinear with the applied voltage to the bulb. [16]

Formula for the light variation versus voltage

Lumens (Low Voltage) = (Low Voltage/Nominal Voltage) $^{3.51}$ x Nominal Lumens.

The "heat' level of the filament depends with the light output and color temperature. Bulbs are responsive to the amount of the wattage used. The filament resistance is not constant adding complex variable. [17]

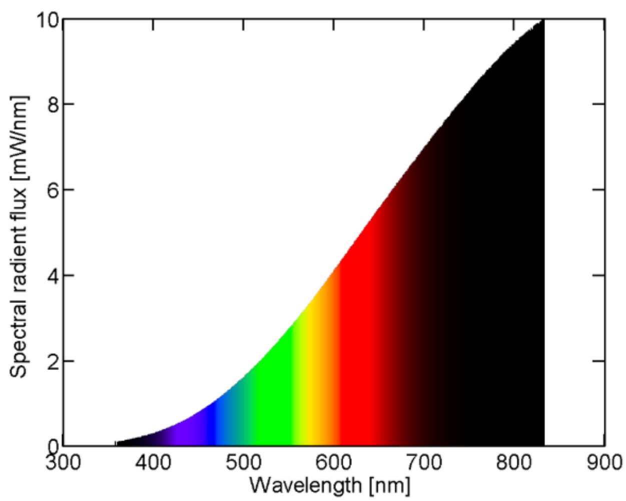


Figure 33: Spectral Power Distribution of Incandescent Bulb [17]

Figure 34, illustrated the schematic diagram of three aspect signal, shows that the signal aspect have three sections. They are relay house (section A), wire cable to signal pole (section B) and signal pole (section c), in different sections each lamp circuits may occur resistance due to above mentioned reasons.

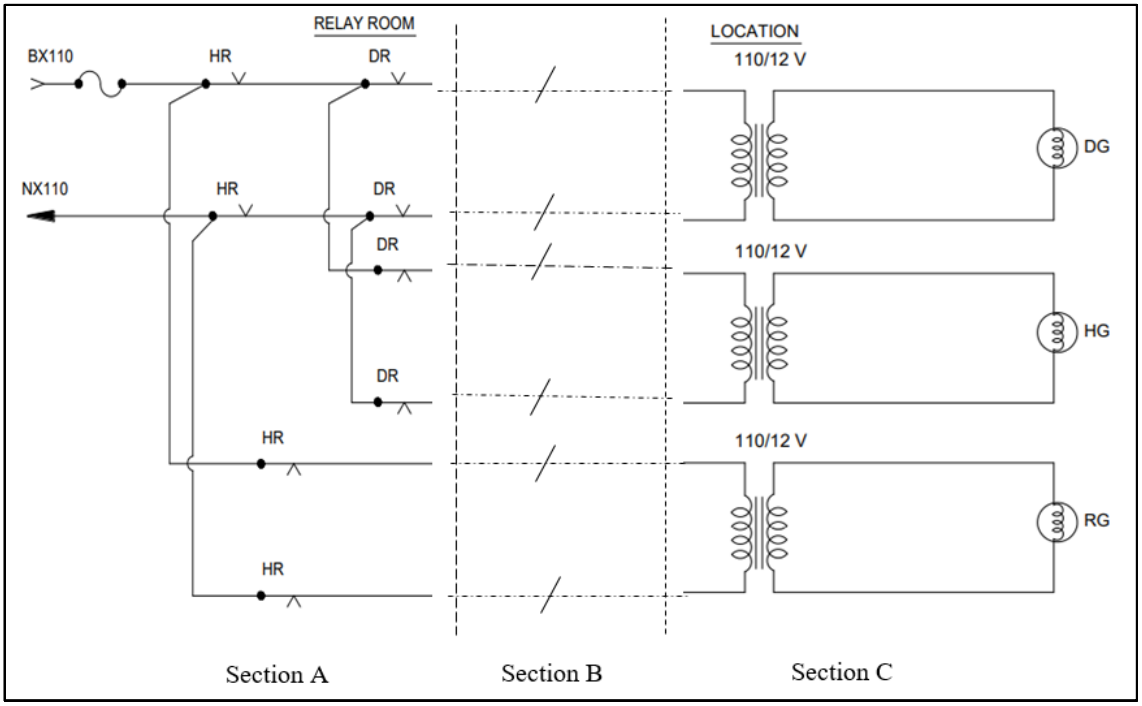


Figure 34: Schematic Diagram of Three Aspect Signal

Table 4, (Observation Voltages Data of Color Signal 263, 550 & 478, 556) shows voltage readings of selected signals. In each section and we can identify that there are certain voltage drops due to unidentified reasons.

We observed readings for Case study 263, voltages taken from Red, Amber and Green bulbs. The Voltage drop from Red bulb circuit is slightly higher than amber and green bulb circuits. Also from case study 550, 478 we can shows there is voltage drop is approximately similar as mentioned in 3.1.4 and 3.1.5. Case study: Signal pole 556 is a two aspect signal and there is a voltage drop between red and amber bulbs. Amber circuit voltage drop is higher than red circuit, Assumed that signal 556 amber circuit voltage drop is higher due to high resistance in amber circuit. Therefore we can justified the given linguistic data to case study 263 fuzzy logic controller is correct.

Section A		Section C Case Study : Signal Pole 263 (600m far from Relay House)		
Relay House	**Input Voltage**	**Cabin Input Voltage**	**Bulb Input Voltage**	**Signal Pole 265**
Red	109.4V	106.32 V	8.541 V	
Amber	109.45V	106.47 V	9.420 V	
Green	109.12 V	106.18 V	9.351 V	
Section A		**Section C** Case Study : Signal Pole 550 (200m far from Relay House)		
Relay House	**Input Voltage**	**Cabin Input Voltage**	**Bulb Input Voltage**	**Signal Pole 550**
Red	109.4V	107.32 V	10.1 V	
Amber	109.45V	108.94 V	11.3 V	
Green	109.12 V	108.45 V	11.031 V	
Section A		**Section C** Case Study : Signal Pole 478 (800m far from Relay House)		
Relay House	**Input Voltage**	**Cabin Input Voltage**	**Bulb Input Voltage**	**Signal Pole 478**
Red	108.4V	103.62 V	7.456 V	
Amber	108.25V	105.14 V	9.420 V	
Green	108.95 V	108.02 V	9.521 V	
Section A		**Section C** Case Study : Signal Pole 556 (200m far from Relay House)		
Relay House	**Input Voltage**	**Cabin Input Voltage**	**Bulb Input Voltage**	**Signal Pole 556**
Red	109.42V	108.02 V	9.10 V	
Amber	109.32V	103.2V	6.72 V	

Table 4: Observation Voltage Data of Color Signal 263, 550 & 478,556)

CHAPTER 4

SYSTEM DESIGN AND DEVELOPMENT

4.1 Experimental Data

To implement the signal aspect circuit model, wanted data was obtained by manually from multi meter (Figure 35: Measuring currents and voltages in relay circuits), and measured data are many more times in faulty condition and proper working condition. Currents and voltages were taken from the case study 263, signal aspect unit. Fallowing input variables used for the model.

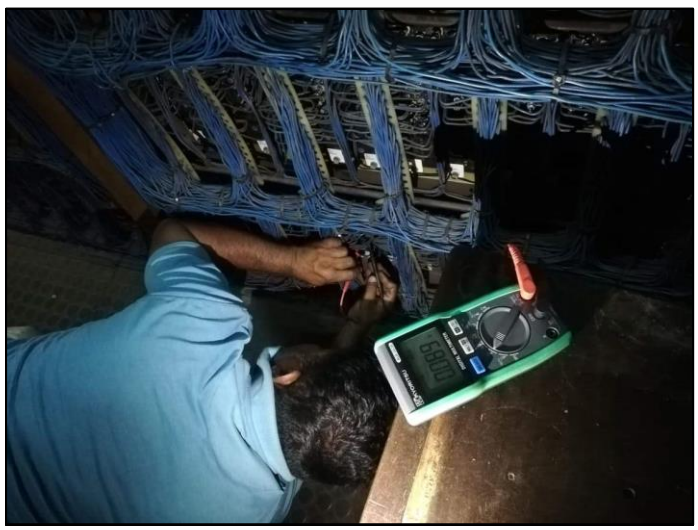


Figure 35: Measuring Currents and Voltages in Relay circuits

Currents and Voltages measurements are taken from Case study Signal 263.

- The Current of HDECR relay $I_{HDCR.}$
- The voltage of HDECR relay $V_{HDCR.}$
- The Current of RECR relay $I_{RECR.}$

- The Voltage of RECR relay $V_{RECR.}$
- The current of Red Lamp IRL.
- The voltage of Red Lamp $V_{RE.}$
- The current of HDR relay $I_{HDR.}$
- The Voltage of HDR relay $V_{HDR.}$
- The current of Rup HR relays $I_{HE.}$
- The voltage of Rup HR relays $V_{HE.}$
- The Current of Amber Lamp I_{HL}
- The voltage of Amber Lamp $V_{HL.}$
- The Current of Rup DR relay $I_{DE.}$
- The Voltage Rup DR relay $V_{DE.}$
- The current of Green Lamp $I_{GL.}$
- The voltage of Green Lamp $V_{GL.}$

To identify the operation of the signal aspect under different conditions, data were collected for each and every failure mode during separate tests with varying signal aspect parameters. Figure 36 illustrates the flow chart of proposed modeled based failure alert system.

Firstly, above mentioned voltages and current readings were taken from lamp circuits. Then, the desired value ranges of each relay inserted to the fuzzy controller, after measured data converted to fuzzification and checked with rule base, then again de-fuzzification. This reading over mapping with desired value ranges. If there is no such variation system again flow in to checking place. If yes it goes to collaboration box. Then it identifies fault component. And engage redundancy with all red, amber, green circuit measures. Then after finding exact failure, from end monitoring get the final results. If the controller couldn’t find the failure results again it will follow the same path.

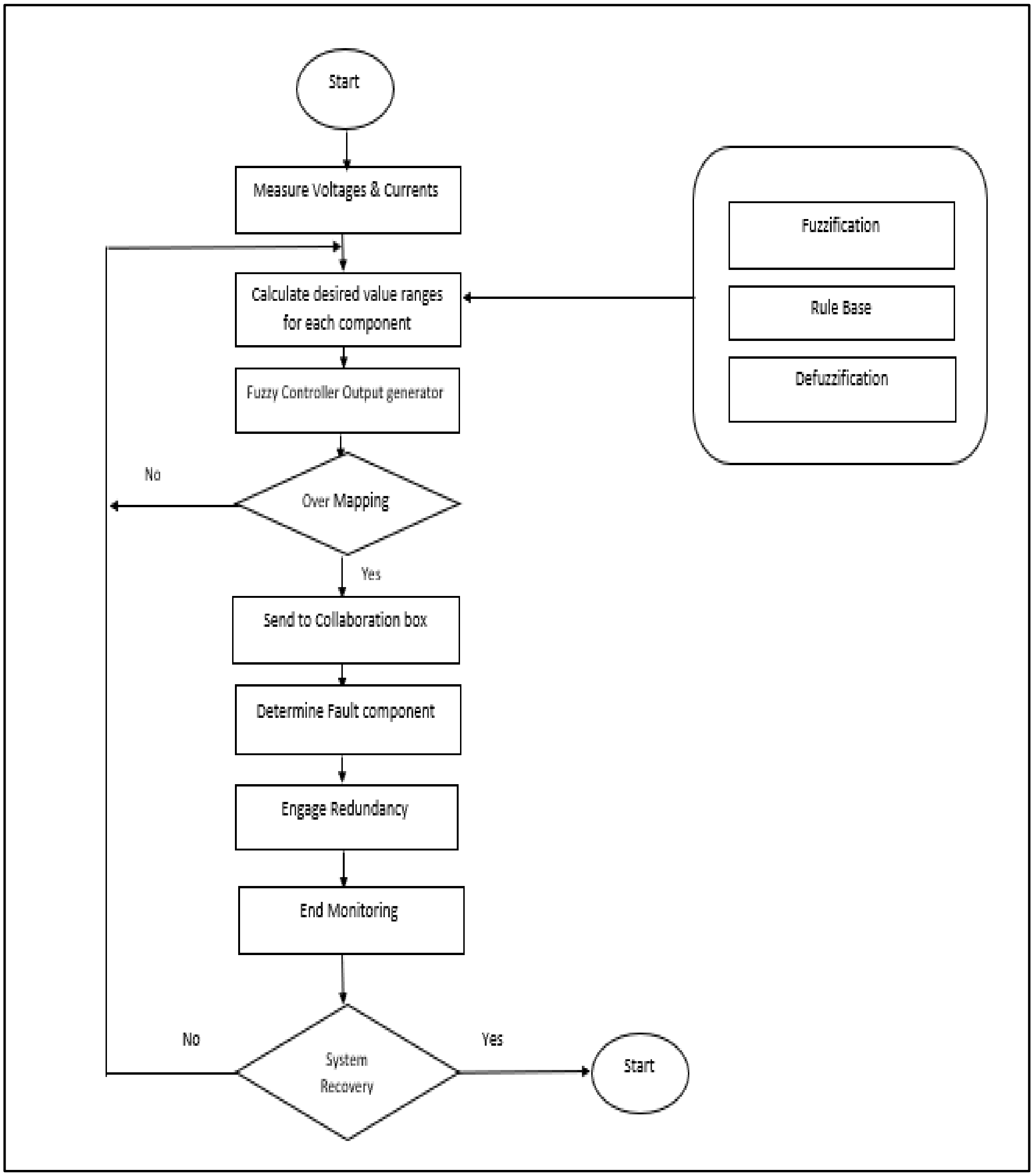


Figure 36: Flow Chart of Proposed Modeled

4.2 Fault Detection and Diagnosis Methodology

This model uses a variation of normal signal working condition in the system. The fault detection method is shown in figure 37. A fault is identified if the observation differs significantly from the model predictions. Conventional model-based fault diagnosis method is divided into three main technologies. They are parity approach, parameter estimation and observer-based approach. Their applications used in industrial applications to find faults.

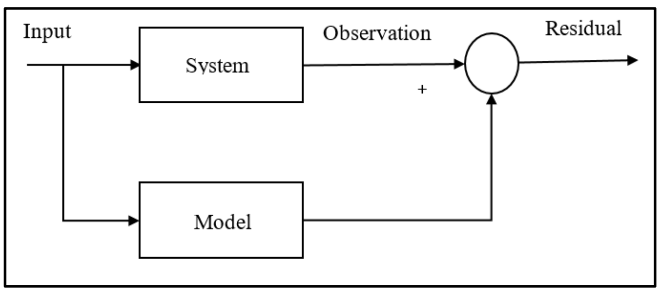


Figure 37: The Concept of Fault Detection [7]

Fuzzy logic intelligent techniques is very useful for the uncertainties systems. The benefit of such an application is that they do not want an actual analytical model of the system. [7].

In fuzzy logic system, fuzzy interference Systems (FIS) transfer numerical values into linguistic values. For example “Large”, “Medium”, and “small”. After developing with membership functions, this fussy system is easy to understand for the people. The system can be modeled using quantitative meanings based on expert’s knowledge about the system. Therefore, a FIS is most suited to dealing with unreliability and uncertainty applications.

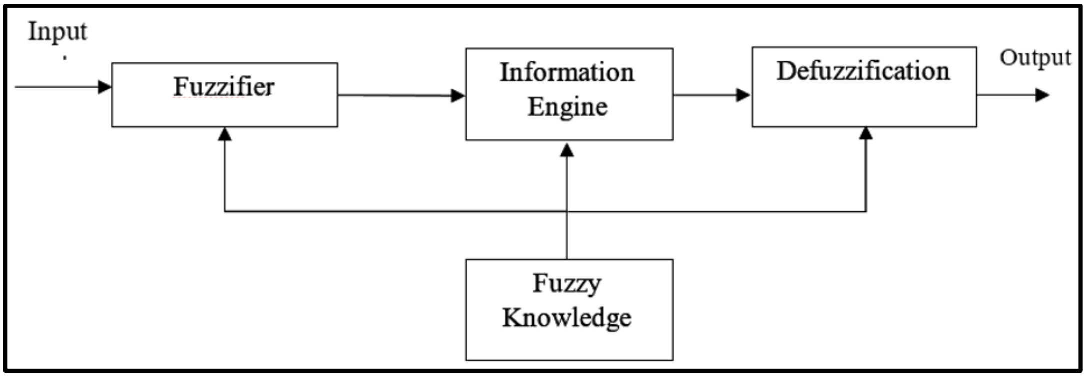


Figure 38: Fuzzy System

4.3 Fuzzy Model for fault detection

As we discuss in signal aspect introduction in section 1.2.3 (figure 06). To activate Lamp Red, RECR relay should be continuously energize, the light checking relay of amber and green should be released to that HDR relay has not operate to activate green Amber lamp HDECR relay should be continuously energize. HDR relay should be picked up and Rup HR relay also should be picked up. To activate green Lamp similar as amber Lamp HDECR relay should be continuously energized. HDR relay should be picked up and Rup DR Relay should be picked up. Table 05, shows the Lamp working condition of current values relays. HDECR and RECR are current checking relays. HDR, HE are voltage relays.

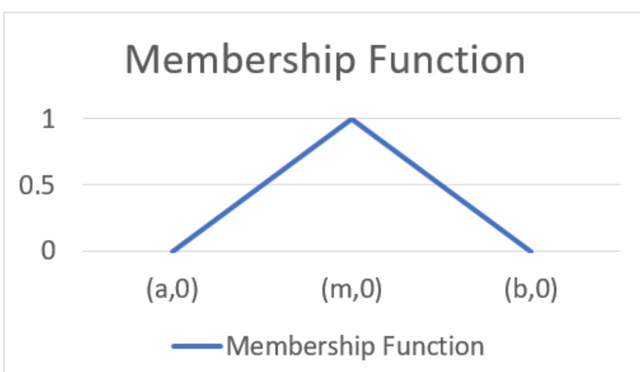
	RED Lamp		**Amber Lamp**		**Green Lamp**	
HDECR relay	0mA	0V	140mA	24V	140mA	24V
RECR relay	140mA	24V	0mA	0V	0mA	0V
HDR relay	0mA	0V	24V	140mA	24V	140mA
HE relays	0mA	0V	24V	140mA	0mA	0V
DE relay	0mA	0V	0mA	0V	24V	140mA

Table 5: Readings of Relays When Each Lamp Working

In Sri Lanka railway we are using different types of Signal Lamps. In this research I am considering about 24W 12V Lamp.

The intelligent signal aspect failure alert system was developed around Mamdani's Fuzzy Interference system modelled and simulated in MATLAB. The System is designed with Mamdani Fuzzy Logic controller because Mamdani Fuzzy Logic controller give high response with time compared to a system without an intelligent technique. The system significantly improves the performance of the system because intelligent techniques are important tools for decision making. In this system Mamdani fuzzy interference method used for triangular function. Because Triangular membership function is the best method to find value variation.

Rule base developed by Triangular Membership function a, m, b are selected based on experiments. The range and fuzzy values are taken by experimental base and partition is uniform. Lower limit is defined by "a", an upper limit is defined by "b" and m is where a < m < b.



$$\mu_A(x) = \begin{cases} 0 & if\ x \leq a \\ -\frac{1}{(x-a)/(m-a)} & if\ a < x \leq m \\ -\frac{1}{(b-x)/(b-m)} & if\ m < x < b \\ 0 & if\ x \geq b \end{cases}$$

Figure 39: Triangular Function

4.3.1 Software Design Consideration: Fuzzy Logic Controller Design

Design of controller for the intelligent based railway signaling failure alert system, input currents and voltages of each relay that affect the operation of the Signal aspect were taken into consideration. These input and output variables of the red lamp, amber amp, green lamp failure condition were more defined by membership functions. The input variables are current and voltages of red lamp, green lamp, and amber lamp and output variables are the failures of components that are shown in Table 6: Failure Mode. Common failures across the signal aspect circuit are observed in this model system, as Table 06. A total of four failure modes of the signal aspect system are observed. This fault is simulated by varying the input and output gains, during the collection of fault data.

Code	Failure Mode
FC 0	Healthy Operation
FC 1	Faulty in Red Lamp Circuit
FC 2	Faulty in Amber Lamp circuit
FC 3	Faulty in Green Lamp Circuit

Table 6: Failure Mode

The five stages of Mamdani’s fuzzy interference system in fuzzification are Fuzzy rules combinations, consequence, aggregation of output and defuzzification were modelled in MATLAB 2013a. (Figure 41. Fuzzy subsystem using MATLAB Simulink window) If this system is used with real application we are considering with exact current and voltages difference and then values are fuzzified.

Relays Current and voltage input variables were fuzzified from crisp input into linguistic values of “Negative High”, “Negative Medium”, “Negative Low”, “Zero” , “Positive Low” , “Positive Medium”, and “Positive High” it is done by Rule base these data keep in a database then again crisp values convert to real values and send outputs to interface machine. The interface machine indicates the failure mode. Red, amber, green circuits' voltages and currents are continuously measuring and sending to the optimizer input function.

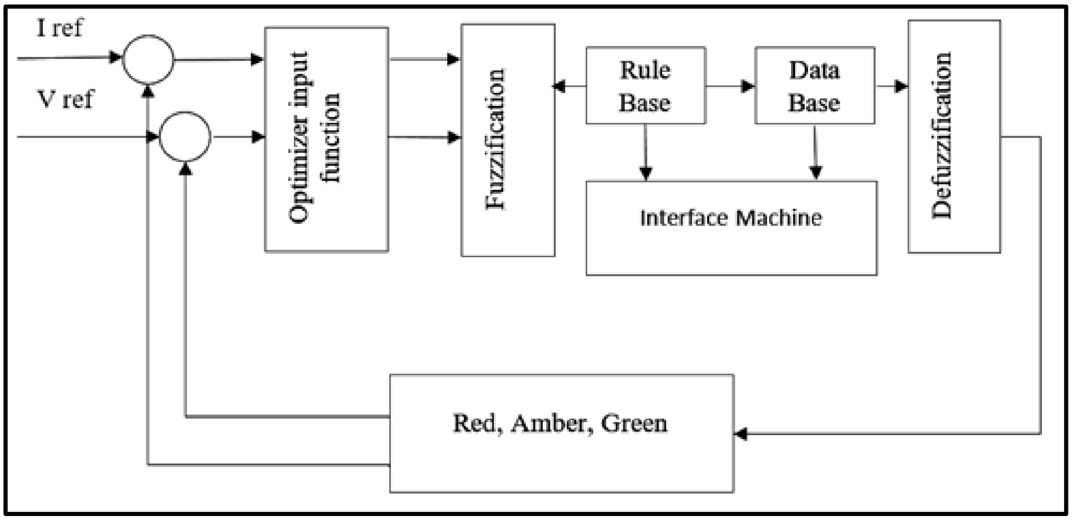


Figure 40: Structure of Fuzzy System

We know V=IR therefore V∞ I

When measuring currents and voltages we identified from small values of variations failures can happen. Therefore, forty-nine rules were developed, so the fuzzy rule for the red bulb intelligent base failure alert system was modeled based on the fuzzified input and output variables using IF and THEN statement relate in Table 07. Same rule base is apply for red signal circuit, amber signal circuit, and green signal circuit, but values change constantly. In this system have 49 rule bases, from which system readings are very accurate and could be used to identify the failure within a short period of time.

4.3.1.1 Rule base for signal circuit failures identification

Rule No.	Rule Statement
1	If I is negative high and V is negative high then relay diagram resistive is negative high.
2	If I is negative medium and V is negative high then relay diagram resistive is negative high.
3	If I is negative low and V is negative high then relay diagram resistive is negative high.
4	If I is zero and V is negative high then relay diagram resistive is negative high.
5	If I is positive low and V is negative high then relay diagram resistive is negative medium.
6	If I is positive medium and V is negative high then relay diagram resistive is negative low.
7	If I is positive high and V is negative high then relay diagram resistive is zero.
8	If I is negative high and V is negative medium then relay diagram resistive is negative high.
9	If I is negative medium and V is negative medium then relay diagram resistive is negative medium.
10	If I is negative low and V is negative medium then relay diagram resistive is negative medium.
11	If I is zero and V is negative medium then relay diagram resistive is negative medium.
12	If I is positive low and V is negative medium then relay diagram resistive is negative high.

13	If I is positive medium and V is negative medium then relay diagram resistive is zero.
14	If I is positive high and V is negative medium then relay diagram resistive is positive low.
15	If I is negative high and V is negative low then relay diagram resistive is negative high.
16	If I is negative high and V is negative low then relay diagram resistive is negative high.
17	If I is negative low and V is negative low then relay diagram resistive is negative high.
18	If I is zero and V is negative low then relay diagram resistive is negative low.
19	If I is positive low and V is negative low then relay diagram resistive is zero.
20	If I is positive medium and V is negative low then relay diagram resistive is positive low.
21	If I is positive high and V is negative low then relay diagram resistive is positive medium.
22	If I is negative high and V is zero then relay diagram resistive is negative high.
23	If I is negative medium and V is zero then relay diagram resistive is negative medium.
24	If I is negative low and V is zero then relay diagram resistive is negative low.
25	If I is zero and V is zero then relay diagram resistive is negative low.
26	If I is positive low and V is zero then relay diagram resistive is positive low.

27	If I is positive medium and V is zero then relay diagram resistive is positive medium.
28	If I is positive high and V is zero then relay diagram resistive is positive high.
29	If I is negative high and V is positive small then relay diagram resistive is negative medium.
30	If I is negative medium and V is positive small then relay diagram resistive is negative low.
31	If I is negative low and V is positive low then relay diagram resistive is zero.
32	If I is zero and V is positive low then relay diagram resistive is positive low.
33	If I is positive low and V is positive low then relay diagram resistive is positive low.
34	If I is positive medium and V is positive low then relay diagram resistive is positive medium.
35	If I is positive high and V is positive low then relay diagram resistive is positive low.
36	If I is negative low and V is positive medium then relay diagram resistive is negative low.
37	If I is negative medium and V is positive medium then relay diagram resistive is zero.
38	If I is negative low and V is positive medium then relay diagram resistive is positive low.
39	If I is zero and V is positive medium then relay diagram resistive is negative medium.
40	If I is positive small and V is positive medium then relay diagram resistive is positive medium.

41	If I is positive medium and V is positive medium then relay diagram resistive is positive medium.
42	If I is positive high and V is positive medium then relay diagram resistive is positive high.
43	If I is negative high and V is positive high then relay diagram resistive is zero.
44	If I is negative medium and V is positive high then relay diagram resistive is positive low.
45	If I is negative low and V is positive high then relay diagram resistive is positive medium.
46	If I is zero and V is zero high then relay diagram resistive is positive high.
47	If I is positive small and V is positive high then relay diagram resistive is positive high.
48	If I is positive medium and V is positive high then relay diagram resistive is positive high.
49	If I am positive high and positive high then relay diagram resistive is positive medium.

Table 7: Rule Base for Signal Circuit Failures Identification

Using the Fuzzy simulate window system (Figure 41, Fuzzy subsystem using MATLAB Simulink window) is taken six inputs. They are red circuit input voltage and current, amber circuit Input current and voltage and green circuit input current and voltage. The linguistic rules in Table.09 was used to map input voltages and currents to identify the system failure.

Rules used are based on the fuzzified input of the current and voltage failure range, consequently a 7 x 7 matrix of forty-nine rules was developed and these inputs were capable of identifying failures from MAX-MIN composition techniques. System is trained to find relay voltages and currents difference from exact voltage and current ranges.

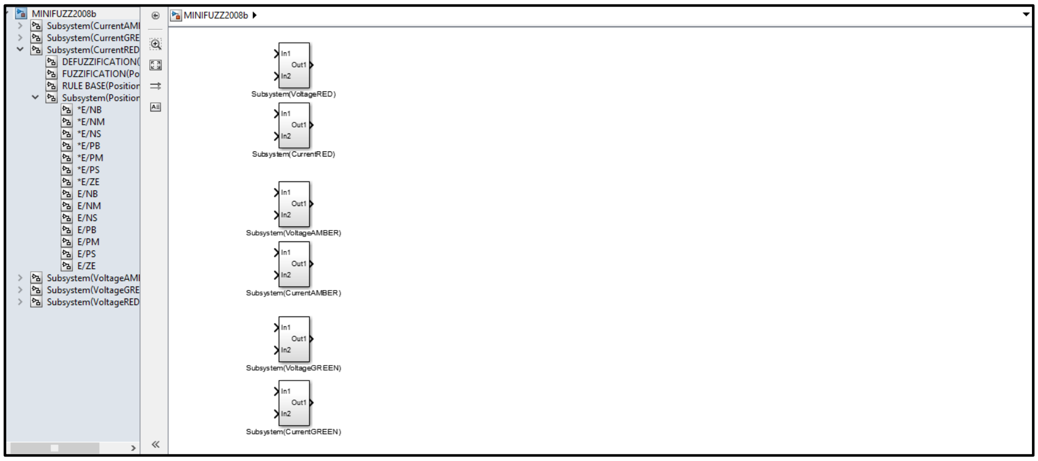


Figure 41: Fuzzy Subsystem Using Mat lab Simulink Window

The system checks the stability of the rules (please refer figure 42). Up to diagonal, system tries to figure out what the signal is giving and the system becomes stable after diagonal then the system is identifies the failure of the circuit.

ΔI / ΔV	**NH**	**NM**	**NL**	**ZE**	**PL**	**PM**	**PL**
NH	NH	NH	NH	NH	NM	NL	ZE
NM	NH	NM	NM	NM	NL	ZE	NL
NL	NH	NL	NM	NL	ZE	NL	NM
ZE	NH	NM	NL	ZE	NL	NM	NH
PL	NM	NL	ZE	NL	NM	NL	NH
PM	NL	ZE	NL	NM	NM	NM	NH
PL	ZE	NL	NM	NH	NH	NH	NH

Figure 42: Fuzzy Rule Matrix of the Intelligent Sub

NH- Negative High , NM- Negative Medium , NL- Negative Low, ZE- Zero , PL - Positive Low, PM- Positive Medium, PH- Positive High

4.4 Red Bulb Rule Base

We practically identified that when there is voltage drop of 3V in relays they are not working, therefore we taken +5V and -5 V as failure range, and for the current failure range is +0.5 mA and -0.5 mA. Fuzzy values are calculated with the use of the triangular membership function described in chapter 03.

Rule No.	Rule Statement
1	If I is negative high and V is negative high then red relay diagram resistive is negative high.
2	If I is negative medium and V is negative high then red relay diagram resistive is negative high.
3	If I is negative low and V is negative high then red relay diagram resistive is negative high.
4	If I is zero and V is negative high then red relay diagram resistive is negative high.
5	If I is positive low and V is negative high then red relay diagram resistive is negative medium.
6	If I is positive medium and V is negative high then red relay diagram resistive is negative low.
7	If I is positive high and V is negative high then red relay diagram resistive is zero.
8	If I is negative high and V is negative medium then red relay diagram resistive is negative high.
9	If I is negative medium and V is negative medium then red relay diagram resistive is negative medium.

10	If I is negative low and V is negative medium then red relay diagram resistive is negative medium.
11	If I is zero and V is negative medium then red relay diagram resistive is negative medium.
12	If I is positive low and V is negative medium then red relay diagram resistive is negative high.
13	If I is positive medium and V is negative medium then red relay diagram resistive is zero.
14	If I is positive high and V is negative medium then red relay diagram resistive is positive low.
15	If I is negative high and V is negative low then red relay diagram resistive is negative high.
16	If I is negative high and V is negative low then red relay diagram resistive is negative high.
17	If I is negative low and V is negative low then red relay diagram resistive is negative high.
18	If I is zero and V is negative low then red relay diagram resistive is negative low.
19	If I is positive low and V is negative low then red relay diagram resistive is zero.
20	If I is positive medium and V is negative low then red relay diagram resistive is positive low.
21	If I is positive high and V is negative low then red relay diagram resistive is positive medium.
22	If I is negative high and V is zero then red relay diagram resistive is negative high.
23	If I is negative medium and V is zero then red relay diagram resistive is negative medium.

24	If I is negative low and V is zero then red relay diagram resistive is negative low.
25	If I is zero and V is zero then red relay diagram resistive is negative high.
26	If I is positive low and V is zero then red relay diagram resistive is positive low.
27	If I is positive medium and V is zero then red relay diagram resistive is positive medium.
28	If I is positive high and V is zero then red relay diagram resistive is positive high.
29	If I is negative high and V is positive low then red relay diagram resistive is negative medium.
30	If I is negative medium and V is positive low then red relay diagram resistive is negative low.
31	If I is negative low and V is positive low then red relay diagram resistive is zero.
32	If I is zero and V is positive low then red Relay diagram resistive is positive low.
33	If I is positive low and V is positive low then red relay diagram resistive is positive low.
34	If I is positive medium and V is positive low then red relay diagram resistive is positive medium.
35	If I is positive high and V is positive low then red relay diagram resistive is positive high.
36	If I is negative high and V is positive medium then red relay diagram resistive is negative low.
37	If I is negative medium and V is positive medium then red relay diagram resistive is zero.

38	If I is negative low and V is positive medium then red relay diagram resistive is positive low.
39	If I is zero and V is positive medium then red relay diagram resistive is negative medium.
40	If I is positive low and V is positive medium then red relay diagram resistive is positive medium.
41	If I is positive medium and V is positive medium then red relay diagram resistive is positive medium.
42	If I is positive high and V is positive medium then red relay diagram resistive is positive high.
43	If I is negative high and V is positive high then red relay diagram resistive is zero.
44	If I is negative medium and V is positive high then red relay diagram resistive is positive low.
45	If I is negative low and V is positive high then red relay diagram resistive is positive medium.
46	If I is zero and V is zero big then red relay diagram resistive is positive high.
47	If I is positive low and V is positive high then red relay diagram resistive is positive high.
48	If I is positive medium and V is positive high then red relay diagram resistive is positive high.
49	If I is positive high and positive high then red relay diagram resistive is positive medium.

Table 8: Rule base for Red Bulb

This universe of discourse of failure range is (+3.059V - -3.059V). This range was used to assign linguistic value to fuzzy linguistic values as fallows, using “Triangular Function”. “Negative high” (-3.059V - - 1.592V), “Negative medium” (-2.294V - -

0.764V), “Negative low” (-1.592V - 0V), “Zero” (-0.764V - 0.764V), “Positive low” (0V - 1.592V), “Positive Medium” (0.764V - 2.294V), “Positive high” (1.592V - 3.059V)

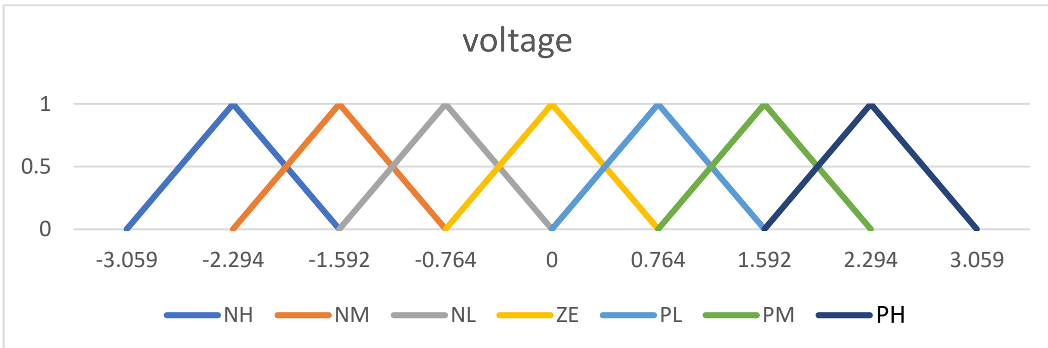


Figure 43: Triangular Functions for Red Lamp Voltage Failure Rate

Universe of discourse of current range (+0.5mA - -0.5mA) was used to assign linguistic values to fuzzified linguistic values, using triangular membership function using red bulb transfer function. “Negative High” (-0.5mA - -0.25mA) “Negative medium” (-0.375mA - -0.125mA), “Negative Low” (-0.25mA - 0mA), “Zero” (-0.125mA - 0.125mA), “Positive Low” (0mA - 0.25mA), “Positive Medium” (0.125mA - 0.375mA), “Positive High” (0.25mA - 0.5mA).

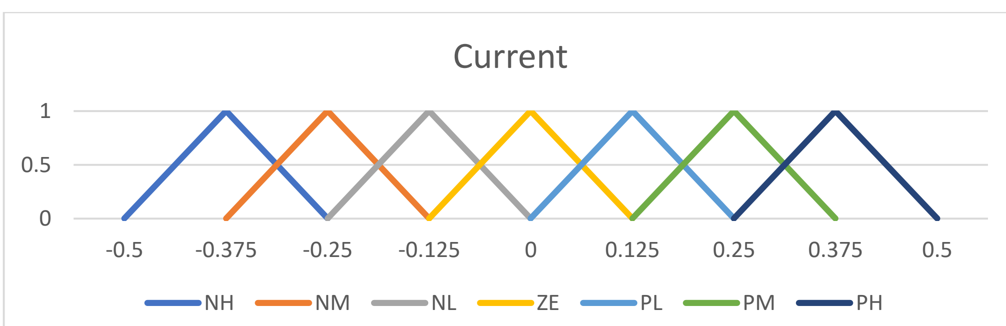


Figure 44: Triangular Function for Red Lamp Current Failure Rate

According to above values fuzzy value system is designed to using fuzzy Simulink. Here inputs to the sub system are current to the red circuit diagram and voltage to the red circuit diagram.

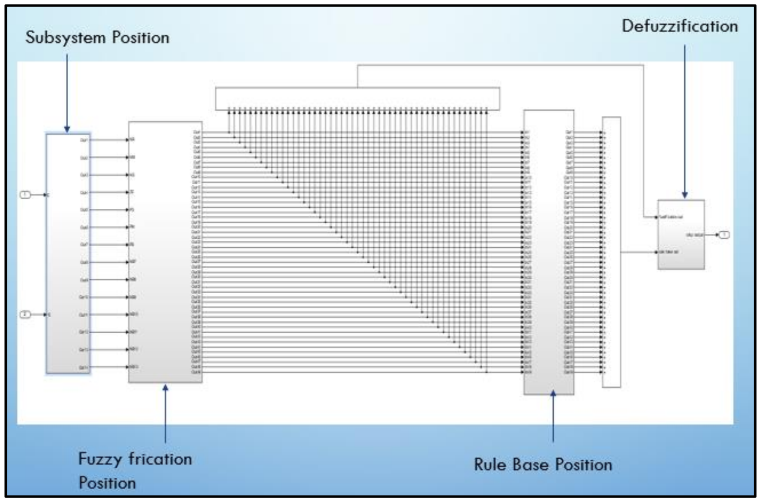


Figure 45: Fuzzification Design

Using min max technique fuzzification positions designed figure 48 illustrates the fuzzification position design.

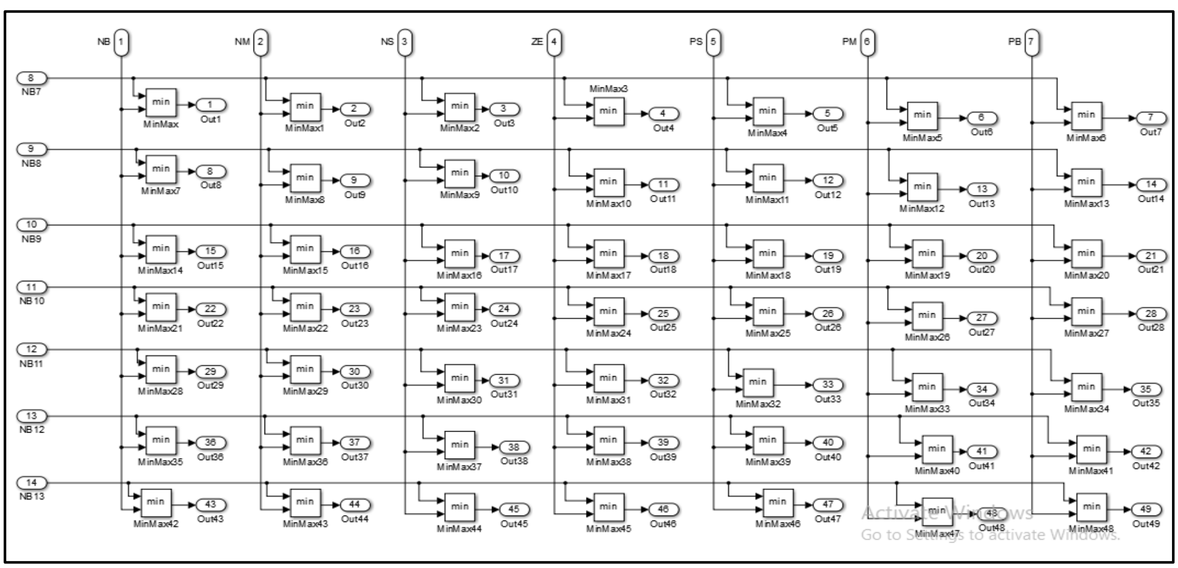


Figure 46: Fuzzification Design of Red Lamp Circuit

Using Min -Max techniques 49 of rules designed. Rule base is designed according to the identified measured values. Figure 47, shows fuzzy Simulink Diagram for rule base designed by MATLAB.

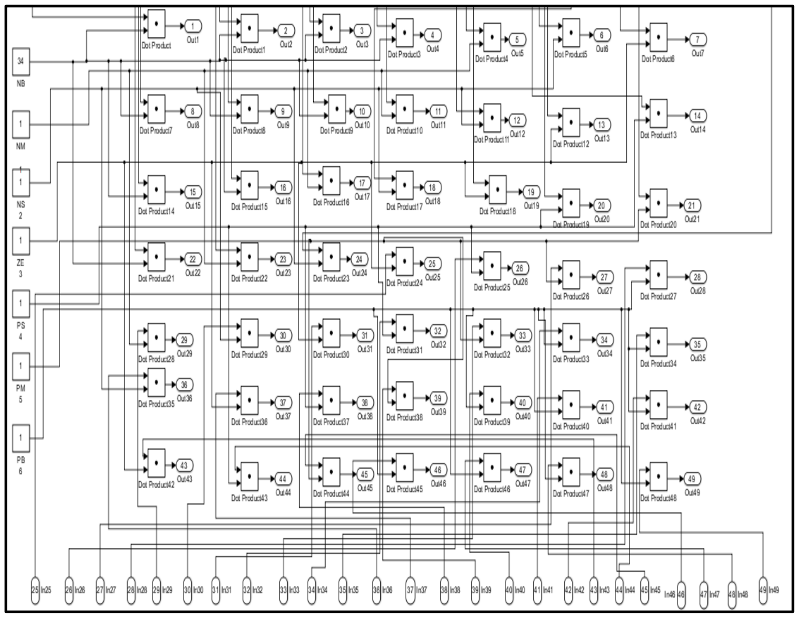


Figure 47: Fuzzy Rule Base

Figure 47 shows rule base of negative big voltage rule. As figure 48, shows every rule base designed using MATLAB Simulink window.

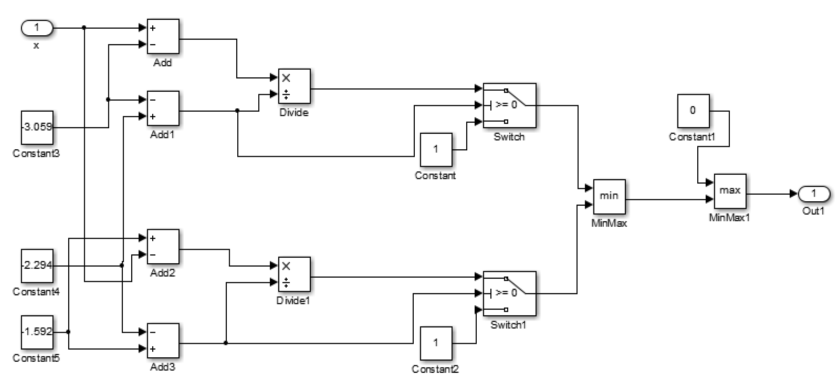


Figure 48: Negative Big Voltage Rule Base

4.5 Amber Bulb Rule Base

Rule No.	Rule Statement
1	If I is negative high and V is negative high then amber relay diagram resistive is negative high.
2	If I is negative medium and V is negative high then amber relay diagram resistive is negative high.
3	If I is negative low and v is negative high then amber relay diagram resistive is negative high.
4	If I is zero and V is negative high then amber relay diagram resistive is negative high.
5	If I is positive low and V is negative high then amber relay diagram resistive is negative medium.
6	If I is positive medium and V is negative high then amber relay diagram resistive is negative low.
7	If I is positive high and V is negative high then amber relay diagram resistive is zero.
8	If I is negative high and V is negative medium then amber relay diagram resistive is negative high.
9	If I is negative medium and V is negative medium then amber relay diagram resistive is negative medium.
10	If I is negative low and V is negative medium then amber relay diagram resistive is negative medium.
11	If I is zero and V is negative medium then amber relay diagram resistive is negative medium.
12	If I is positive low and V is negative medium then amber relay diagram resistive is negative high.

13	If I is positive medium and V is negative medium then amber relay diagram resistive is zero.
14	If I is positive high and V is negative medium then amber relay diagram resistive is positive low.
15	If I is negative high and V is negative low then amber relay diagram resistive is negative high.
16	If I is negative high and V is negative low then amber relay diagram resistive is negative high.
17	If I is negative low and V is negative low then amber relay diagram resistive is negative high.
18	If I is zero and V is negative low then amber relay diagram resistive is negative low.
19	If I is positive low and V is negative low then amber relay diagram resistive is zero.
20	If I is positive medium and V is negative low then amber relay diagram resistive is positive low.
21	If I is positive high and V is negative low then amber relay diagram resistive is positive medium.
22	If I is negative high and V is zero then amber relay diagram resistive is negative high.
23	If I is negative medium and V is zero then amber relay diagram resistive is negative medium.
24	If I is negative low and V is zero then amber relay diagram resistive is negative low.
25	If I is zero and V is zero then amber relay diagram resistive is negative high.
26	If I is positive low and V is zero then amber relay diagram resistive is positive low.

27	If I is positive medium and V is zero then amber relay diagram resistive is positive medium.
28	If I is positive high and V is zero then amber relay diagram resistive is positive high.
29	If I is negative high and V is positive low then amber relay diagram resistive is negative medium.
30	If I is negative medium and V is positive low then amber relay diagram resistive is negative low.
31	If I is negative low and V is positive low then amber relay diagram resistive is zero.
32	If I is zero and V is positive low then amber relay diagram resistive is positive low.
33	If I is positive low and V is positive low then amber relay diagram resistive is positive low.
34	If I is positive medium and V is positive low then amber relay diagram resistive is positive medium.
35	If I is positive high and V is positive low then amber relay diagram resistive is positive high.
36	If I is negative high and v is positive medium then amber relay diagram resistive is negative low.
37	If I is negative medium and V is positive medium then amber relay diagram resistive is zero.
38	If I is negative low and V is positive medium then amber relay diagram resistive is positive low.
39	If I is zero and V is positive medium then amber relay diagram resistive is negative medium.
40	If I is positive low and V is positive medium then amber relay diagram resistive is positive medium.

41	If I is positive medium and V is positive medium then amber relay diagram resistive is positive medium.
42	If I is positive high and V is positive medium then amber relay diagram resistive is positive high.
43	If I is negative high and V is positive high then amber relay diagram resistive is zero.
44	If I is negative medium and V is positive high then amber relay diagram resistive is positive low.
45	If I is negative low and V is positive high then amber relay diagram resistive is positive medium.
46	If I is zero and V is positive high then amber relay diagram resistive is positive high.
47	If I is positive low and V is positive high then amber relay diagram resistive is positive high.
48	If I is positive medium and V is positive high then amber relay diagram resistive is positive high.
49	If I is positive high and V is positive high then amber relay diagram resistive is positive medium.

Table 9: Amber Bulb Rule Base

This universe of discourse of failure range is (-2.962V - 2.962V). This range was used to assign linguistic value to fuzzy linguistic values as fallows Using Triangular Function. “Negative High” (-2.962V - -1.481V), “Negative Medium” (-2.221 V - - 0.74V), “Negative Low” (-1.481V - 0V), “Zero” (-0.74V - 0.74V), “Positive Low” (0V - 1.481V), “Positive Medium” (0.74V - 2.221V), “Positive High” (1.481V - 2.962V)

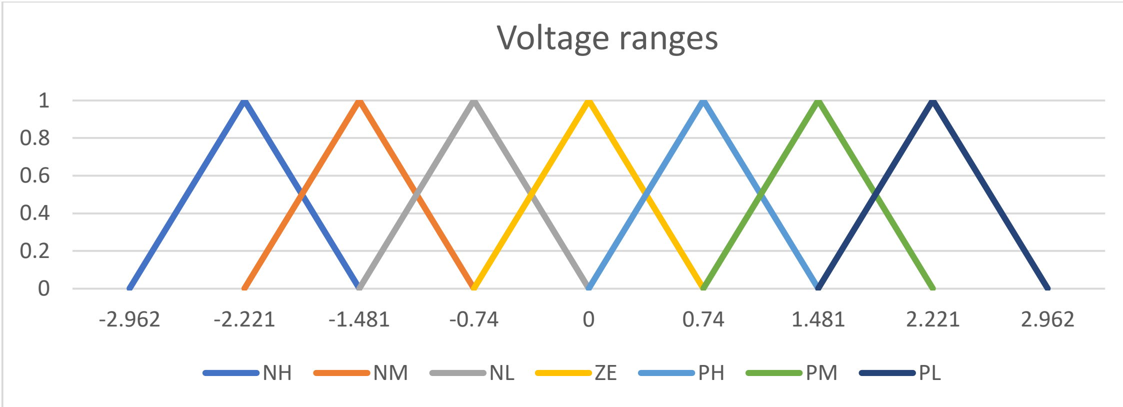


Figure 49: Triangular Functions for Amber Lamp Voltage Failure Rate

From Transfer function Amber circuit current fuzzy values using triangular function. “Negative Big” (-0.5mA - -0.25mA), “Negative medium” (-0.375 mA - -0.125mA), “Negative Small” (-0.25mA - 0mA), “Zero” (-0.125mA - 0.125mA), “Positive Small” (0mA - 0.25mA), “Positive Medium” (0.125mA - 0.375mA), “Positive Big” (0.25mA - 0.5mA).

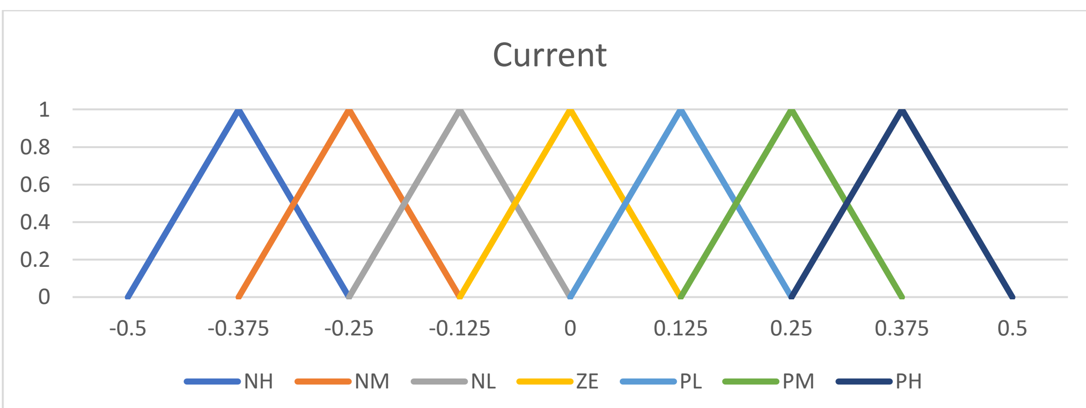


Figure 50: Triangular Functions for Amber Lamp Current Failure Rate

Same as Red bulb Fuzzy controller for Amber Lamp circuit is designed using MATLAB Simulink.

4.6 Green Bulb Rule Base

Rule No.	Rule Statement
1	If I is negative high and V is negative high then green relay diagram resistive is negative high.
2	If I is negative medium and V is negative high then green relay diagram resistive is negative high.
3	If I is negative low and V is negative high then green relay diagram resistive is negative high.
4	If I is zero and V is negative high then green relay diagram resistive is negative high.
5	If I is positive low and V is negative high then green relay diagram resistive is negative medium.
6	If I is positive medium and V is negative high then green relay diagram resistive is negative low.
7	If I is positive high and V is negative high then green relay diagram resistive is zero.
8	If I is negative high and V is negative medium then green relay diagram resistive is negative high.
9	If I is negative medium and V is negative medium then amber relay diagram resistive is negative medium.
10	If I is negative low and V is negative medium then green relay diagram resistive is negative medium.
11	If I is zero and V is negative medium then green relay diagram resistive is negative medium.
12	If I is positive low and V is negative medium then green relay diagram resistive is negative high.

13	If I is positive medium and V is negative medium then green relay diagram resistive is zero.
14	If I is positive high and V is negative medium then green relay diagram resistive is positive low.
15	If I is negative high and V is negative low then green relay diagram resistive is negative high.
16	If I is negative high and V is negative low then green relay diagram resistive is negative high.
17	If I is negative low and V is negative low then green relay diagram resistive is negative high.
18	If I is zero and V is negative low then green relay diagram resistive is negative low.
19	If I is positive low and V is negative low then green relay diagram resistive is zero.
20	If I is positive medium and V is negative low then green relay diagram resistive is positive low.
21	If I is positive high and V is negative low then green relay diagram resistive is positive medium.
22	If I is negative high and V is zero then green relay diagram resistive is negative high.
23	If I is negative medium and V is zero then green relay diagram resistive is negative medium.
24	If I is negative low and V is zero then green relay diagram resistive is negative low.
25	If I is zero and V is zero then green relay diagram resistive is negative high.
26	If I is positive low and V is zero then green relay diagram resistive is positive low.

27	If I is positive medium and V is zero then green relay diagram resistive is positive medium.
28	If I is positive high and V is zero then amber green relay diagram resistive is positive high.
29	If I is negative high and V is positive low then green relay diagram resistive is negative medium.
30	If I is negative medium and V is positive low then green relay diagram resistive is negative low.
31	If I is negative low and V is positive low then green relay diagram resistive is zero.
32	If I is zero and V is positive low then green relay diagram resistive is positive low.
33	If I is positive low and V is positive low then green relay diagram resistive is positive low.
34	If I is positive medium and V is positive low then green relay diagram resistive is positive medium.
35	If I is positive high and V is positive low then green relay diagram resistive is positive high.
36	If I is negative high and V is positive medium then green relay diagram resistive is negative low.
37	If I is negative medium and V is positive medium then green relay diagram resistive is zero.
38	If I is negative low and V is positive medium then green relay diagram resistive is positive low.
39	If I is zero and V is positive medium then green relay diagram resistive is negative medium.
40	If I is positive low and V is positive medium then green relay diagram resistive is positive medium.

41	If I is positive medium and V is positive medium then green relay diagram resistive is positive medium.
42	If I is positive high and V is positive medium then green relay diagram resistive is positive high.
43	If I is negative high and V is positive high then green relay diagram resistive is zero.
44	If I is negative medium and V is positive high then green relay diagram resistive is positive low.
45	If I is negative low and V is positive high then green relay diagram resistive is positive medium.
46	If I is zero and V is zero high then green relay diagram resistive is positive high.
47	If I is positive low and V is positive high then green relay diagram resistive is positive high.
48	If I is positive medium and V is positive high then green relay diagram resistive is positive high.
49	If I is positive high and V is positive high then green relay diagram resistive is positive medium.

Table 10: Green Bulb Rule Base

This universe of discourse of failure range is (2.313V - 2.313V). This range was used to assign linguistic value to fuzzy linguistic values as follow using triangular function of green lamp circuit. “Negative High” (-2.313V - 1.170V), “Negative Medium” (-2.110 V -0.429V), “Negative Low” (-1.170V 0V), “Zero” (-0.429V - 0.429V), “Positive Low” (0V - 1.170V), “Positive Medium” (0.429V - 2.110V), “Positive High” (1.170V - 2.9313V).

This universe of discourse of failure current range is (-0.031mA - - 0.031mA). This range was used to assign linguistic value to fuzzy linguistic values as follow using triangular function of green lamp circuit. “Negative High” (-0.031mA - 0.015mA), “Negative Medium” (-0.023 mA - -0.07mA), “Negative Low” (-0.015mA - 0.000mA), “Zero” (-0.007mA - 0.07mA), “Positive Low” (-0.015mA - 0.000mA), “Positive Medium” (0.007mA - 0.023mA), “Positive High” (0.015mA - 0.031mA). Figure 51 shows the triangular functions.

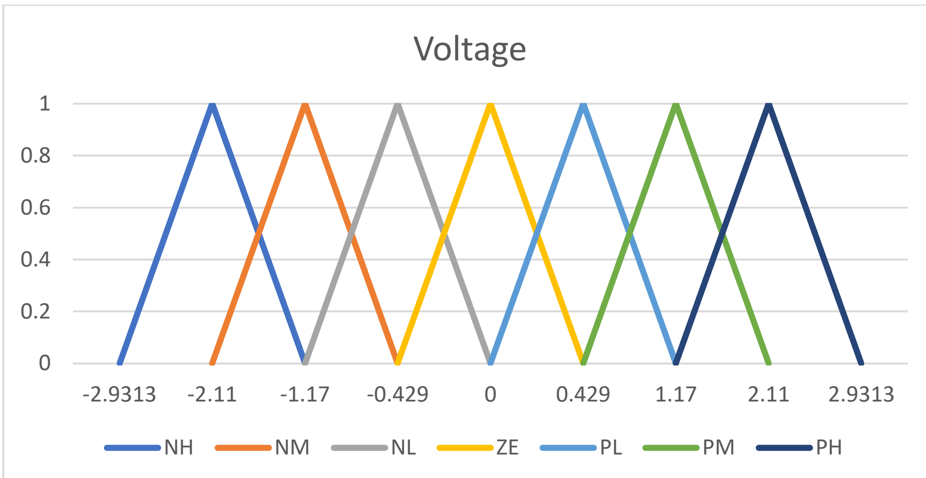


Figure 51: Triangular Functions for Green Lamp Voltage Failure Rate

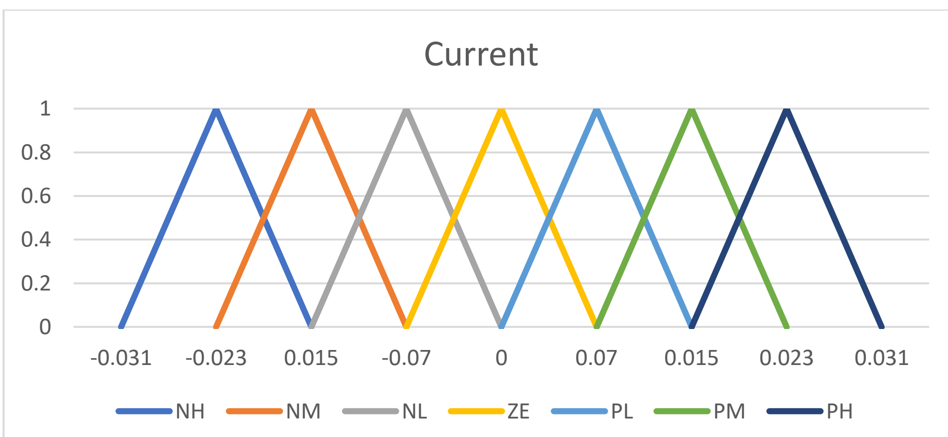


Figure 52: Triangular Functions for Green Lamp Current Failure Rate

CHAPTER 5

MODEL DESCRIPTION WITH ASSUMPTIONS

According to the rule base in chapter 4, this model is developed to 600m away from the case study signal pole 263 Colombo fort yard. Signal pole is powered from three phase. For the MATLAB we gave 400V .and the resistance is change with the distance. But for the relay circuit take around 25V relay operating voltage as mentioned in chapter 3.

According to those calculated values, system models were developed. Identified failure range is -4V and +4V, when relay process is changes with small time. The circuit used copper cable and according to cable specifications 600m cable maximum is resistivity is 0.45 ϱ for this model we assign that maximum resistive value to get an accurate signal. From integral functions all the possibilities are added to get accurate error rate value. Model is designed to 0.01s time intervals to generate voltage over current range

5.1 Lamp Circuit Failure Identification

Figure 53, shows current over time graph, red line is failure range, if model generate a line below the red line it is a failure (F1), failure in Red circuit that means RECR is damage. Figure 54 shows the voltage over time graph as earlier described mode is generate to voltage failure range, if there are any anomalies happened red line is generating below voltage line. Above the red line readings are healthy condition in Red Lamp circuit. That's means RECR relay hasn't any failure.

To find more results model is checked by MATLAB 2014a. When there is no failure in circuit, the red line is not within failure range and it is increased in short period.

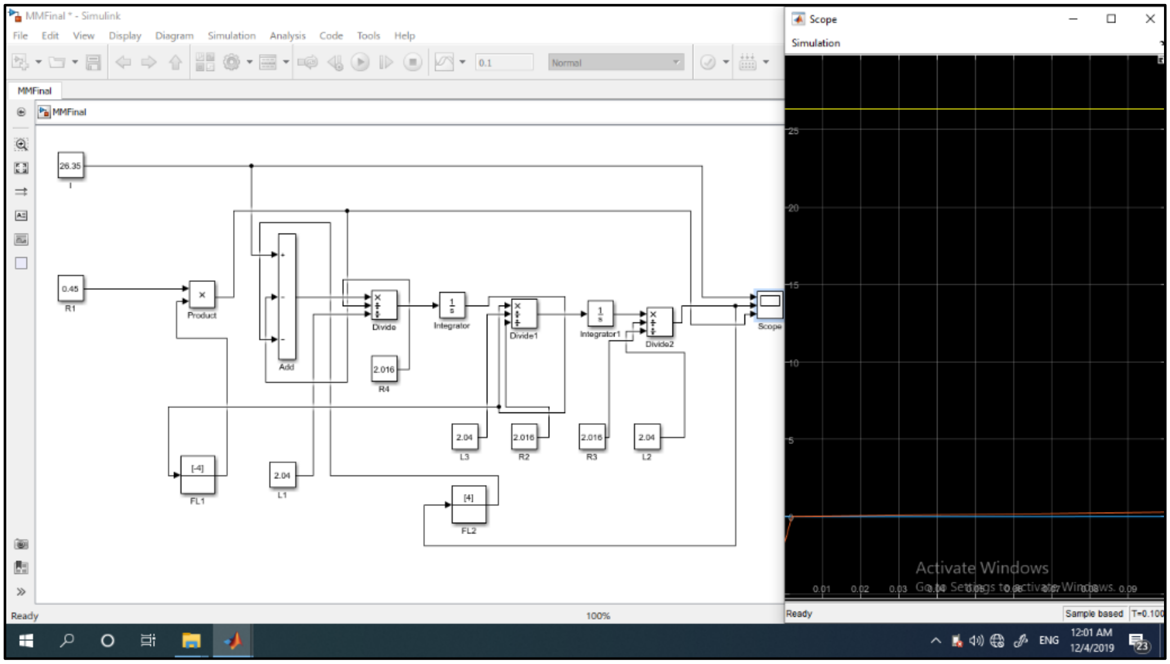


Figure 53: MATLAB 2014a Model for the Red Bulb Circuit and Current Faulty Diagram

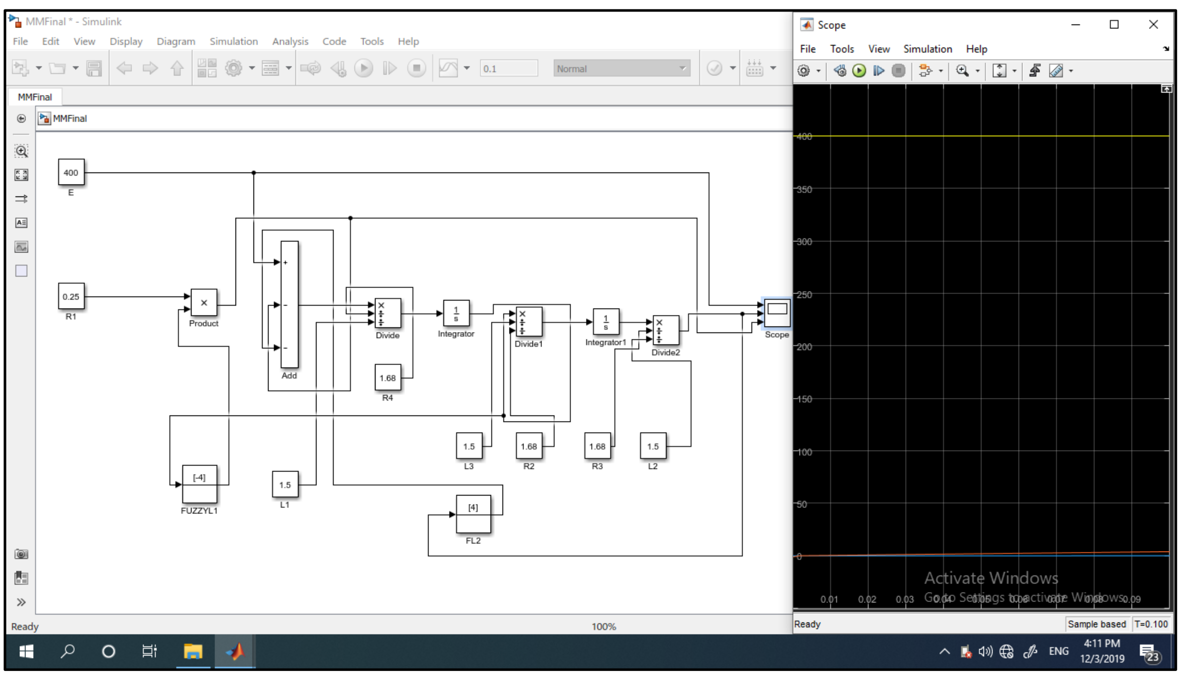


Figure 54: MATLAB 2014a Model for the Red Bulb Circuit and Voltage Faulty Diagram

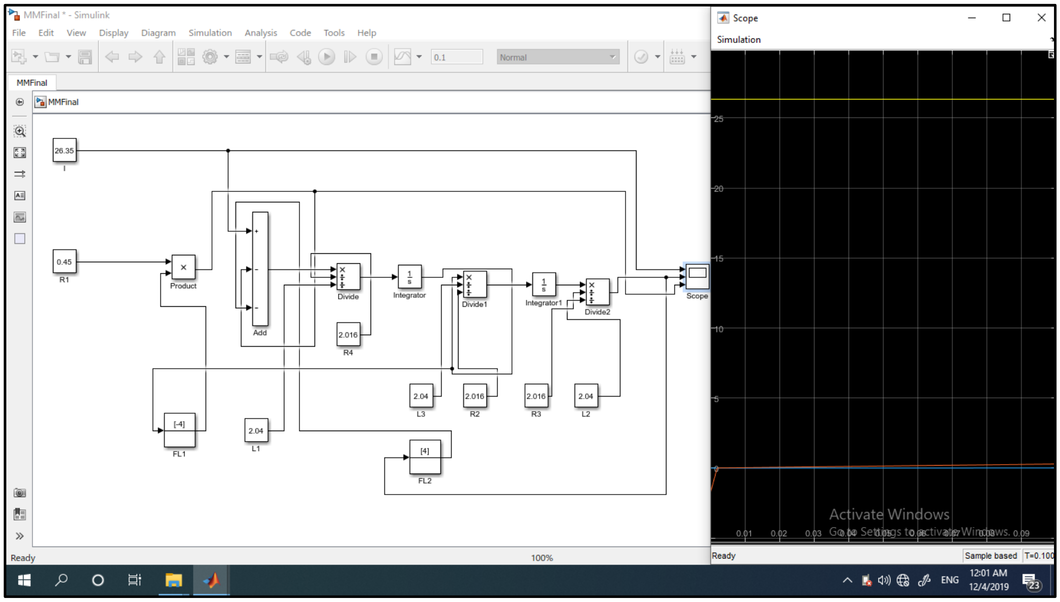


Figure 55: MATLAB 2014a Model for the Amber Bulb Circuit and Current Faulty Diagram

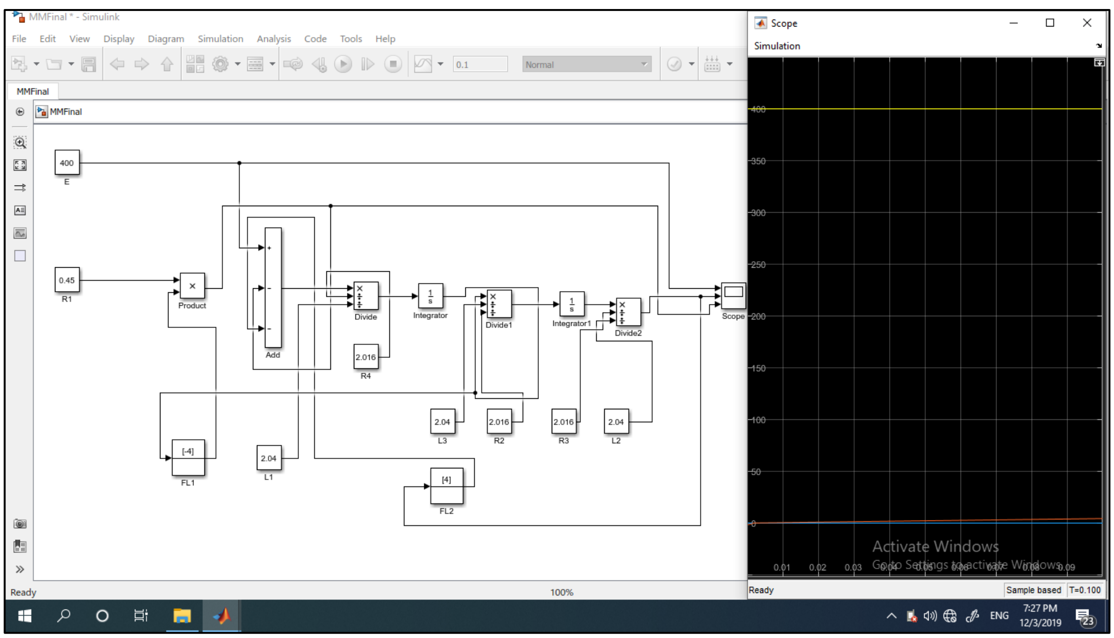


Figure 56: MATLAB 2014a Model for the Amber Bulb Circuit and Voltage Faulty Diagram

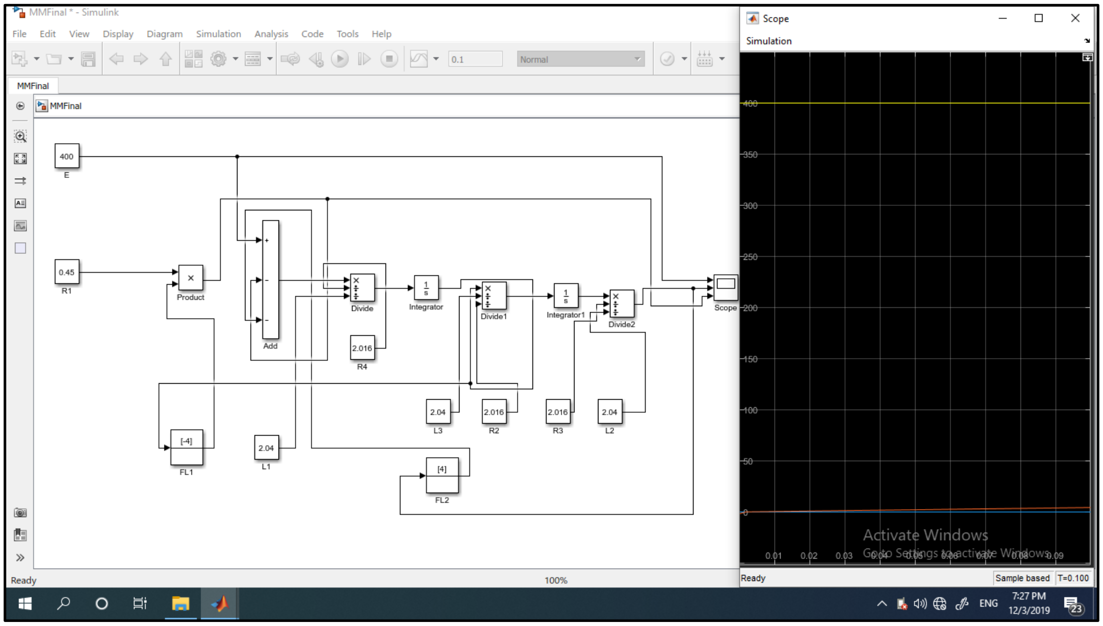


Figure 57: MATLAB 2014a Model for the Green Bulb Circuit and Current Faulty Diagram

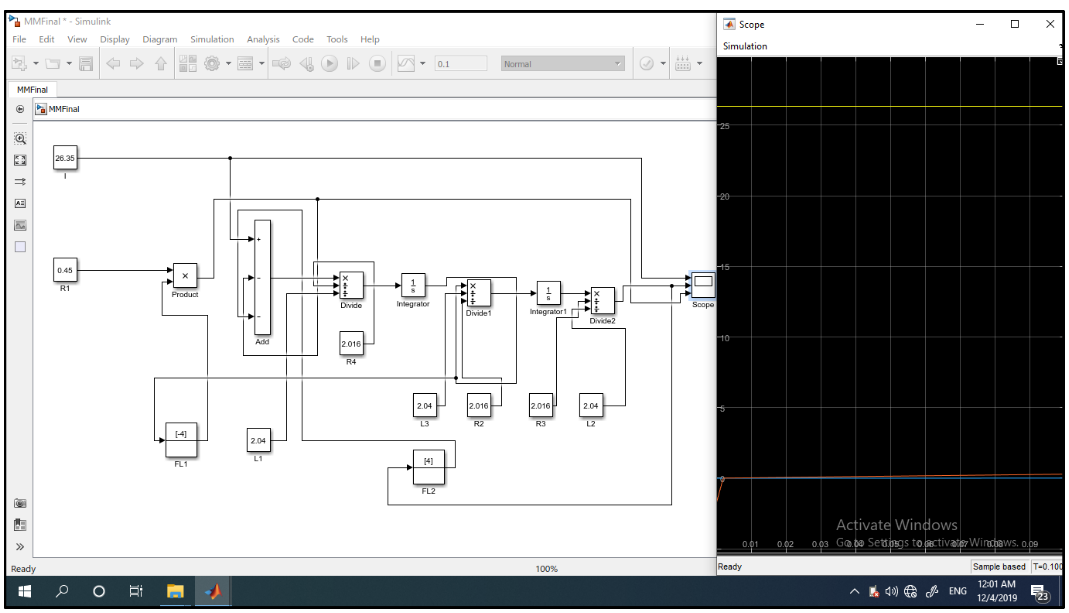


Figure 58: MATLAB 2014a Model for the Green Bulb Circuit and Voltage Faulty Diagram

Same as the Red Lamp circuit current over time graph (figure 53), amber lamp current over time graph shows in figure 55. And Green Lamp current over time graph shows in figure 57. As mentioned earlier, Bellow the Red line is failure range, if model generate a line below the red line it is a failure, if line is bellow in Amber lamp circuit graph red line it is faulty F2 mode, if line is bellow in Green lamp circuit graph red line, it is faulty F3 mode.

When there is no failure in circuit. The line is not within failure range and rise in short period.

As shows in figure 54, MATLAB 2014a model for the red bulb circuit and voltage faulty diagram, voltage failure range is below the red line. If there are any anomalies happened in lamp circuit (red, amber or green) a line will generated by model below the red line. (Please refer figure 56 and 58). If model generate a line below the red line it is a failure, if line is bellow in Amber lamp circuit graph red line it is faulty F2 mode, if line is bellow in Green lamp circuit graph red line it is faulty F3 mode.

When there is no failure in circuit. The line is not within failure range and it is rise in a very short period.

5.2 Validation of the Results of Intelligent Base Signaling Failure Alert System

To validate the intelligent base signaling failure alert system, the system is checked with actual readings of the case study 263 signal. The final output of the intelligent base signaling failure alert system model is designed with mat lab interface. If the system output displayed “0” there is no failure, if “1” displayed there is a failure in the circuit.

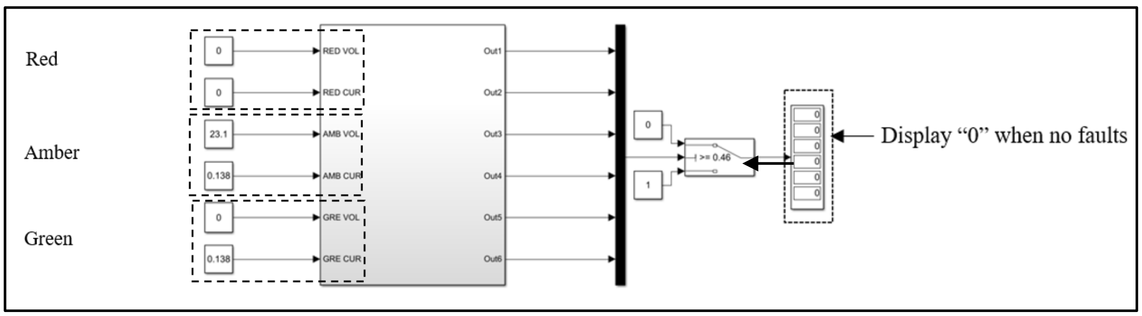


Figure 59: When No Failures in the Circuit

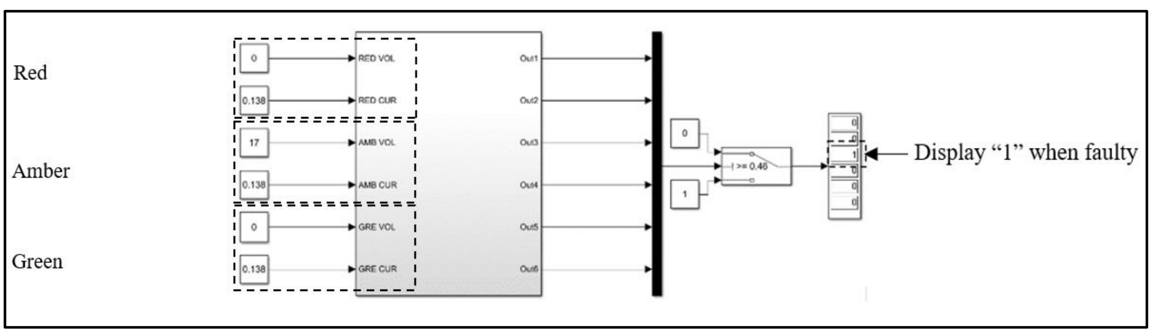
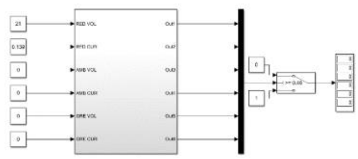
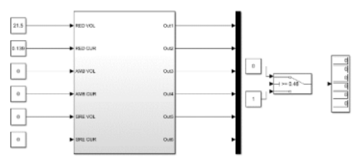
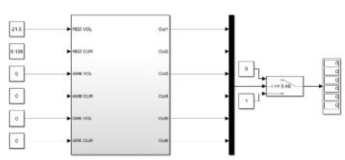
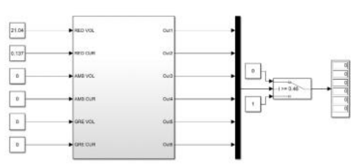
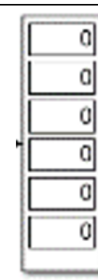


Figure 60: When failure in the circuit

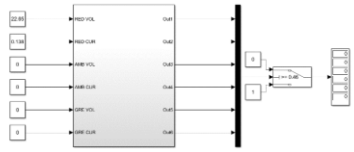
Finally overall intelligent base signaling failure alert system model tested for FC0 , FC1, FC2, FC3, FC4 modes describe in section 4.3.1 , Table 6 and validate with actual readings of case study 263.

5.2.1 Case Study 263 signal Red Bulb Results

<table>
<tr><th>Test No.</th><th>Actual readings in Red Lamp Circuit (AC) (When working condition)</th><th>Model 0utput No failure mode (FC 0)</th><th>Output Result of the Model (FC 0)</th></tr>
<tr><td>1.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>139 mA</td><td>21 V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
<tr><td>2.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>139.10mA</td><td>21.5 V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
<tr><td>3.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>138.45.mA</td><td>21.5 V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
<tr><td>4.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>137mA</td><td>21.04 V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
</table>

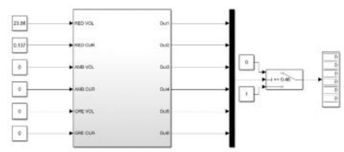
5.

	Current	Voltage
Red Lamp Circuit	138.16mA	22.65V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V



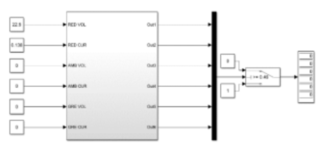
6.

	Current	Voltage
Red Lamp Circuit	137.3 mA	23.56V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V



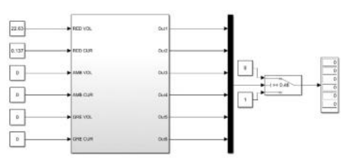
7.

	Current	Voltage
Red Lamp Circuit	138mA	22.5V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V



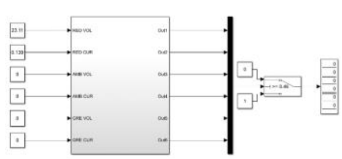
8.

	Current	Voltage
Red Lamp Circuit	137.14mA	22.63V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V



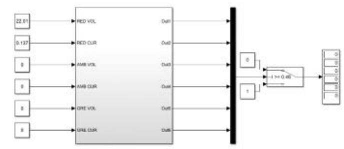
9.

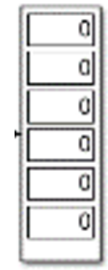
	Current	Voltage
Red Lamp Circuit	139.88mA	23.11V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V



10.

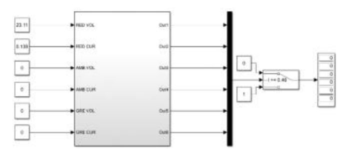
	Current	Voltage
Red Lamp Circuit	137.88mA	22.01V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V

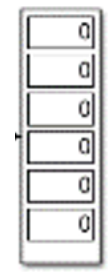




11.

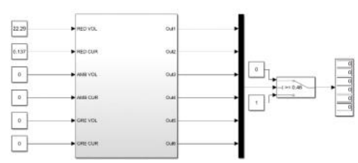
	Current	Voltage
Red Lamp Circuit	139.88mA	23.11V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V





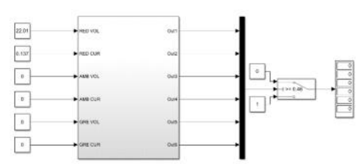
12.

	Current	Voltage
Red Lamp Circuit	137.66mA	22.29V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V



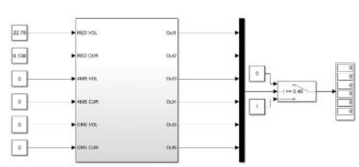
13.

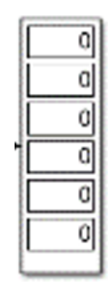
	Current	Voltage
Red Lamp Circuit	137.88mA	22.01V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V



14.

	Current	Voltage
Red Lamp Circuit	138.47mA	22.79V
Green Lamp Circuit	0 mA	0 V
Amber Lamp Circuit	0 mA	0 V





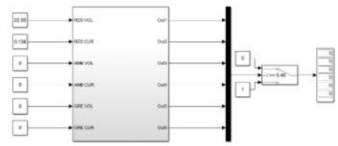
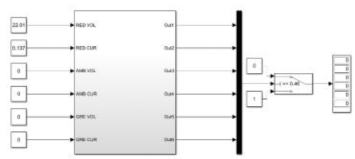
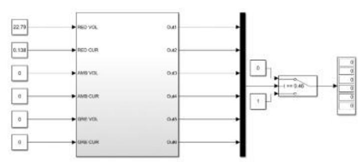
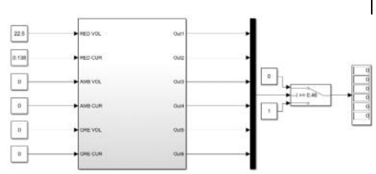
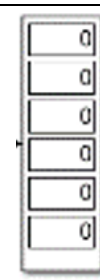
<table>
<tr><td>15.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>138.48mA</td><td>22.60V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
<tr><td>16</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>137.92mA</td><td>22.01V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
<tr><td>17.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>138mA</td><td>22.79V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
<tr><td>18.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>138.55mA</td><td>22.5V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
</table>

Table 11: Red Lamp Working Conditions Results

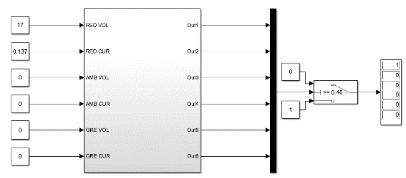
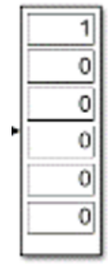
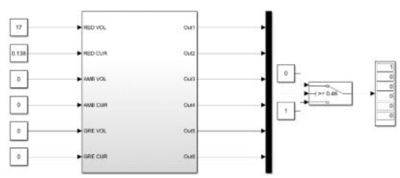
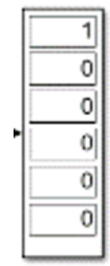
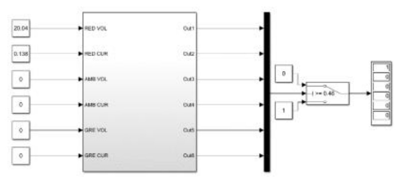
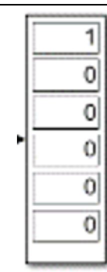
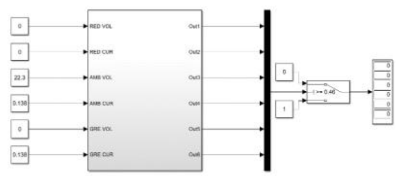
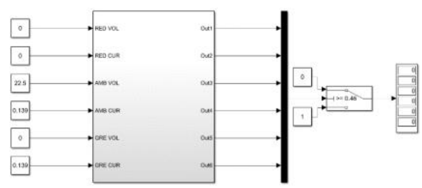
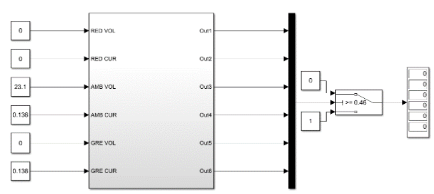
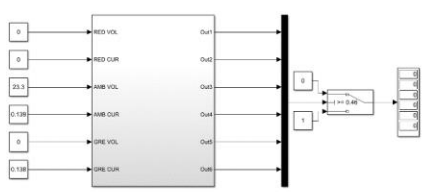
<table>
<tr><th>Test No.</th><th>Actual readings in Red Lamp Circuit
Red Lamp Circuit faulty</th><th>Model 0utput
failure mode (FC 1)</th><th>Output Result of the Model (FC1)</th></tr>
<tr><td>19.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>137.92mA</td><td>17V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td>
</td></tr>
<tr><td>20.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>138.22 mA</td><td>17 V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td>
</td></tr>
<tr><td>21.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>138.55mA</td><td>20.04 V</td></tr><tr><td>Green Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr></table></td><td></td><td>
</td></tr>
</table>

Table 12: Red Lamp Circuit Faulty Condition

As shown as in the table 11, the actual values were measured while the red bulb circuit is operating without any failure. And those values were given to the model and tested. Final results were displayed as expected "Healthy Mode" (FC 0). 24 V to 21V Red bulb circuit voltages values gives FC 0.

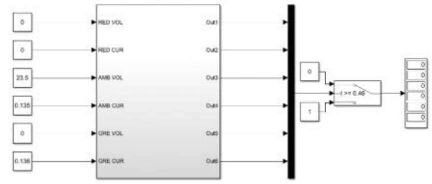
Similarly the actual values were obtained manually when the red bulb circuit is faulty. As shown in table 12, the output results displayed as "Faulty in Red Lamp Circuit "(FC 1). Red Bulb circuit voltage bellow 21 V displayed as Faulty mode (FC1).

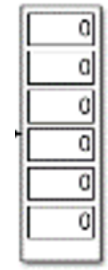
5.2.2 Case Study 263 signal Amber Lamp Results

Test No.	Actual readings in Amber Lamp (AC) (When working condition)	Model 0utput No failure mode	Output Result of the Model (FC0)
22.	| | Current | Voltage | Red Lamp Circuit | 0 mA | 0 V Green Lamp Circuit | 138 mA | 0 V Amber Lamp Circuit | 138 mA | 22.3 V		
23.	| | Current | Voltage | Red Lamp Circuit | 0 mA | 0 V Green Lamp Circuit | 139.01mA | 0 V Amber Lamp Circuit | 139.01mA | 22.5 V		
24.	| | Current | Voltage | Red Lamp Circuit | 0 V | 0 V Green Lamp Circuit | 138.22 mA | 0 V Amber Lamp Circuit | 138.67 mA | 23.1 V		
25.	| | Current | Voltage | Red Lamp Circuit | 0 mA | 0 V Green Lamp Circuit | 138 mA | 0 V Amber Lamp Circuit | 139.9 mA | 23.3 V		

26..

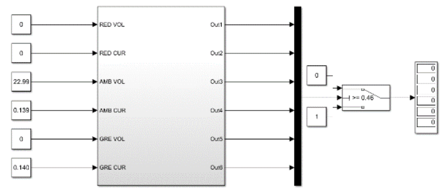
	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	136.01mA	0 V
Amber Lamp Circuit	135.01mA	23.5 V

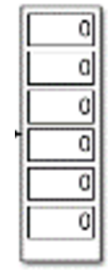




27.

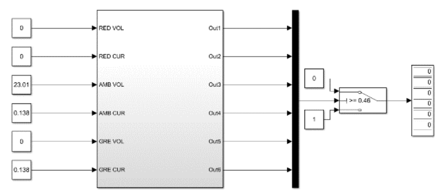
	Current	Voltage
Red Lamp Circuit	0	0
Green Lamp Circuit	140 mA	0 V
Amber Lamp Circuit	139.7 mA	22.99 V

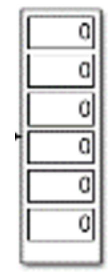




28.

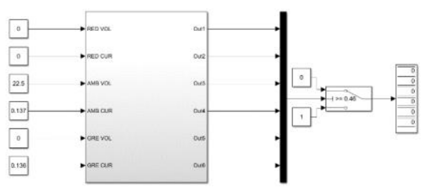
	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	138 .2 mA	0 V
Amber Lamp Circuit	138.89 mA	23.01V

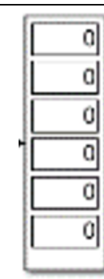




29.

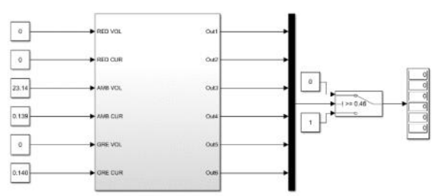
	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	136.94 mA	0 V
Amber Lamp Circuit	137.06mA	22.5 V

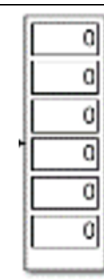




30.

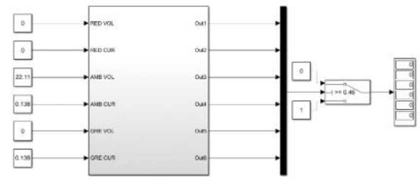
	Current	Voltage
Red Lamp Circuit	0	0
Green Lamp Circuit	140 mA	0 V
Amber Lamp Circuit	139.7 mA	23.14 V





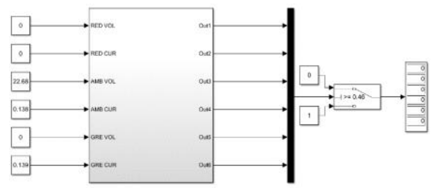
31.

	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	139 .24 mA	0 V
Amber Lamp Circuit	138.48 mA	22.11 V



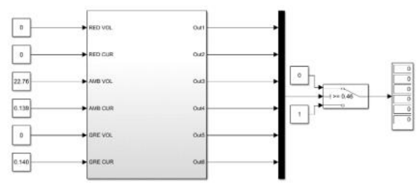
32.

	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	139.21 mA	0 V
Amber Lamp Circuit	138.88 mA	22.68 V



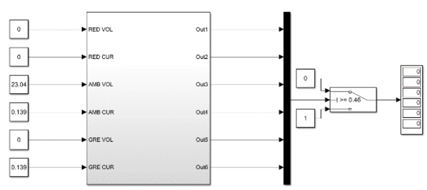
33.

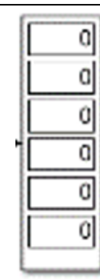
	Current	Voltage
Red Lamp Circuit	0	0
Green Lamp Circuit	140 mA	0 V
Amber Lamp Circuit	139.7 mA	22.76 V



34.

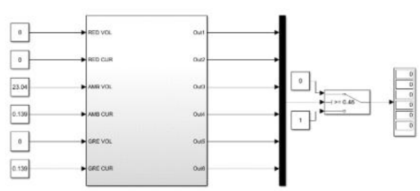
	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	139 mA	0 V
Amber Lamp Circuit	139.34 mA	23.04 V





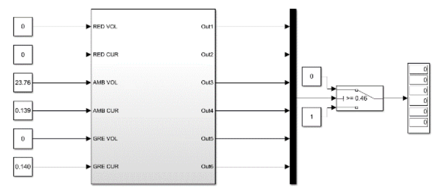
35.

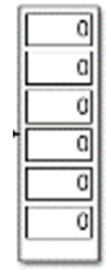
	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	138.25 mA	0 V
Amber Lamp Circuit	138.97 mA	23.68 V



36.

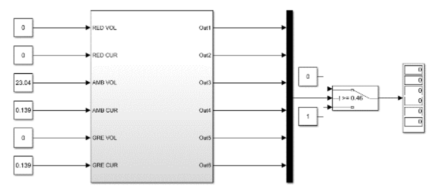
	Current	Voltage
Red Lamp Circuit	0	0
Green Lamp Circuit	140 mA	0 V
Amber Lamp Circuit	139.25 mA	23.76 V





37.

	Current	Voltage
Red Lamp Circuit	136 mA	0 V
Green Lamp Circuit	139 mA	0 V
Amber Lamp Circuit	139.34 mA	23.04 V



38.

	Current	Voltage
Red Lamp Circuit	137 mA	0 V
Green Lamp Circuit	138.25 mA	0 V
Amber Lamp Circuit	138.97 mA	23.68 V

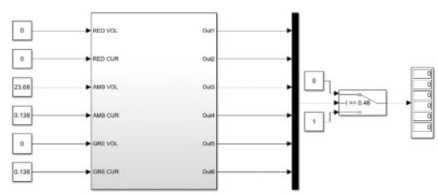


Table 13: Amber Lamp Working Condition

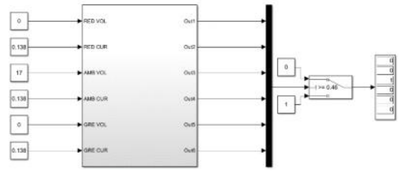
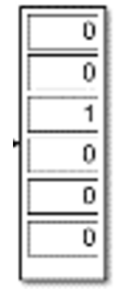
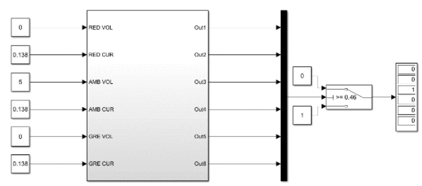
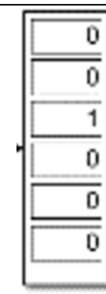
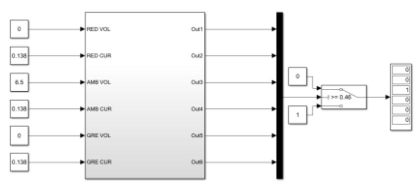
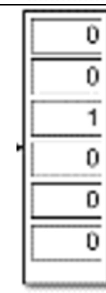
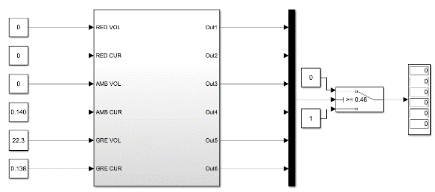
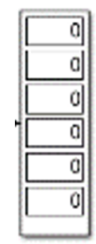
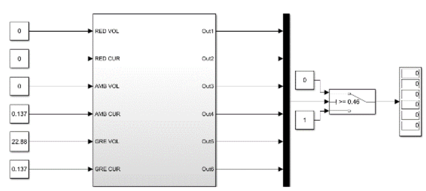
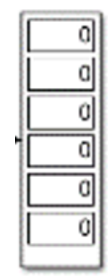
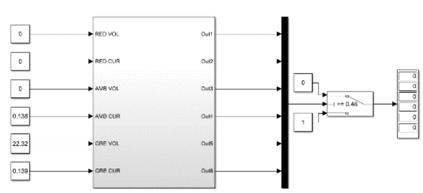
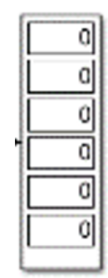
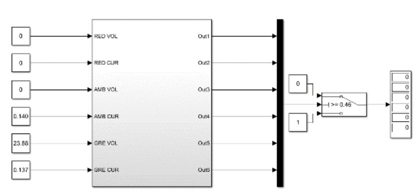
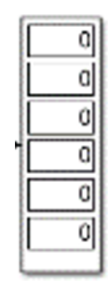
<table>
<tr><th>Test No.</th><th>Actual readings Amber Lamp Circuit faulty</th><th>Model 0utput failure mode (FC 2)</th><th>Output Result of the Model (FC 2)</th></tr>
<tr><td>39.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>138|mA</td><td>0 V</td></tr><tr><td>Green Lamp Circuit</td><td>138.72 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>139 mA</td><td>7.5 V</td></tr></table></td><td></td><td>
</td></tr>
<tr><td>40.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>138 mA</td><td>0 V</td></tr><tr><td>Green Lamp Circuit</td><td>138.29mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>138.67 mA</td><td>5.3 V</td></tr></table></td><td></td><td>
</td></tr>
<tr><td>41.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>0</td><td>0</td></tr><tr><td>Green Lamp Circuit</td><td>138.34 mA</td><td>0 V</td></tr><tr><td>Amber Lamp Circuit</td><td>138.25 mA</td><td>17 V</td></tr></table></td><td></td><td>
</td></tr>
</table>

Table 14 : Amber Lamp Circuit Faulty Condition

The actual values were measured while the Amber bulb circuit case study 263 is operating without any failure. And those values were given to the model and tested. Final results were displayed as expected “Healthy Mode” (FC 0).

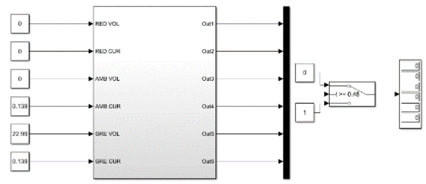
Similarly the actual values were obtained manually when the amber bulb circuit is faulty. As shown in table 14, output results displayed as “Faulty in Amber Lamp Circuit”(FC2).

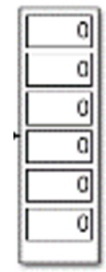
5.2.3 Case Study 263 Signal Green Bulb Results

<table>
<tr><th>Test No.</th><th>Actual readings in Green Lamp Circuit
(When working condition)</th><th>Model 0utput
No failure mode (FC0)</th><th>Output Result of the Model
(FC0)</th></tr>
<tr><td>42.</td><td><table>
<tr><th></th><th>Current</th><th>Voltage</th></tr>
<tr><td>Red Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr>
<tr><td>Green Lamp Circuit</td><td>138 mA</td><td>22.3 V</td></tr>
<tr><td>Amber Lamp Circuit</td><td>140 mA</td><td>0 V</td></tr>
</table></td><td></td><td></td></tr>
<tr><td>43.</td><td><table>
<tr><th></th><th>Current</th><th>Voltage</th></tr>
<tr><td>Red Lamp Circuit</td><td>0mA</td><td>0V</td></tr>
<tr><td>Green Lamp Circuit</td><td>137.22mA</td><td>22.88V</td></tr>
<tr><td>Amber Lamp Circuit</td><td>137.22 mA</td><td>0 V</td></tr>
</table></td><td></td><td></td></tr>
<tr><td>44.</td><td><table>
<tr><th></th><th>Current</th><th>Voltage</th></tr>
<tr><td>Red Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr>
<tr><td>Green Lamp Circuit</td><td>139.22 mA</td><td>22.32V</td></tr>
<tr><td>Amber Lamp Circuit</td><td>138.93 mA</td><td>0 V</td></tr>
</table></td><td></td><td></td></tr>
<tr><td>45.</td><td><table>
<tr><th></th><th>Current</th><th>Voltage</th></tr>
<tr><td>Red Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr>
<tr><td>Green Lamp Circuit</td><td>137.96mA</td><td>23.88 V</td></tr>
<tr><td>Amber Lamp Circuit</td><td>140 mA</td><td>0 V</td></tr>
</table></td><td></td><td></td></tr>
</table>

46.

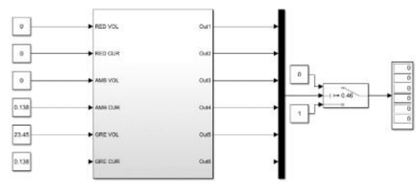
	Current	Voltage
Red Lamp Circuit	0mA	0V
Green Lamp Circuit	139.01mA	22.99V
Amber Lamp Circuit	139.10 mA	0 V

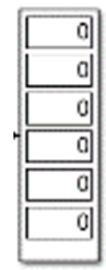




47.

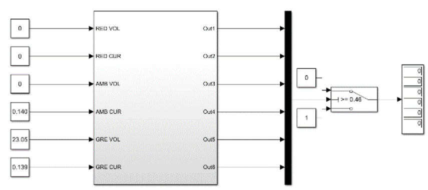
	Current	Voltage
Red Lamp Circuit	0	0
Green Lamp Circuit	138 mA	23.45 V
Amber Lamp Circuit	138.2.mA	0 V

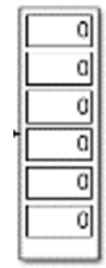




48.

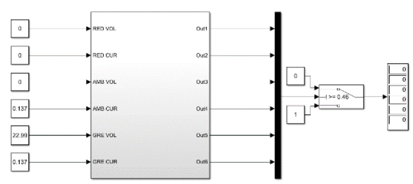
	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	139.02mA	23.05 V
Amber Lamp Circuit	140 mA	0 V

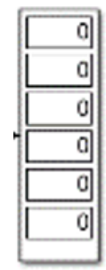




49.

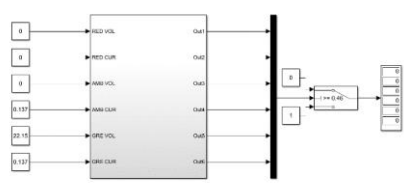
	Current	Voltage
Red Lamp Circuit	0mA	0V
Green Lamp Circuit	137.01mA	22.99V
Amber Lamp Circuit	137.10 mA	0 V

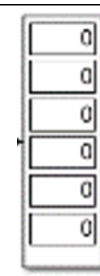




50.

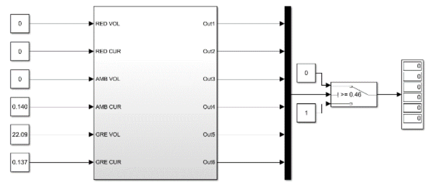
	Current	Voltage
Red Lamp Circuit	0	0
Green Lamp Circuit	137.89mA	22.15 V
Amber Lamp Circuit	137.2.mA	0 V

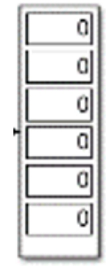




51.

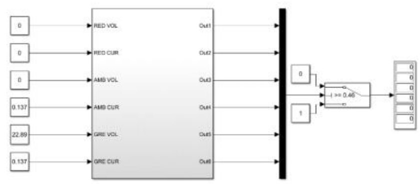
	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	137.11mA	22.09 V
Amber Lamp Circuit	140 mA	0 V

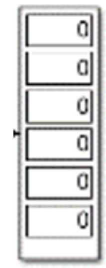




52.

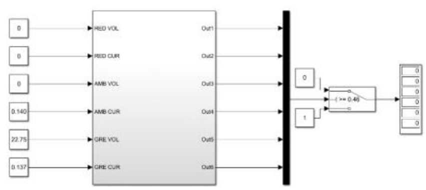
	Current	Voltage
Red Lamp Circuit	0mA	0V
Green Lamp Circuit	137.40mA	22.89V
Amber Lamp Circuit	137.22 mA	0 V





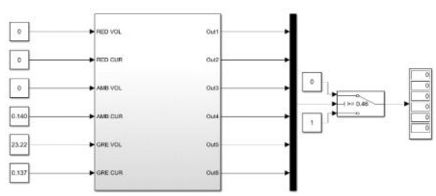
53.

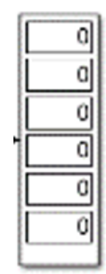
	Current	Voltage
Red Lamp Circuit	0	0
Green Lamp Circuit	137.89mA	22.75 V
Amber Lamp Circuit	137.89mA	0 V



54.

	Current	Voltage
Red Lamp Circuit	0 mA	0 V
Green Lamp Circuit	137 mA	23.22V
Amber Lamp Circuit	140 mA	0 V





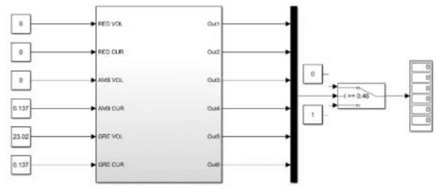
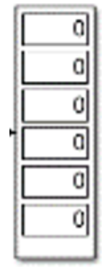
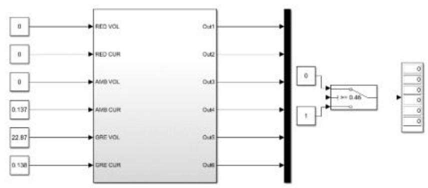
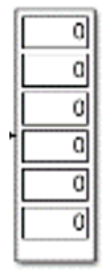
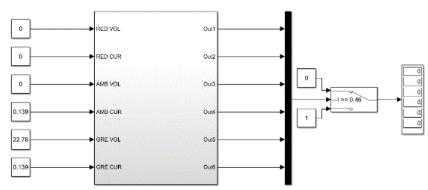
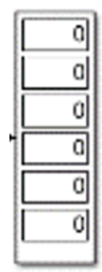
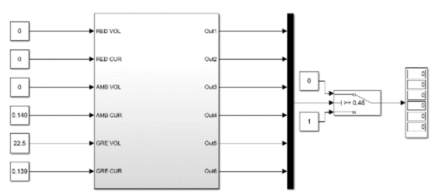
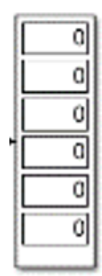
<table>
<tr>
<td>55.</td>
<td>
<table>
<tr><th></th><th>Current</th><th>Voltage</th></tr>
<tr><td>Red Lamp Circuit</td><td>0mA</td><td>0V</td></tr>
<tr><td>Green Lamp Circuit</td><td>137.22mA</td><td>23.02V</td></tr>
<tr><td>Amber Lamp Circuit</td><td>137.22 mA</td><td>0 V</td></tr>
</table>
</td>
<td></td>
<td></td>
</tr>
<tr>
<td>56.</td>
<td>
<table>
<tr><th></th><th>Current</th><th>Voltage</th></tr>
<tr><td>Red Lamp Circuit</td><td>0</td><td>0</td></tr>
<tr><td>Green Lamp Circuit</td><td>138.01mA</td><td>22.87 V</td></tr>
<tr><td>Amber Lamp Circuit</td><td>137.66mA</td><td>0 V</td></tr>
</table>
</td>
<td></td>
<td></td>
</tr>
<tr>
<td>57.</td>
<td>
<table>
<tr><th></th><th>Current</th><th>Voltage</th></tr>
<tr><td>Red Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr>
<tr><td>Green Lamp Circuit</td><td>139.01 mA</td><td>22.78V</td></tr>
<tr><td>Amber Lamp Circuit</td><td>139.42 mA</td><td>0 V</td></tr>
</table>
</td>
<td></td>
<td></td>
</tr>
<tr>
<td>59.</td>
<td>
<table>
<tr><th></th><th>Current</th><th>Voltage</th></tr>
<tr><td>Red Lamp Circuit</td><td>0mA</td><td>0 V</td></tr>
<tr><td>Green Lamp Circuit</td><td>139.01mA</td><td>22.5 V</td></tr>
<tr><td>Amber Lamp Circuit</td><td>140 mA</td><td>0 V</td></tr>
</table>
</td>
<td></td>
<td></td>
</tr>
</table>

Table 15: Green Lamp Working Condition

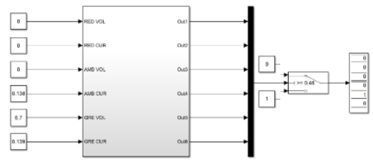
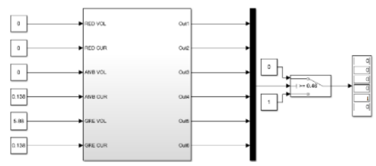
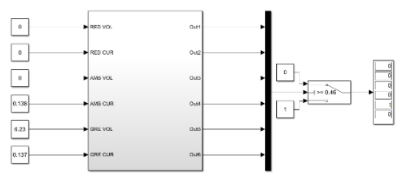
<table>
<tr><th>Test No.</th><th>Actual readings in Green Lamp Circuit (Case Study 263)</th><th>Model 0utput failure mode (FC 3)</th><th>Output Result of the Model (FC0)</th></tr>
<tr><td>60.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>0 mA</td><td>0 V</td></tr><tr><td>Green Lamp Circuit</td><td>139.22 mA</td><td>6.7 V</td></tr><tr><td>Amber Lamp Circuit</td><td>138.93 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
<tr><td>61.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>0mA</td><td>0V</td></tr><tr><td>Green Lamp Circuit</td><td>138.43.mA</td><td>5.88V</td></tr><tr><td>Amber Lamp Circuit</td><td>138.73 mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
<tr><td>62.</td><td><table><tr><th></th><th>Current</th><th>Voltage</th></tr><tr><td>Red Lamp Circuit</td><td>0</td><td>0</td></tr><tr><td>Green Lamp Circuit</td><td>137.84mA</td><td>6.23 V</td></tr><tr><td>Amber Lamp Circuit</td><td>138.mA</td><td>0 V</td></tr></table></td><td></td><td></td></tr>
</table>

Table 16: Green Lamp Circuit Faulty Condition

Similarly to the red bulb circuit and the amber bulb circuits, green bulb circuits' actual current and actual voltage values were obtained manually in working condition and the faulty condition and tested as shown in Table 15, green Lamp Working Condition and shown in Table16, Green Lamp Circuit Faulty Condition.

Finally model was tested with actual readings of different causes and model output results were 100% accurate, therefore the system validates with actual readings of case study 263.

CHAPTER 6

CONCLUSION

6.1 Research Summary and Conclusion

The implemented intelligent based failure alert system is designed to satisfy the failure in each red lamp circuit, and amber lamp circuit, green lamp circuit. To implement this, went throw literature reviews on intelligent control systems and railway researchers regarding signals and diagnosis systems.

Then for the construction the proper rule bases for the proposed controllers, selected one signal pole and observed and tested each signal aspect circuits, when in healthy condition and faulty conditions. Then from the observed data and theories, the fuzzy controller is developed using "MAT Lab Simulink 2014a". The model is tested with actual readings and validated the results. The fuzzy logic controller model was seen to achieve objectives.

The developed model of the intelligent base signaling failure alert system is capable of detecting signal aspect circuit failure and a real time application. The system depicted in figure 61 could be modify for the preventive maintenance by training many faulty data, as well healthy condition data using neural network and fussy logic theories.

The large-scale implementation of the developed intelligent based railway signaling failure alert system can be used for the preventive maintenance and increase the efficiency of railway service as well as it can improve the nation's economy through efficient passenger and delivery of goods services in Sri Lanka.

The following scopes are suggested for future researchers.

- Design intelligent fault diagnosis system for other railway relay circuits such as Track circuit, point machine circuits, Level crossing circuits etc.
- Design central monitoring preventive maintenance system for the railway.

6.2 Scope for Future Research

This research, presented the design and MATLAB model development of an intelligent railway signal failure alert system using fuzzy logic control technique. Further, this model can be implemented with microcontroller such as “at mega 2560”, the fuzzy engines aid to effectiveness and efficient control of the entire operations of the system. System can be implemented as Figure 61, structure of intelligent based future implementation and as a research objective, system could implement for the maintenance staff to get failure messages. This would enable them to attend to failures immediately and could also be used for preventive maintenance diagnosis.

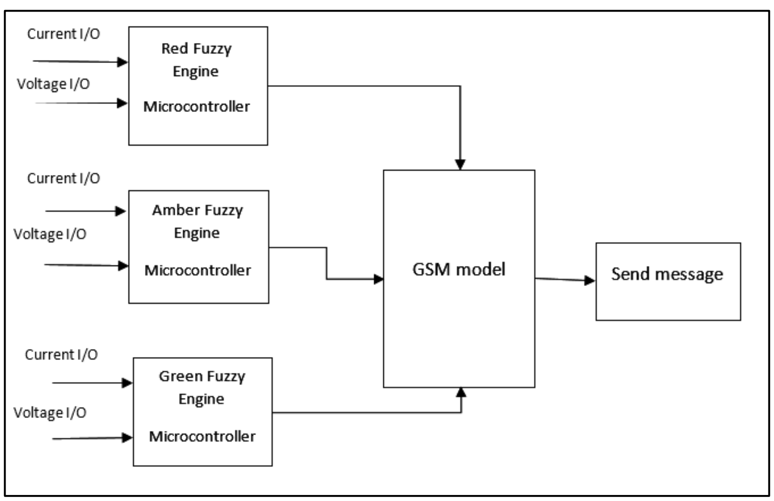


Figure 61: Structure of Intelligent Based Future Implementation

REFERENCES

[1] J. Chen, C. Roberts, and P. Weston,” Neuro-Fuzzy Fault Detection and Diagnosis for Railway Track Circuits,” *Fault Detection, Supervision and safety of Technical Process* 2006, Vol.6. Pp.585-596, 2007.

[2] A.C Pinto and G.V Mattioli, “Intelligent Traffic Lights Control Systems using Fuzzy Logic,” *SAE Technical Paper Series*, 2014.

[3] C.W.D. Silva. “Fundamentals of Fuzzy Logic, “Intelligent Control, pp.43-68.

[4] Frank w. Brayan “CTC: Remotely directing the movement of trains”, May 1, 2006

[5] *All Relay Interlocking Ericsson*, Ceylon Government Railway, Sri Lanka.SL.1990.

[6] Olaniiyi.O.M, Abdullahi, and I.M., Maliki.D., Lasore T.M “Intelligent Railway cross level gates and signalling system using fuzzy logic control technique”. *research gate technical paper*.2016.

[7] Jiehua .C, Clive. R, and Weston. P, “Neuro-fuzzy fault detection and diagnosis for railway Track circuit” Railway research group, School of Engineering, University of Birmingham, B152TT, UK.2016.

[8] L. Oukhellou, A. Debiolles, T. Denœux, and P. Aknin, “Fault diagnosis in railway track circuits using Dempster–Shafer classifier fusion,” *Engineering Applications of Artificial Intelligence*, vol. 23, no. 1, pp. 117–128, 2010.

[9] S. Sun and H. Zhao, “Fault Diagnosis in Railway Track Circuits Using Support Vector Machines,” *2013 12th International Conference on Machine Learning and Applications*, 2013.

[10] Dassanayake H.P.B, Roberts. C and Goodman C. J “An Architecture for system -wide fault detection and isolation” 2001.School of Electrical and Electronic Engineering, The University of Birmingham, UK. 2001.

[11] Tim de Bruin, Kim Verbert and Robert Babuska “Railway Track Circuit Fault Diagnosis using Recurrent Neural Networks” *IEEE transactions on neural networks and* R4TLI Conference *learning systems*, Vol.28, No.03 March 2017.

[12] Mansi R.Sarwan, ,Ankita S.Sonawane and Prof. Parneet chowdhary Prof.S.M.More “Automated Railway Track Fault Detection System Using Robot” Department of Electrical Engineering Organization Name: Guru Gobind Singh Polytechnic, Nashik, Maharashtra, India. 2000.

[13] *S10 color Light and automatic signaling,* Institute Indian Railways of Signal Engineering & Telecommunications. IN. June 2013.

[14] JID Jayasundara, Railway Signaling in Sri Lanka: Appraisal of Technical and Economic Rationale *R4TLI Conference, 2018.*

[15] Model Railway Musings, “Electronic – Wire Size and Voltage Drop," Accessed: Feb12, 2021. [Online]. Available: modelrailmusings.weebly.com/ wire-sizes-and-voltage-drop.html.

[16] Mark Gurries, “LED VS BULBS,” Accessed: Feb 10, 2019. [Online]. Available: https://sites.google.com/site/markgurries/home/part-sources/led-s/led-vs-bulbs.

[17] Wikipedia, “Incandescent light bulb, “Accessed: Feb 12, 2021. [Online]. Available: https://en.wikipedia.org/wiki/Incandescent_light_bulb.

[18] Mike Smith, “Power operated and color light signals” Accessed: Sep 23, 2019. [Online]. Available: https://www.igg.org.uk/rail/3-sigs/powersig.htm.