ADAPTIVE DISTANCE RELAY FOR RENEWABLES

PROJECT

Submitted By

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In partial fulfillment for the award of the Degree of

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BACHELOR OF TECHNOLOGY
IN
ELECTRICAL AND ELECTRONICS ENGINEERING

Under the guidance of

Dr. Deepak M

DEPARTMENT OF ELECTRICAL ENGINEERING

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DECLARATION

We hereby declare that this submission is our own work and that, to the best of our knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made by me in the text.

Place: Kozhikode

Date: 26-4-2023

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CERTIFICATE

This is to certify that the project entitled "ADAPTIVE DISTANCE RELAY FOR RENEWABLES" submitted by ***DEEPENDU PRASAD (Roll No. B190325EE), DEVIPRASAD V R (Roll No. B190191EE), FAHAD ABDUL VAHAB (Roll No. B190748EE) & LOVE KUSH PRANU (Roll No. B191184EE)*** *to the National Institute of Technology Calicut towards partial fulfillment of the requirements for the award of* ***Degree of Bachelor of Technology in Electrical and Electronics Engineering*** *is a bona fide record of the work carried out by them, under my supervision and guidance.*

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ABSTRACT

An increasing number of renewables are being integrated into the power grid every day. However, the ideal characteristics of a relay are affected in the presence of renewables (e.g. wind) and other factors such as mutual coupling of transmission lines. Since it can detect faults from a distance and respond quickly compared to other relays, distance relay is the primary type of relay used for transmission line protection. Protection zones can also be applied to distance relay in order to offer backup protection for other transmission line relays. The variations in loading level, source impedance, voltage level, frequency, etc. cause the trip boundaries of relays to change. In this scenario, it is necessary to develop an adaptive strategy to improve the performance of the relays. Presently, various theoretical formulations are available, which explain how an adaptive system may be developed. In this project, we seek to bridge the gap between the theory and practice, wherein we simulate the working of an adaptive distance relay, constructed from existing theoretical methods of implementation. The project has progressed in mainly three separate phases – understanding, coding and simulating. The working of a distance relay is understood first through various simulations and this was followed by developing a code, translating equations into machine-readable form. The final step was transforming this into the electrical domain, where we have simulated a power system and tested the working of our code. We have made use of MATLAB™ Simulink™ for the simulations

Index Terms – Adaptive protection, distance relaying, adaptive distance relaying, power system protection and control

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List of Figures

List of Abbreviations and Symbols

MATLAB™ - Matrix Laboratory

PSCAD™ - Power Systems Computer Aided Design

CSMF - Control System Modelling Functions

TI™ – Texas Instruments

CCS™ – Code Composer Studio

ADR – Adaptive Distance Realy

TBG – Trip Boundary Generator

RSI – Relay Seen Impedance

K_0 = zero sequence compensating factor

D_1 = Positive distribution factors

D_0 = Zero Sequence distribution factors

ΔZ = function of (ρ, δ, Z_{1SW}, Z_{1SP}, Z_{0SW}, Z_{0SP}, R_F, n)

R_F = Fault Resistance

δ = power transfer angle

ρ = voltage amplitude ratio

Z_{1L} = total positive sequence line impedance

Z_{1sw} = Positive sequence impedance Wind Farm

Z_{0SW} =Zero sequence impedance Wind Farm

Z_{1SP} =Positive sequence impedance Grid

Z_{0SP} =Zero sequence impedance Grid

Z_{1L} =Positive sequence impedance Line Data

Z_{OL} =Zero sequence impedance Line Data

Z_{SUM} = the sum of positive, negative, and zero sequence

E_{AW} = wind source 1 voltage for systems

2 = negative sequence
1 = positive sequence
0 = zero sequence

INTRODUCTION

Background

The depletion of fossil fuel reserves is a major driver of increased renewable energy generation. The energy produced by renewable energy resources is environmentally friendly, eco-green, and long-lasting. If the power generated by these sources is in bulk anddispatchable, it can be directly integrated into power transmission networks.

Also, modern implementation of power electronic components are seen tobe highly efficient, however the efficiency comes at the extreme cost which will make very tough for certain developing countries with limited income to work on these projects. This in turn gives the relays a sizeable advantage over the modern implementation.

Transmission networks are traditionally protected by distance relays. The power input fromrenewable energy sources may cause under-reach operation of existing distance relays in power transmission networks. The use of distributed renewable energy sources (RES) in power transmission systems has both advantages and disadvantages. They can assist utilities in improving nodal voltage profiles, reducing system losses, sharing peak load, andincreasing power reliability. One of the most difficult challenges is protecting and controlling these sources in power transmission networks. Distributed RES injection can potentially jeopardize existing distance protection schemes in power transmission networks.

The topology of power networks is altered by distributed RES injection. Distance relays are typically used to protect power networks at the transmission and sub-transmission levels. These relays are programmed to operate in a predefined configuration of power transmission networks. RES are site-specific, and their power output is highly unpredictable. Depending on the availability and size of the RES, they are connected to a power transmission network for bulk electric power transfer to load centers.

The performance of existing distance relays will be quite inadequate in those operational scenarios. They may malfunction as a result of the in-feed of fault currents from the connected RES. As the number of RES in the transmission system grows, so will the in- feed contribution from RES, and existing distance relays will require new relay settings under these operational scenarios. Furthermore, the contribution of in-feed from new RESis not comparable to the contribution of in-feed from the connection of a conventional power generator. In the case of a conventional generator, the in-feed is constant, and distance relays can be easily set for a new network configuration.

However, as stated above, in the case of a new RES connection with transmission, these sources are highly unpredictable and intermittent in nature, resulting in variable in-feed fault currents to the distance relays.

Literature Review

In an adaptive relay, the tripping boundary gets changed with a change in the power system operating conditions. This concept can be used for a variety of fault conditions. [1]

In a fixed setting approach, the area (trip boundary) of the relay characteristic is pre-defined based on overall system study. With an adaptive with feature in a distance relay, the area is set online in accordance the prevailing condition [2]

In relay, trip boundary is set adaptively through the supervisory control and data acquisition (SCADA) or the phasor measurement unit (PMU) voltages and line flows of all parts of the system which are available. [3]

CHAPTER 1
DISTANCE RELAY

1.1 Introduction

The most popular kind of protection relay for transmission line protection is the distance relay. More specifically, the relay's operation is based on the impedance between the fault and the relay installation point. These relays are also referred to as impedance or distance relays.

The use of protective relays in the electric power sector is not new. Over the years, they have changed in terms of design ideas, parts, functionality, complexity, size, and other aspects. However, they continue to be an essential part of power systems since their primary function—to protect power system components (lines, transformers, etc.)—has not altered throughout time. Modern protective relays are computers that offer the user a variety of information and varied capabilities.

When overcurrent relaying is too sluggish or nonselective, distance relaying should be taken into consideration. On transmission lines and sub-transmission lines where high-speed automatic reclosing is not required to maintain stability and where the short time delay for end-zone faults can be tolerated, distance relays are typically employed for phase-fault primary and backup protection. Although distance relays are increasingly being employed for ground faults, overcurrent relays have traditionally been used as the primary and backup protection against ground faults.

1.2 Operation

The operation of a distance relay or impedance relay is pretty simple. One voltage element is fed by the potential transformer, while the system's current element is fed by the current transformer. The secondary current of the CT generates the deflecting torque, while the voltage of the potential transformer generates the restoring torque. Deflecting torque is more than restoring torque in typical operating conditions. Relay will therefore not work. However, when something goes wrong, the voltage drops and the current increases significantly. Deflecting torque then exceeds restoring torque, and dynamic components of the relay begin to move as a result, closing the NO contact of the relay.

Thus, the distance relay's functioning or working principle depends on the system's voltage to current ratio. A distance relay is also referred to as an impedance relay since the impedance ratio of voltage to current is impedance itself. Such relays operate according to a predetermined ratio of voltage to current, i.e., the set impedance. Only once this voltage to current ratio falls below the set value will the relay turn on. Therefore, it may be claimed that the relay will only turn on when the line's impedance falls below a set impedance (voltage/current) value. A distance relay can only be used if a defect occurs within a specific distance or along a specific length of line because a transmission line's impedance is directly proportional to its length.

Operating Condition: When the line voltage or restoring torque is greater than the current or deflecting torque, it is referred to as an operating state. A distance relay or impedance is installed on the transmission line between the points AB. Assume that the line's operating impedance is Z. Only when the line's impedance is lower than the relay's impedance Z does the distance relay begin to operate.

Faulty Condition: When the magnitude of the current is greater than the voltage, there is a possibility of a fault developing on the transmission line (less). This indicates that the relay's impedance and the current flowing through the line have an inverse relationship. The relay activates in this situation because the line's impedance drops below the predetermined impedance value.
The relay starts operating by sending the tripping command to the circuit breaker if a fault F1 has occurred on line AB and the impedance of the line has reduced below the predetermined value of the relay. If the fault extends past the positive condition, the contacts of the relay would become open.

The characteristics of the distance relay under operation are displayed below. The voltage supplied by the PT is taken on the Y-axis, and the current flowing through the CT is captured on the X-axis.

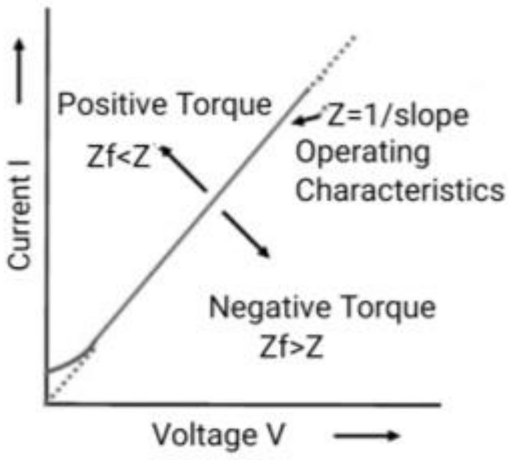

Fig 1.1. Characteristics of the distance relay under operation

In a fault scenario, the positive torque is created above the operational characteristic line if the transmission line's impedance is greater than the relay's impedance. Similar to the last example, negative torque is generated when the line's impedance is lower than the relay's impedance in a fault scenario.

1.3 Relay Testing

A number of problems are brought up during the testing and verification of protection measures and devices. This occurs because testing protective devices under typical operating settings is impossible because their primary purpose is connected to operation during fault conditions. Relay protection device testing and verification can be split into four categories:

- Routine factory production tests
- Type tests
- Commissioning tests
- Occasional maintenance tests

To demonstrate that a protection relay satisfies the claimed specification and complies with all applicable standards, **type tests** are required. It is essential that the functioning is assessed under such circumstances because the fundamental purpose of a protection relay is to operate correctly under abnormal power conditions. As a result, during the development and certification of equipment, intricate type tests replicating the working conditions are carried out at the manufacturer's facilities.

Protection relays are put through **routine factory production testing** to demonstrate that there are no flaws throughout the manufacturing process. Testing will take place throughout the manufacturing process to ensure that issues are found as soon as feasible and reduce the need for corrective action. The intricacy of the relay and previous manufacturing expertise will have an impact on the testing scope.

Prior to going into operation, commissioning tests are performed to demonstrate that a specific protective configuration has been appropriately applied. From installing the appropriate equipment to checking the wiring and the performance of each piece of equipment individually to testing the entire configuration, every part of the design is thoroughly examined.

For regular corrective actions to be performed, periodic maintenance verifications are required to find equipment failures and service degradation. Defects might not be found for a long time before a problem occurs because a protective configuration only functions in the presence of a fault. Regular testing helps find problems that may otherwise go unnoticed until they manifest themselves.

1.4 Advantages

Some of the advantages of distance relay over overcurrent relay are:

- It replaces the protection of overcurrent transmission lines.
- Provides quick protection.
- Coordination and application are very simple.
- Available with permanent settings and there is no need to readjust the settings.
- Effect of a generation of fault levels, fault current magnitude is less.
- Permits high load lining.

1.5 Disadvantages

The disadvantages of distance relay or impedance relay are:

- As it operates on both sides faults of a line, it is said to be non-directional.
- It fails to recognize between internal and external faults of a line
- The resistance of the arc of a fault line affects the function of the distance relay. Since an arc exists when the fault occurs at any point.
- The power swings affect the performance of the distance relay because the area covered by the circle on the sides of the R-X plane is large
- The measurement capacity of fault resistance is limited.

CHAPTER 2
ADAPTIVE RELAYING

Electrical power systems experience a variety of failures and disturbances during operation, despite strong design and construction. Protection systems are used to reduce the danger to human life as well as the consequences of defects and disturbances on the network elements.
When a change is detected, the adaptive protection recalculates the load flow, checks the network's current information and the status of the breakers, and modifies the relay settings as necessary. The relays must interact with a main centre for the application of this protection system; otherwise, the calculations cannot be relayed back to the relays after the alterations. Additionally, since a fault could occur at any time, the communication should be very quick.
When a change is detected, the adaptive protection recalculates the load flow, checks the network's current information and the status of the breakers, and modifies the relay settings as necessary. The relays must interact with a main centre for the application of this protection system, otherwise, the calculations cannot be relayed back to the relays after the alterations. Additionally, since a fault could occur at any time, the communication should be very quick.
Adaptive protection systems offer protection setting of changing parameters in accordance with the status of the protect region of the protection relay thanks to the multi-setting group. As a result, the protective mechanism adjusts to various operating circumstances. The likelihood of the protection system malfunctioning can be reduced in this way.
Compared to traditional protection systems, adaptive protection systems provide more reliable and selective protection because of their dynamic structure. As a result, adaptive protection systems rather than traditional ones are favoured in today's electric power systems.

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CHAPTER 3
ADAPTIVE DISTANCE RELAYING

Adaptive distance relays safeguard transmission lines against faults such as short circuits and earth faults by measuring the distance to the fault location and tripping the associated circuit breakers. Conventional distance relays might trip unintentionally or respond slowly because they have fixed parameters that may not be appropriate for all fault conditions. On the other hand, adaptive distance relays are made to alter their settings depending on the network circumstances and the location of the fault, assuring the best performance and dependability. They accomplish this by continuously checking the voltage and impedance of the line and adjusting their settings.

Adaptive distance relays come in a variety of designs, including ones that depend on impedance, reactive power, and frequency. The most widespread adaptive relays are impedance-based ones, and they operate by determining the impedance that the relay perceives by detecting the voltage and current at the relay position. Once this impedance has been compared to a characteristic impedance that has been predetermined, the relay trips if the measured impedance is within a predetermined range.

Similar in operation, reactive power-based adaptive relays assess the reactive power flow as opposed to impedance. On the other hand, frequency-based adaptive relays keep track on the power system's frequency and change their settings accordingly.
Adaptive distance relays provide various advantages over standard relays, including enhanced defect identification and faster tripping times. They can be used with a variety of power system designs, from straightforward radial systems to intricate meshed networks, and are also capable of handling a larger range of failure scenarios.

In conclusion, adaptive distance relays are an essential part of contemporary power networks because they offer effective and dependable protection against faults. They are a crucial instrument for preserving the stability and integrity of power networks because of their flexibility in responding to shifting fault locations and network conditions

CHAPTER 4

WORKING OF ADAPTIVE DISTANCE RELAYING

Adaptive distance relays are used to protect power transmission lines from faults by determining the distance to the fault location and starting the trip of the relevant circuit breakers. Conventional distance relays trip unintentionally or respond slowly because they have fixed parameters that might not be appropriate for all fault conditions.

Adaptive distance relays work by continuously checking the transmission line's impedance and adjusting its settings as necessary. In order to do this, they determine the impedance that the relay perceives by monitoring the voltage and current at the relay position. Once this impedance has been compared to a characteristic impedance that has been predetermined, the relay trips if the measured impedance is within a predetermined range.

Adaptive distance relays use an adaptive algorithm that continuously modifies the parameters based on the altering network conditions and fault location to maintain optimal performance. The program takes the measured data, filters out the noise, and then employs signal processing and filtering techniques to retrieve the important data.

A group of adaptive parameters that regulate how the relay behaves are also included in the adaptive algorithm. Based on the measured data and the relay's performance, these parameters are regularly adjusted, guaranteeing that the relay is always performing at its best.

Reactive power and frequency-based adaptive relays are two further varieties of adaptive relays in addition to impedance-based ones. These relays use similar operating principles but measure several parameters to calculate the distance to the fault.

In conclusion, adaptive distance relays are an essential part of contemporary power networks because they offer effective and dependable protection against faults. They are a vital instrument for preserving the stability and integrity of power networks because of their capacity to adjust to shifting network conditions and fault locations. The relays are always running at their best capacity thanks to the use of adaptive algorithms and settings, which enable quick and precise fault detection and tripping.

CHAPTER 5
OVERVIEW OF THE MAIN TOOLS USED IN THE PROJECT

5.1 MATLAB & SIMULINK

MATLAB and Simulink are strong software tools that are widely used in industries such as engineering, research, and finance. High-level programming languages like MATLAB enable users to conduct data analysis and numerical computations. The graphical environment for modeling, simulating, and analyzing dynamic systems is called Simulink, on the other hand.

MATLAB is a flexible tool for a variety of applications since it includes a variety of built-in functions for data analysis, signal processing, optimization, and visualization. It also performs matrix operations very effectively, which makes it the perfect instrument for calculations involving linear algebra. Users may easily execute complex computations and view data thanks to MATLAB's user-friendly interface.

Simulink, on the other hand, provides a graphical interface for modelling and simulating dynamic systems such as mechanical, electrical, and control systems. It makes it straightforward to depict complex systems in an easy-to-understand manner by enabling users to design models using drag-and-drop blocks. Simulink is a crucial tool for system design and optimization because of its simulation capabilities, which allow users to examine the behavior of the system under various circumstances.

The integration of MATLAB and Simulink is one of their main benefits. Simulink models and MATLAB code can be easily integrated, enabling users to carry out intricate calculations and analyses on the output of the system. A Simulink model can be connected to actual hardware for real-time testing in hardware-in-the-loop simulations, which are also made possible by this connection.

Moreover, a variety of toolboxes and add-ons for diverse applications, such as image processing, control systems, and machine learning, are available for MATLAB and Simulink. These toolboxes offer pre-built models and functionalities for particular applications, simplifying complex work for users.

To sum up, MATLAB and Simulink are strong software applications that give users a variety of options for numerical calculations, data analysis, system modelling, and simulation. They are vital tools for a variety of disciplines, including engineering, science, and finance, thanks to their integration and broad toolkits.

CHAPTER 6

TRANSLATING FORMULA TO CODE

Adaptive relaying seeks to implement dynamically changing relay properties. The trip boundaries of the distance relay are varied ("adapted") according to changing parameters in the power system. These may be, the fault location, load angle, source voltage or any of the combinations of the above. In this project, we have used the adaptive relay trip boundary generation calculations taken from **[1].** The power system on which the study and simulation is done is as given below:

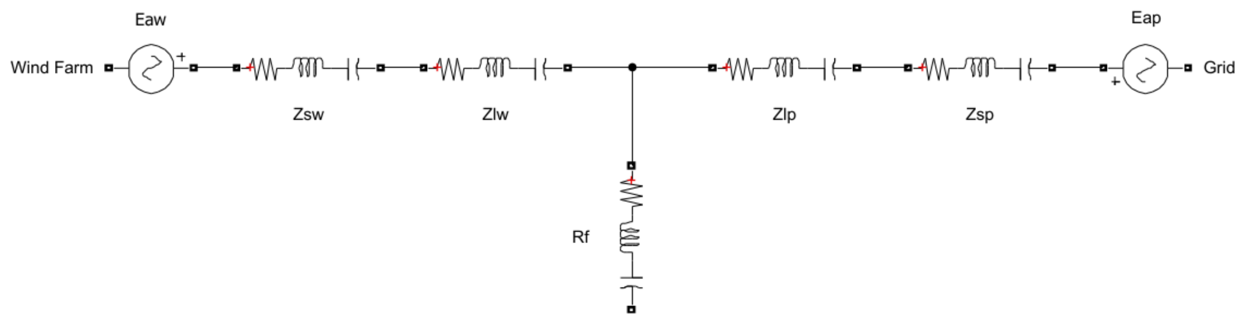


Fig 6.1. Circuit diagram of the system (created on Simulink)

In this code, we take the power system parameters of wind farm voltage level, the load angle, fault resistance and distance of the fault from the relay on the transmission line. Using these parameters and the impedances of the transmission line, source and grid (which are given), the symmetrical components are calculated as given in the algorithm and the apparent impedance at the relay is measured. This impedance is used for the trip decision-making.

As a quadrilateral relay is used here, it is required to plot the four zones (depicted by the sides). Each of the sides of the quadrilateral are plotted by varying the fault resistance and distance from the relay from 0 to 500 ohm and 0 to 0.9 respectively. From the four possible combinations, we obtain the trip boundaries. Do note that switch cases inside the for loops code is written solely for the purpose of ease of plotting and is not a functional element.

The quadrilateral characteristics hence obtained is of an adaptive nature as it varies when the power system parameters are changed. In this simulation, we vary the load angle and the distance of the fault and observe how the relay changes its trip boundaries as a result of this. This MATLAB code is further incorporated as a MATLAB function block in Simulink. This gives a graphical overview to the entire code and it becomes easier to understand the functioning of the overall process. Furthermore, this Simulink model may be developed to work as a relay model in a Simulink model of the power system.

The flowchart given below provides a brief overview of how the adaptive relay algorithm would work in a real scenario:

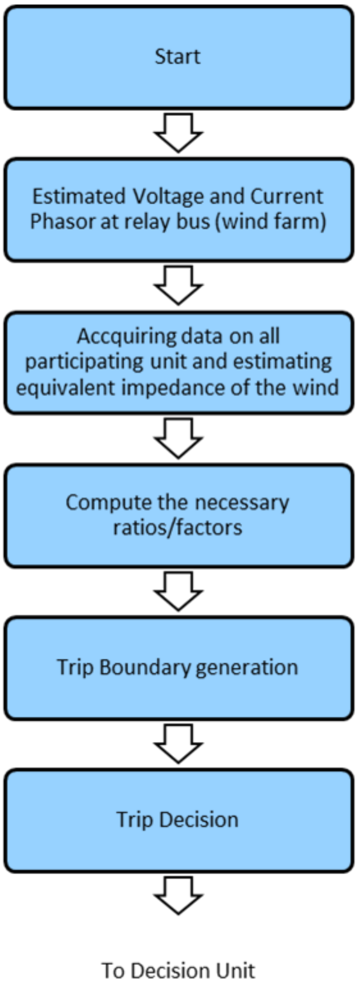


Fig 6.2. Flowchart representing adaptive relay algorithm

CHAPTER 7

THE MATLAB CODE AND MODEL

7.1 Declaration of Values

```
%F is a Line to Ground Fault
%values
Eaw = 400000;
p = 0.9;
delta = deg2rad(30);
```

7.2 Loop to generate output graph

```
for v = 1:1:4
switch v
    case 1
        Rf = linspace(0,1000,50);
        n =  0;
    case 2
       Rf = linspace(0,1000,500);
        n =  0.9;
    case 3
        Rf = 0;
        n =  linspace(0,0.9,500);
    case 4
        Rf = 50/0.05;
        n =  linspace(0,0.9,500);
end
```

7.3 Circuit Parameters

```
%Wind Farm

Z1sw = exp(deg2rad(85)*i)*20;
Z0sw = exp(deg2rad(85)*i)*30;

%Grid

Z1sp = exp(deg2rad(85)*i)*1;
Z0sp = exp(deg2rad(85)*i)*1.5;
```

```
%Line

Z1l = exp(deg2rad(86)*i)*28.75;
Z0l = exp(deg2rad(83)*i)*87.35;
```

7.4 Calculation of Parameters

```
Z1 = Z1sw + Z1lw + Z1lp + Z1sp;
Eap = Eaw*p*exp(-delta*1i);
Iwp = (Eaw-Eap)./Z1;

%from appendixZ0lw

Z1lw = n*Z1l;
Z1lp = (1-n)*Z1l;

Z0lw = n*Z0l;
Z0lp = (1-n)*Z0l;

Z1p = Z1sp + Z1lp;
Z0p = Z0sp + Z0lp;

Zsum = (Z0lw.^(-1) + Z0lp.^(-1)).^(-1) + ((Z1lw.^(-1) + Z1lp.^(-1)).^(-1))*2;
%Zsum=0;
%Zsum = (Z0sw+2.*Z1sw) + (Z0sp+2.*Z1sp) + (Z0l+2.*Z1l);
Vaf = Eaw - Iwp.*Z1w;
I0f =(Vaf./(3*Rf+Zsum));
I1f = I0f;
I2f = I0f;

D0 = Z0p./(Z0w+Z0p);
D1 = Z1p./(Z1w+Z1p);

K0 = (Z0l - Z1l)./Z1l;

I2w = D1.*I1f;
I1w = D1.*I1f;
I0w = D0.*I0f;

Dd = (3*Rf + Zsum)*(1-p*exp(-delta*1i))./(Z1p + Z1w*(p*exp(-delta*1i)));

dZ = 3*Rf./(Dd+2D1+D0*(1+K0));
Za = Z1lw + dZ;
```

7.5 Plotting Curve

```
plot(Za,'b')
hold on
grid on
end
```

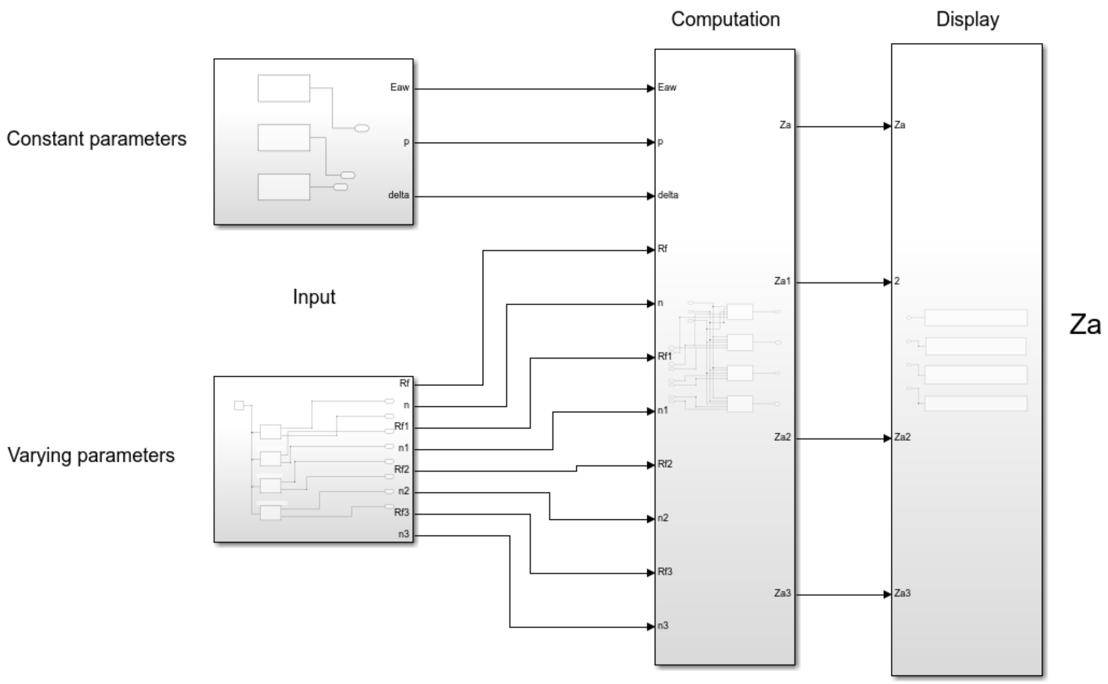


Fig 7.1. Subsystem model of the system on Simulink

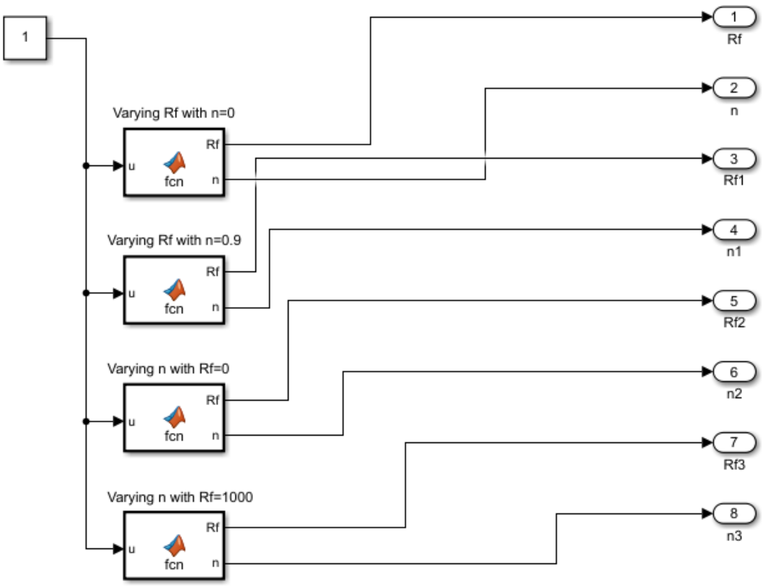


Fig 7.1.a Varying parameter input subsystem

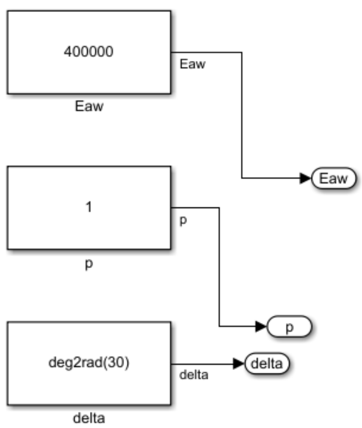


Fig 7.1.b Fixed parameter input subsystem

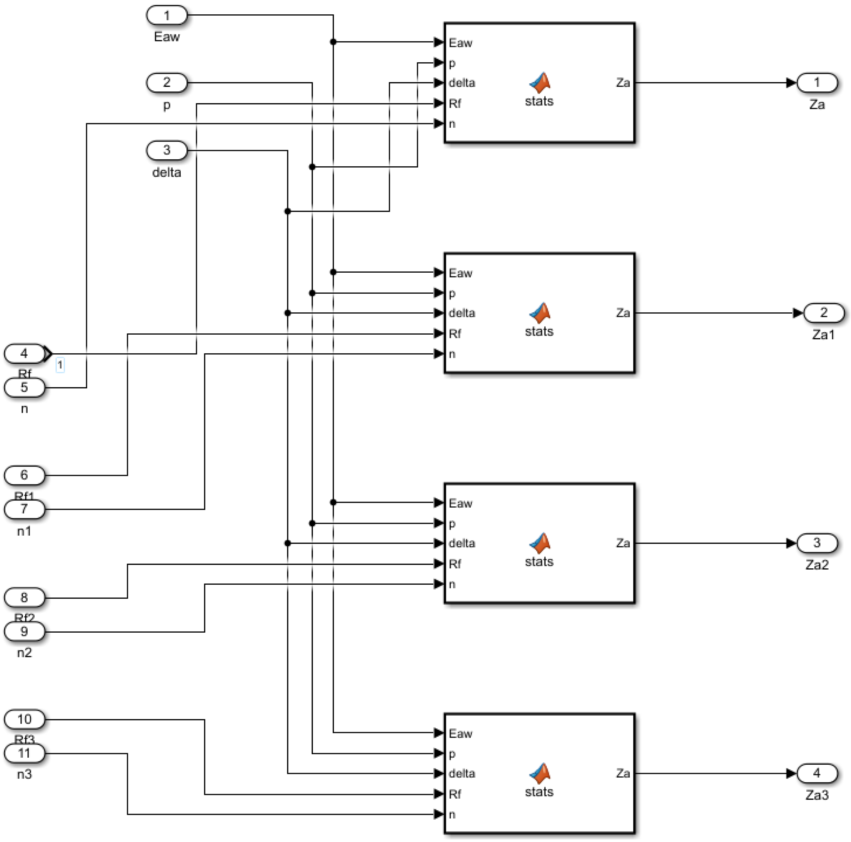


Fig 7.1.c Computation subsystem

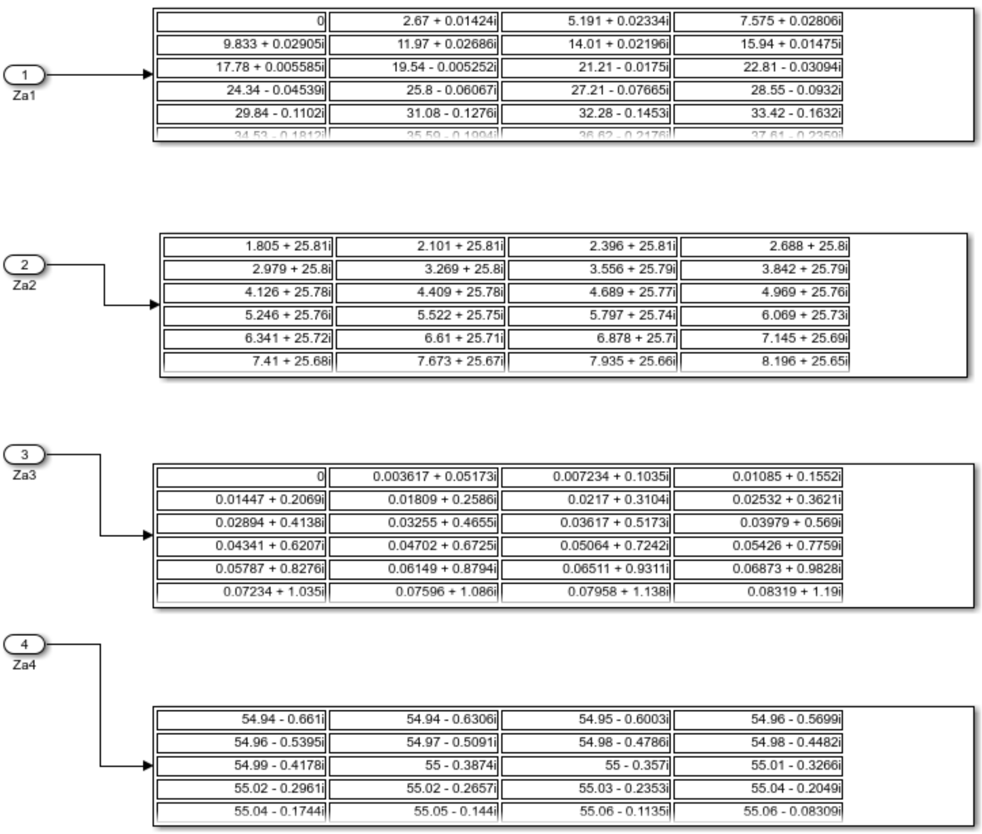


Fig 7.1.d Display subsystem

CHAPTER 8

RESULTS FROM THE MODEL AND CODE

8.1 Graphs

Obtained from MATLAB (For Eaw = 400kV)

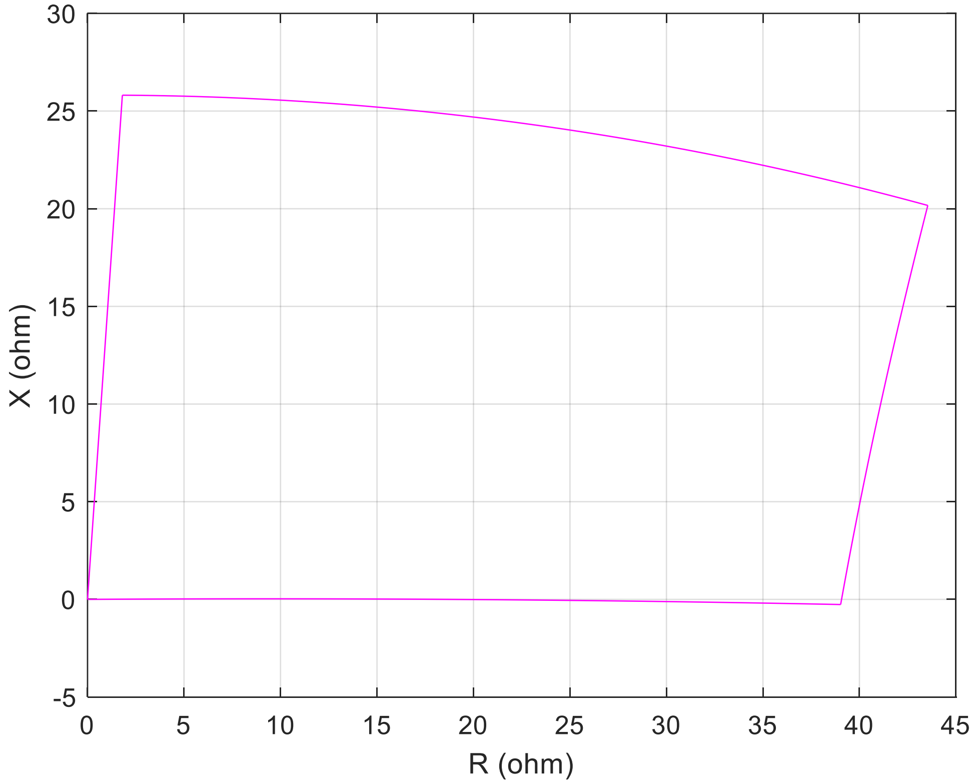


Fig 8.1.1 Trip boundaries for different wind farm loading levels ($\delta = 30^\circ$ and p = 1.0)

The proposed adaptive distance relay setting algorithm was tested using simulations in MATLAB/Simulink. The simulations were performed on a power system model with a wind farm connected to a transmission line. It was found that the proposed algorithm is effective in detecting and localizing faults in the wind farm transmission line.

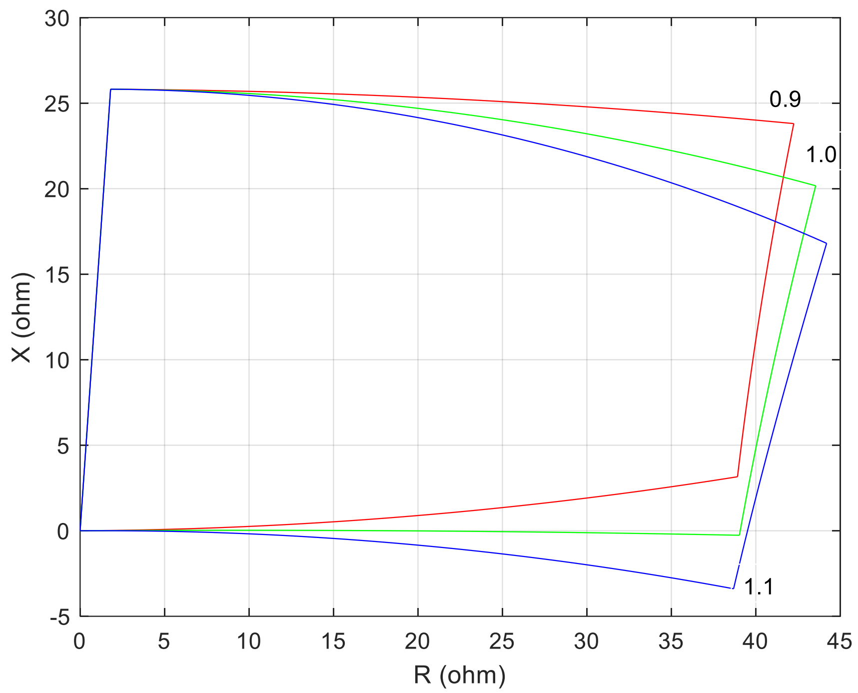


Fig 8.1.2. Trip boundaries for different voltage amplitude ratio (p = 0.9, 1.0, 1.1)

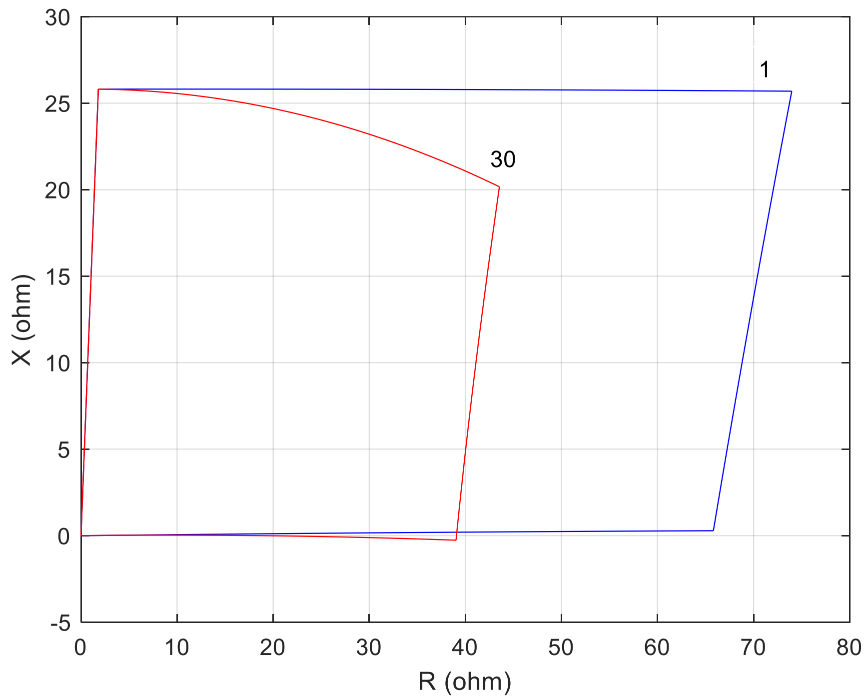


Fig 8.1.3. Trip boundaries for different wind farm loading levels (δ = 30◦ and 1◦)

8.2 Summary

Faults were detected within one cycle and localized by transmission line length. The performance of the proposed algorithm was compared with a conventional distance relay setting algorithm by the authors. It was observed that the adaptive algorithm outperforms the conventional algorithm in terms of fault detection and localization accuracy. The adaptive algorithm was also found to be more robust to changes in wind farm output and variations in fault impedance.

CHAPTER 9

DESCRIPTION OF SIMULINK MODEL OF ADAPTIVE RELAY

9.1 Introduction

The system proposed in Pradhan et.al has been adopted here to simulate the model of the adaptive distance relay in MATLAB Simulink. This model would serve as a baseline work for future studies, as the method used here may be used to implement different types of algorithms and even new techniques such as Machine Learning. The entire system comprises of two parts, namely the Adaptive Distance Relay (ADR) and the model of the windfarm-grid network. The relay in turn is comprised of two parts – the Trip Boundary Generator (TBG) block and the Relay Seen Impedance (RSI) block. The various measuring blocks needed for calculating are also included inside the ADR. It should be noted here that the ADR works completely on local information obtained at the windfarm and the voltage and currents at the relay location. Some additional information such as the relay reach and the maximum fault resistance are provided inside the ADR system. Using this system, the TBG determines the trip boundaries in a completely adaptive way wherein the quadrilateral boundary created by the TBG adjusts itself when changes in load angle, fault resistance etc. happens. The Simulink model is shown in Fig

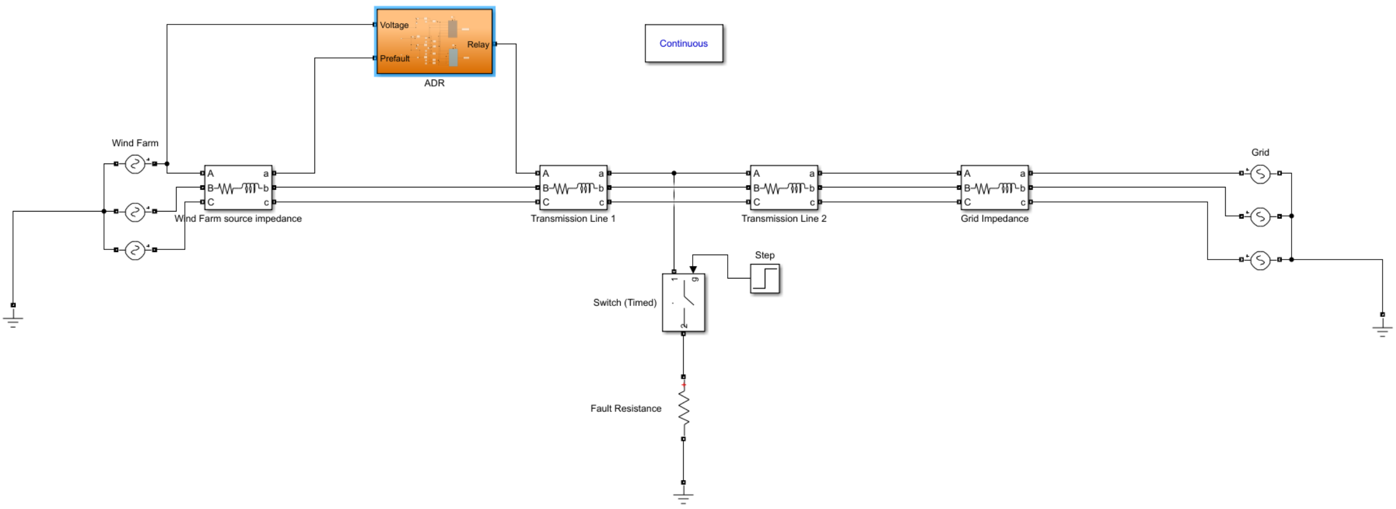


Figure 9.1.1 Simulink Model

9.2 Values of the quantities used

1. Windfarm Source voltage – 400000V
2. Windfarm Source Impedance – 6.1 Ω and 0.22 H
3. Transmission Lines – 7.32 Ω and 0.22 H
4. Grid Impedance – 0.3 Ω and 0.01 H
5. Grid Voltage – 400000 V
6. Frequency – 50 Hz

9.3 The Adaptive Distance Relay (ADR)

The ADR is the main computing part of the system and works as the model to implement the adaptive relay algorithm. The ADR works on local information and requires three input ports for generating the seen impedance at the relay and the trip boundary. The TBG adaptively adjusts the trip boundaries when the quantities obtained from these input ports are changed The ADR inputs (shown in Fig) consists of:

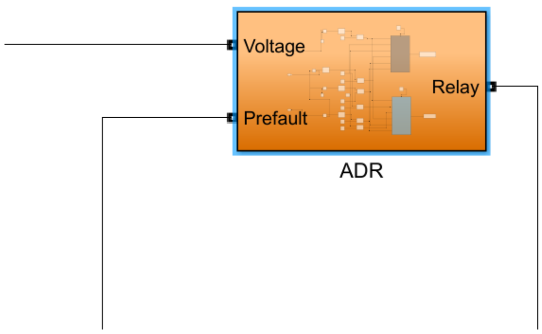


Fig 9.3.1 ADR with 3 inputs

1. Voltage port – This is to obtain the voltage levels generated by the windfarm
2. Relay port – The current and voltage levels at the bus where the relay is located in, is obtained here
3. Prefault port – This is for obtaining the prefault current level

These inputs are given to the TBG and RSI blocks present inside the ADR and is used for further computation

9.4 Inside the ADR

The ADR consists of the measurement blocks, TBG, RSI and other additional information which are required for the relay to function. The interior of the ADR is as shown in Fig

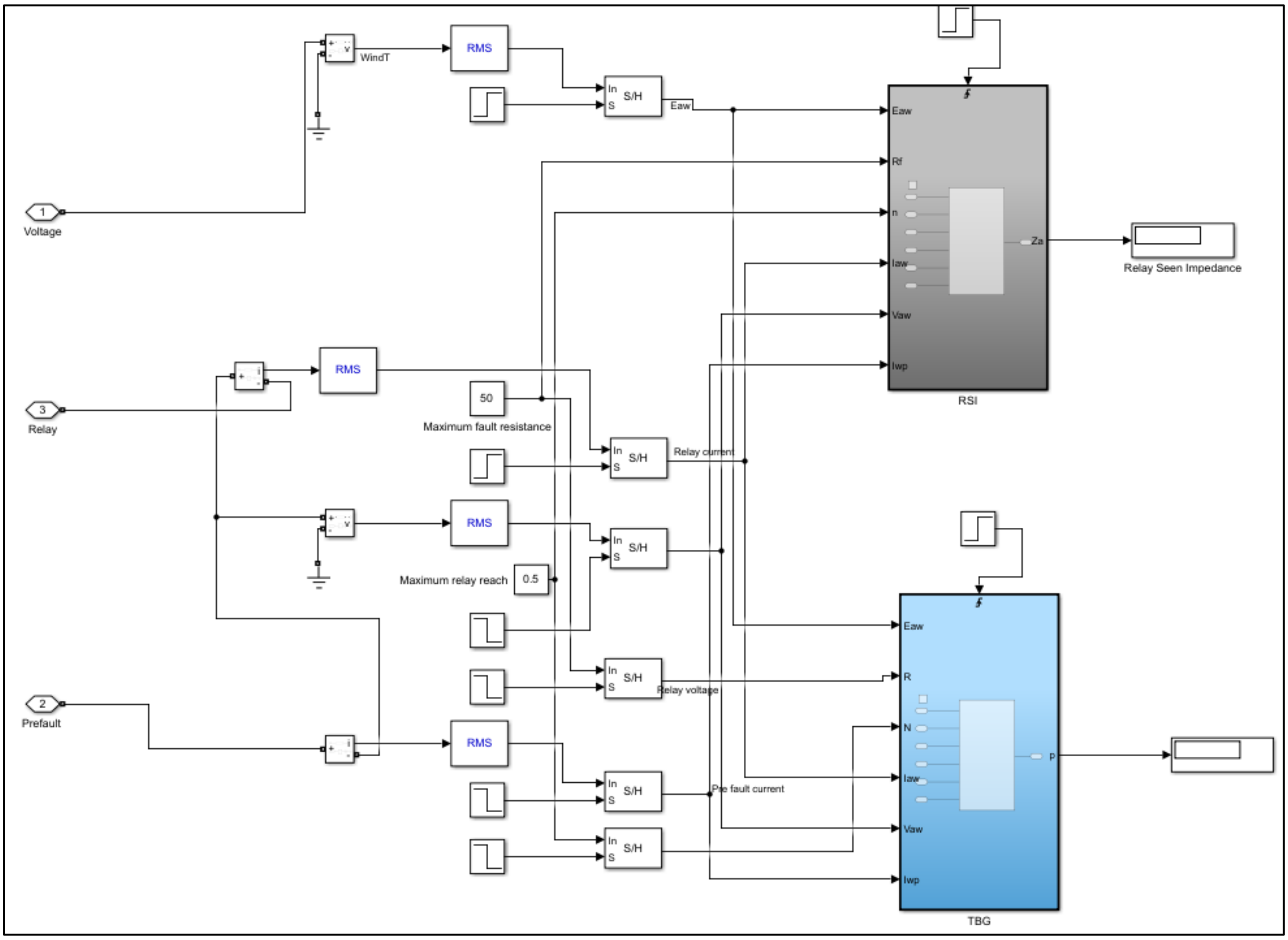


Figure 9.4.1 Interior of the ADR

The various part of the interior of the ADR are described as below:

1. The first row of the components depicts the ports.
2. Following the ports are the measurement blocks. These measure the pre-fault current, relay current and voltage and the voltage levels generated at the windfarm.
3. This is followed by RMS blocks which converts the parameters measured into their corresponding root-mean-square values
4. After this, Sample and Hold (S/H) blocks are present along with Step blocks, the latter which are used for triggering the S/H

5. Two constants, the relay reach and the maximum fault resistance are defined are Constant blocks inside the ADR. These values are also sent as signals to the TBG and the RSI blocks
6. All these signals are finally given to the TBG and the RSI as signals. It is to be noted that the RSI and TBG are both triggered subsystems. The triggers are Step blocks. This ensures that the entire process proceeds in a step-by-step manner and the values are only calculated once the relevant parameters are obtained from the electrical network
7. The output from the RSI is obtained as a complex number, which denotes the relay seen impedance calculated adaptively and the TBG outputs the trip boundary. This is generated using almost 2000 complex values points, also calculated using the present state of the system.
8. The trip boundary generated and the seen impedance are plotted together and this data is used to compute the trip decision

9.5 Relay Seen Impedance (RSI) Block

9.5.1 RSI Overview

The RSI block is used to compute the seen impedance at the relay connected bus, which is used to arrive at the trip decision. The RSI Block consists of 6 inputs, the seen impedance as output and a MATLAB Function Block which is the brain of the RSI and implements the algorithm necessary for computation of the impedance. The interior of the RSI Block is shown in Fig

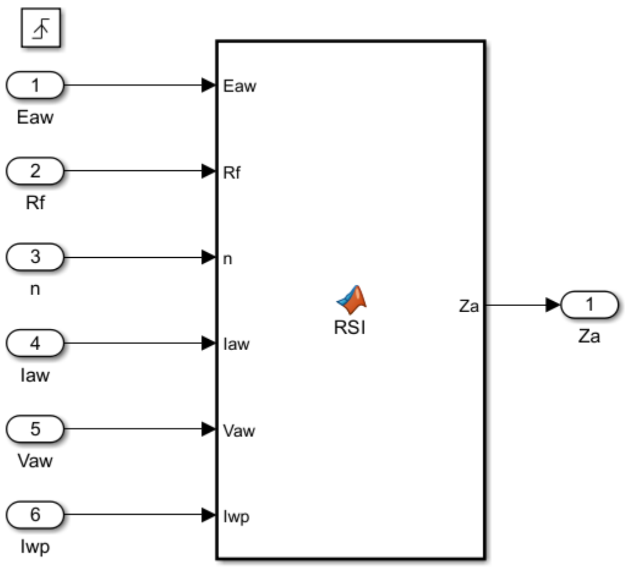


Figure 9.5.1.1 Interior of the RSI block

The inputs and output of the RSI Block are:

1. Eaw – Windfarm voltage level
2. Rf – Maximum Fault resistance
3. n – Relay reach
4. Iaw – Current through the relay bus (post-fault)
5. Vaw – Voltage at the relay bus (post-fault)
6. Iwp – Pre-fault current through the transmission line
7. Za – The relay seen impedance output (complex valued)

9.5.2 RSI Algorithm

The RSI Algorithm, written in MATLAB Code, is used to calculate the seen impedance as well as to plot the point. This point plotted is later combined with the trip boundary generated by the TBG and used for the trip decision.

```
function Za    = RSI(Eaw,Rf,n, Iaw, Vaw, Iwp)
 persistent executed;
  persistent result;

    if isempty(executed)

%Wind Farm
Z1sw = exp(deg2rad(85)*i)*20;
Z0sw = exp(deg2rad(85)*i)*30;


%Grid

Z1sp = exp(deg2rad(85)*i)*1;
Z0sp = exp(deg2rad(85)*i)*1.5;


%Line

Z1l = exp(deg2rad(86)*i)*28.75;
Z0l = exp(deg2rad(83)*i)*87.35;


Z1lw = n*Z1l;
Z1lp = (1-n)*Z1l;

Z0lw = n*Z0l;
Z0lp = (1-n)*Z0l;
Z1w = Z1sw + Z1lw;
Z0w = Z0sw + Z0lw;

Z1p = Z1sp + Z1lp;
```

```
Z0p = Z0sp + Z0lp;


Z1 = Z1sw + Z1lw + Z1lp + Z1sp;
Eap = Eaw*(1 - ((Iwp/Eaw)*Z1));

Zsum = (Z0lw.^(-1) + Z0lp.^(-1)).^(-1) + ((Z1lw.^(-1) + Z1lp.^(-1)).^(-1))*2;
Vaf = Eaw - Iwp.*Z1w;
I0f =(Vaf./(3*Rf+Zsum));
I1f = I0f;
I2f = I0f;

D0 = Z0p./(Z0w+Z0p);
D1 = Z1p./(Z1w+Z1p);

K0 = (Z0l - Z1l)./Z1l;

I2w = D1.*I1f;
I1w = D1.*I1f;
I0w = D0.*I0f;


Za = Vaw/(Iaw+K0*I0w)

plot(Za,'*');
hold on
grid on
result = Za;
        executed = true;

    end
 Za = result;
end
```

9.6 Trip Boundary Generator (TBG) Block

9.6.1 TBG Overview

The TBG block is used for trip boundary generation is one of the two main components of the ADR along with the RSI. The inputs to the TBG are same as that of the RSI. The output of the TBG is denoted as “p” in Simulink. However, this is inserted only for the sake of running the code. This is due to the fact that the MATLAB function block in Simulink compulsorily requires the presence of an output signal in a datatype form. For the intended function of the TBG in generation of the trip boundaries, this is inconsequential. The output of interest here is the quadrilateral trip boundary characteristics obtained from the TBG Algorithm which is implemented in the MATLAB function block. The interior of the TBG is as shown in Fig

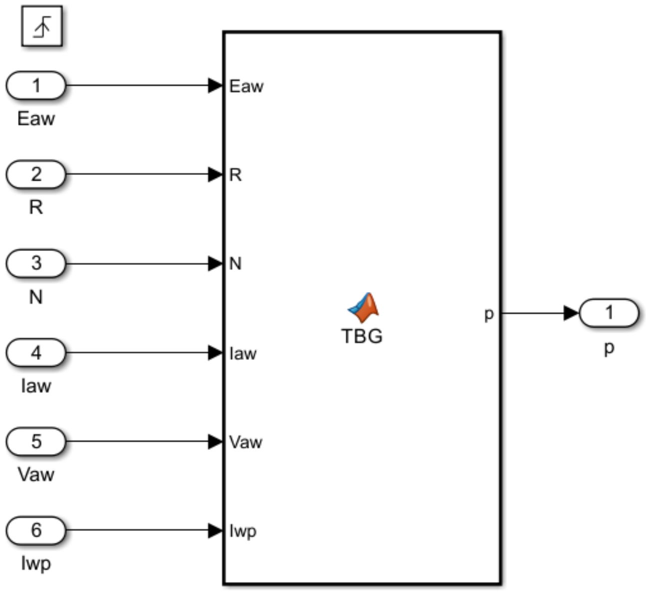


Figure 9.6.1.1 Interior of the TBG block

As it is observed from the figure, the inputs to the TBG are same as that for RSI (albeit a few differences in notations). The TBG algorithm inside the Function Block is provided in the next section and is a key component to the working of the ADR.

9.6.2 TBG Algorithm

The TBG Algorithm is almost similar in construction to the RSI as both follows the same principles. However, the code is changed here to run in a loop four times to generated the four sides of the quadrilateral trip characteristic. In this process, almost 2000 complex values impedances are plotted. The plot generated thus and the seen impedance calculated by the RSI is plotted together to arrive at the trip decision

```
function p = TBG(Eaw,R,N,Iaw,Vaw,Iwp)
%values
p =1;
Rf=R;
n=0;
for v = 1:1:4
switch v
    case 1
        Rf = linspace(0,R,500);
        n =  0 ;
    case 2
       Rf =linspace(0,R,500);
        n =  0.9 ;
    case 3
```

```
        Rf = 0;
        n =  linspace(0,0.9,500);
    case 4
        Rf = R;
        n =  linspace(0,0.9,500);
end


Z1sw = exp(deg2rad(85)*i)*20;
Z0sw = exp(deg2rad(85)*i)*30;


Z1sp = exp(deg2rad(85)*i)*1;
Z0sp = exp(deg2rad(85)*i)*1.5;


Z1l = exp(deg2rad(86)*i)*28.75;
Z0l = exp(deg2rad(83)*i)*87.35;


Z1lw = n*Z1l;
Z1lp = (1-n)*Z1l;

Z0lw = n*Z0l;
Z0lp = (1-n)*Z0l;
Z1w = Z1sw + Z1lw;
Z0w = Z0sw + Z0lw;

Z1p = Z1sp + Z1lp;
Z0p = Z0sp + Z0lp;


Z1 = Z1sw + Z1lw + Z1lp + Z1sp;
Eap = Eaw*(1 - ((Iwp/Eaw)*Z1));


Zsum = (Z0lw.^(-1) + Z0lp.^(-1)).^(-1) + ((Z1lw.^(-1) + Z1lp.^(-1)).^(-1))*2;
Vaf = Eaw - Iwp.*Z1w;
I0f =(Vaf./(3*Rf+Zsum));
I1f = I0f;
I2f = I0f;

D0 = Z0p./(Z0w+Z0p);
D1 = Z1p./(Z1w+Z1p);

K0 = (Z0l - Z1l)./Z1l;

I2w = D1.*I1f;
I1w = D1.*I1f;
I0w = D0.*I0f;

Za = Vaw./(Iaw+K0*I0w);
plot(Za,'r')
hold on
grid on
end
```

9.7 Summary

This chapter consists of the modeling done to symbolize the real-life working of ADR. ADR consists of 3 ports: Voltage Relay and Prefault Port, each with their significance. Then, we look into each and every component present in the ADR, like the step response sample and hold, and making sure we are taking the RMS value for the source voltage to remove spike voltage from the source, allowing the TBG to execute trip boundary. Then, we look into the main components in ADR, namely, TBG and RSI. Also, we see the code implemented in both of the blocks to get the desired value. In both cases, we require Za.

CHAPTER 10
SIMULATION OF SIMULINK MODEL OF ADAPTIVE RELAY

10.1 Introduction

The system is now tested, simulating a line-to-ground fault in the A phase. The fault occurs at 50% of the transmission line measured from the location of the relay towards the grid. It should be noted here that the entire time of operation in this simulation is taken as 5 seconds of runtime. This is set by correspondingly adjusting the time frame for the occurrence of the fault and the time taken for the triggering of operation of the ADR. For a real system, the entire operational time can be scaled down appropriately, while the underlying scheme of events remains the same.

10.2 Simulation

The events of the simulation are explained here, separately for the pre-fault and post-fault operations. The initial conditions of the system are:

1. Voltage level at the Wind Farm (E_{aw}) – 400,000 V
2. Load angle = 30°
3. Ratio of the Wind Farm voltage to the Grid Voltage = 1
4. Frequency = 50 Hz

Taking these initial conditions, a fault is simulated at 3 seconds using a timed switch. For a real system, all the triggers for the S/H would be done by measuring the values of the system currents and voltages

10.2.1 Pre-Fault

After the simulation has started, the S/H blocks hold the values of the constants of the maximum fault resistance and the reach of the relay in 1 s while the voltage level of the Wind Farm is taken at 1.5 s. The pre-fault current is taken at 2 s. The TBG and the RSI gets triggered only after the occurrence of the fault. The waveforms of the electrical parameters prior to the fault and given in the figures below:

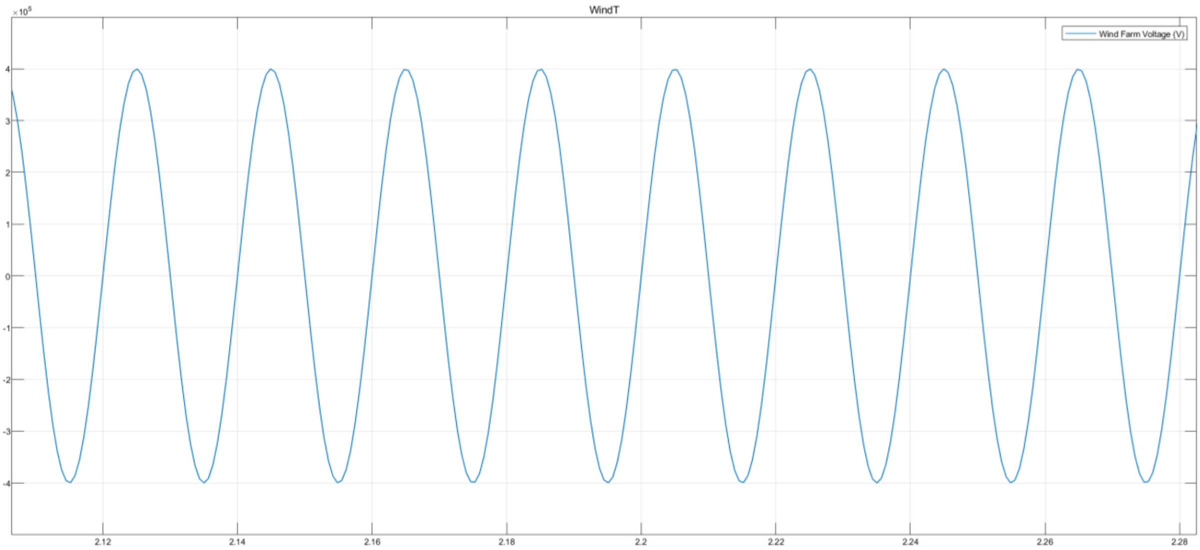


Figure 10.2.1.1. Voltage Waveform of the Windfarm prior to fault

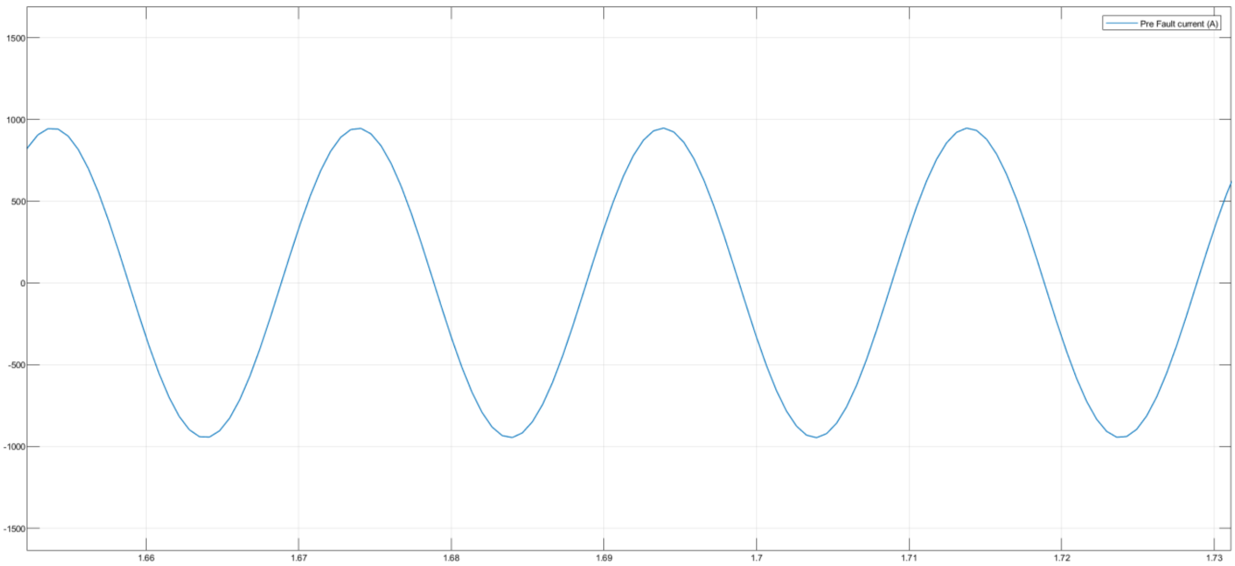


Figure 10.2.1.2. Current Waveform of the Windfarm prior to fault

10.2.2 Post-Fault

Using the timed switch, triggered using the Step block, the line-to-ground fault is created at 3 seconds. This leads a fault condition in the system and thus, the current and voltage values change. At 4 s, the current and voltage through the bus at the relay in A phase are sampled. The TBG and the RSI are also triggered. The waveforms corresponding the fault, are as shown in the figures given

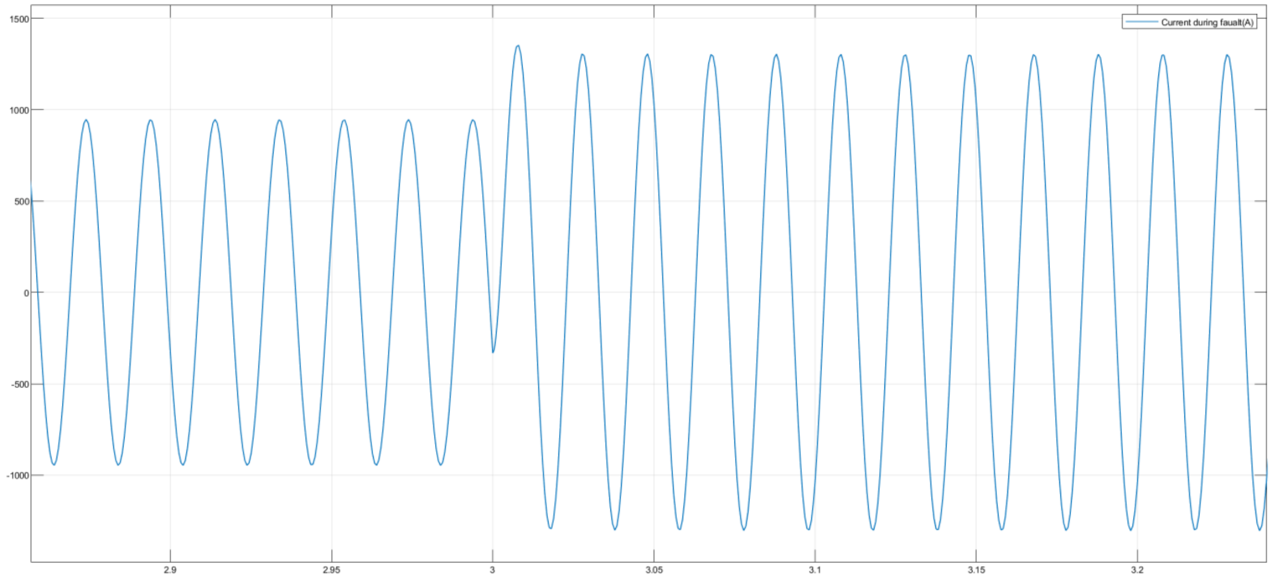


Figure 10.2.2.1. Current waveform of the windfarm during fault

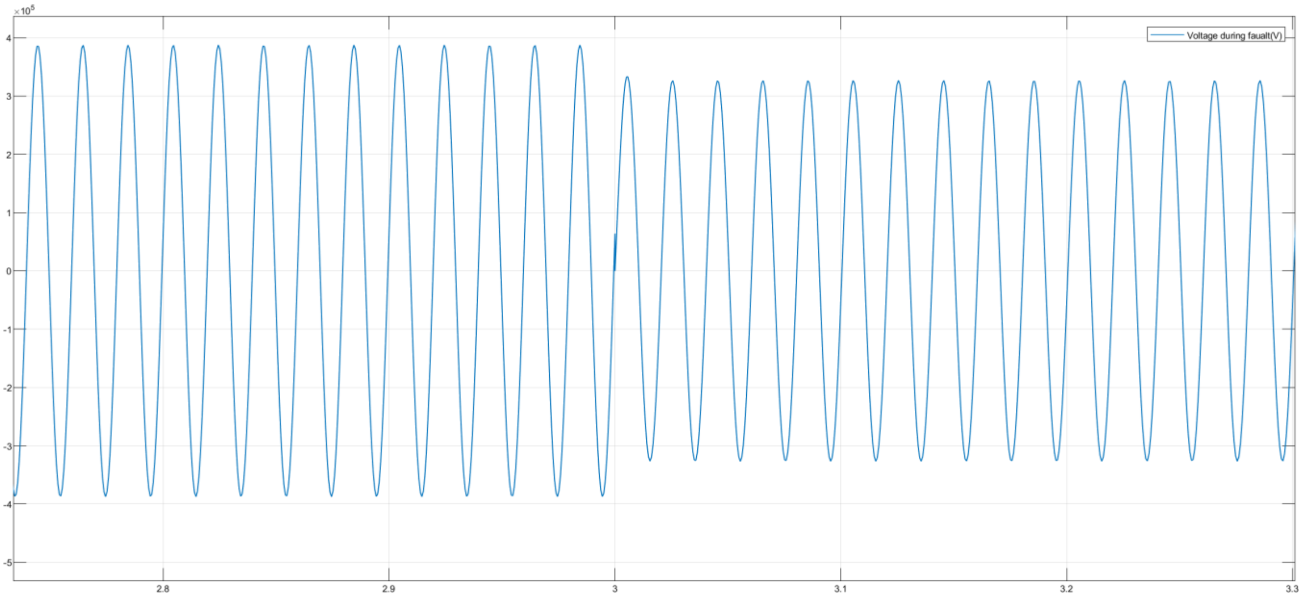


Figure 10.2.2.2. Voltage waveform of the windfarm during fault

10.2.3 Results of Algorithm

As we observe, these parameters are changed due to the fault created. The TBG and RSI now compute the trip boundary and the seen impedance of the relay respectively, the graphs for the same are provided

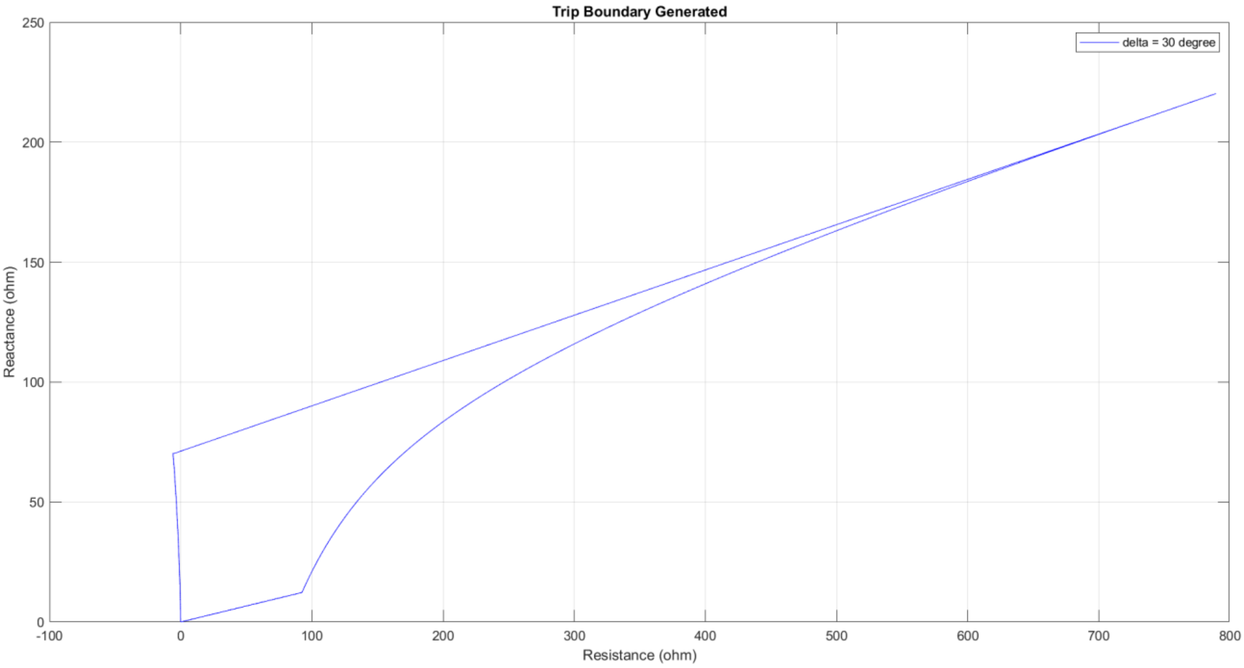


Figure 10.2.3.1. Trip Boundary Generated Plot

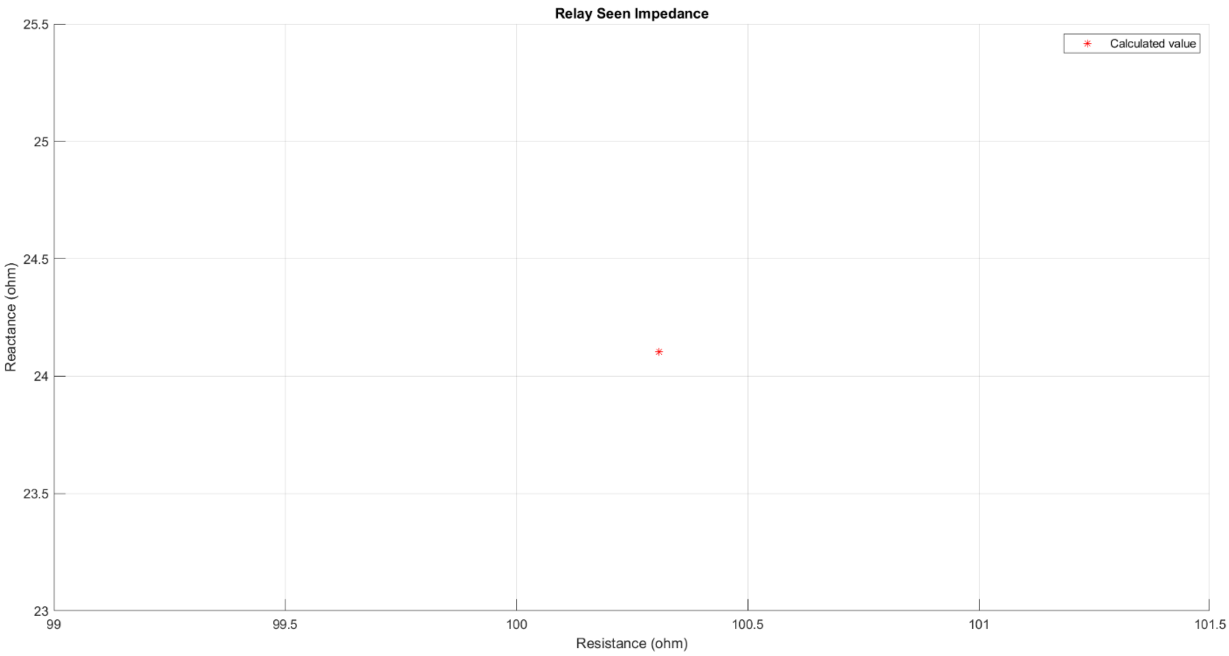
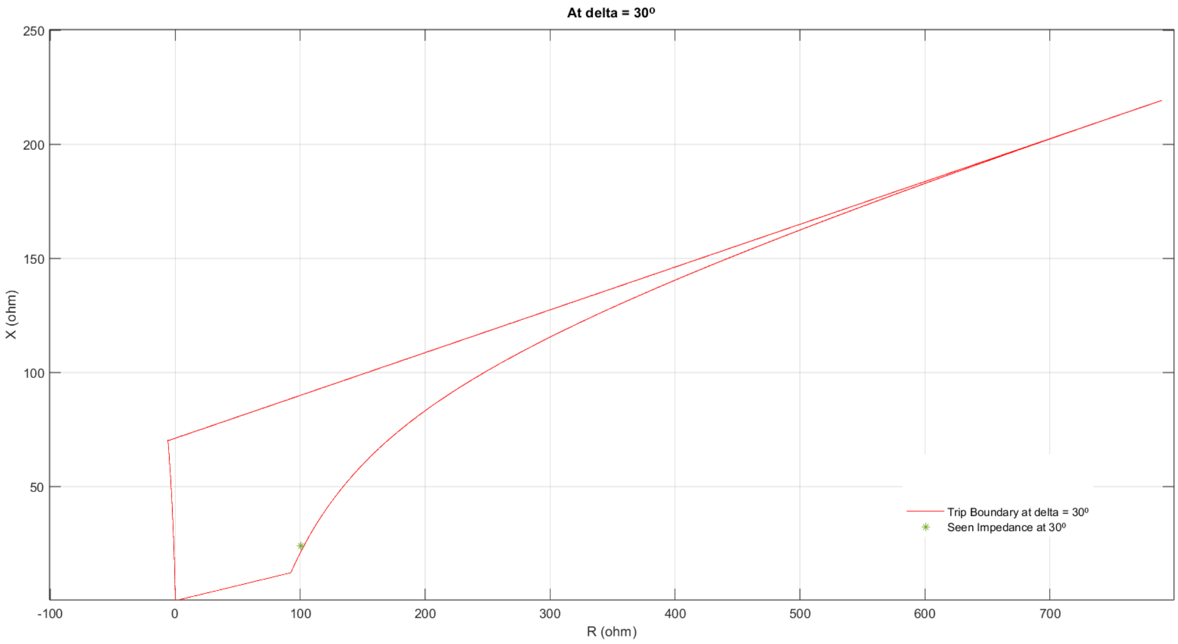


Figure 1.2.3.2 Relay Seen Impedance Plot

CHAPTER 11

RESULTS OF SIMULINK MODEL OF ADAPTIVE RELAY

11.1 Delta = 30º



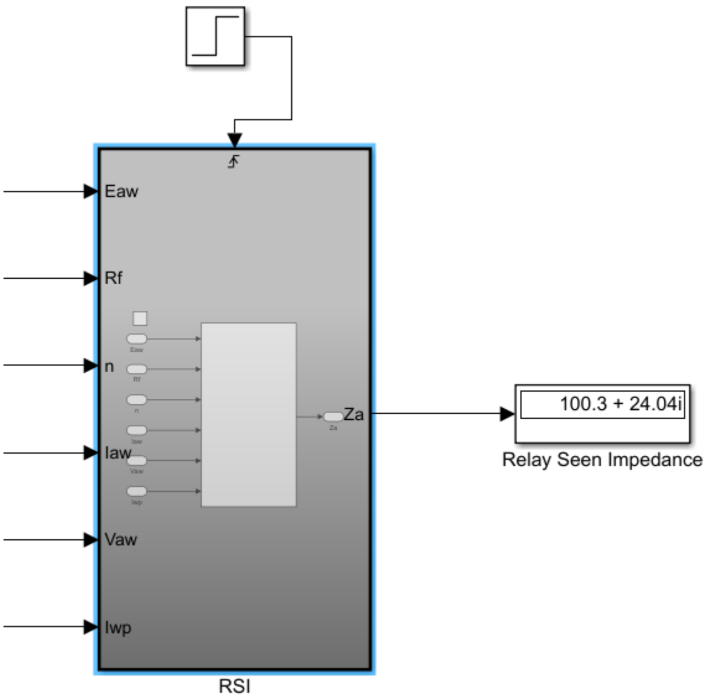
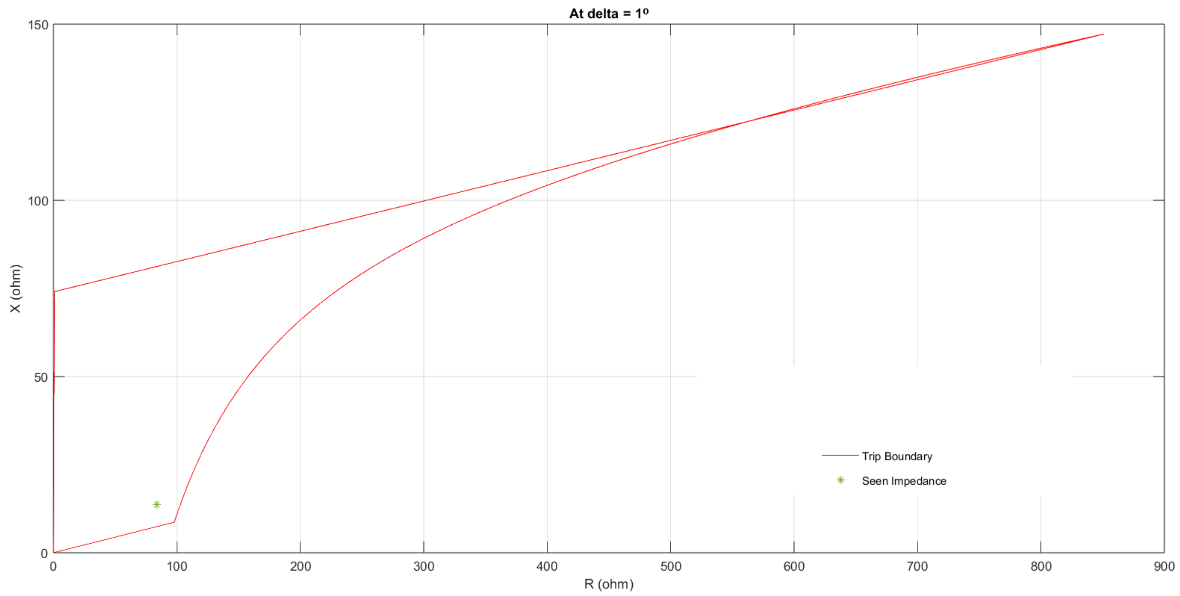


Figure 11.1.1. TBG & RSI for delta = 30º

11.2 Delta = 1º



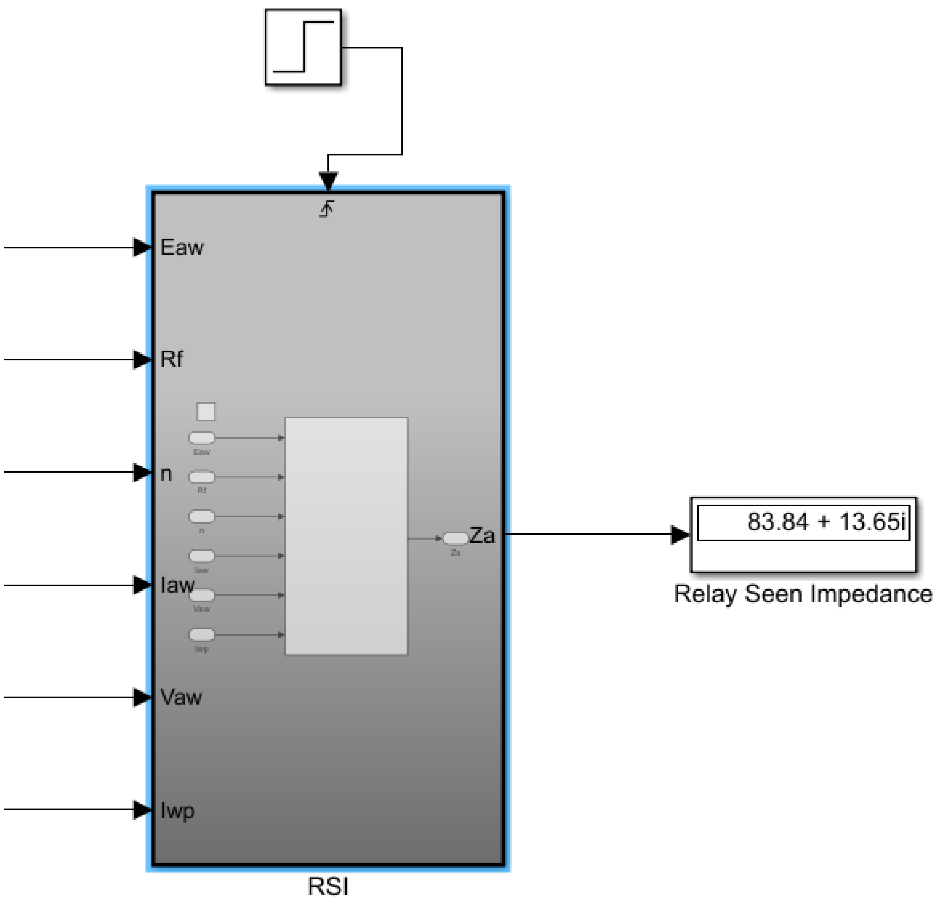


Figure 11.2.1. TBG & RSI for Delta = 1º

11.3 Combined (delta = 1⁰ and 30⁰, showing adaptive property)

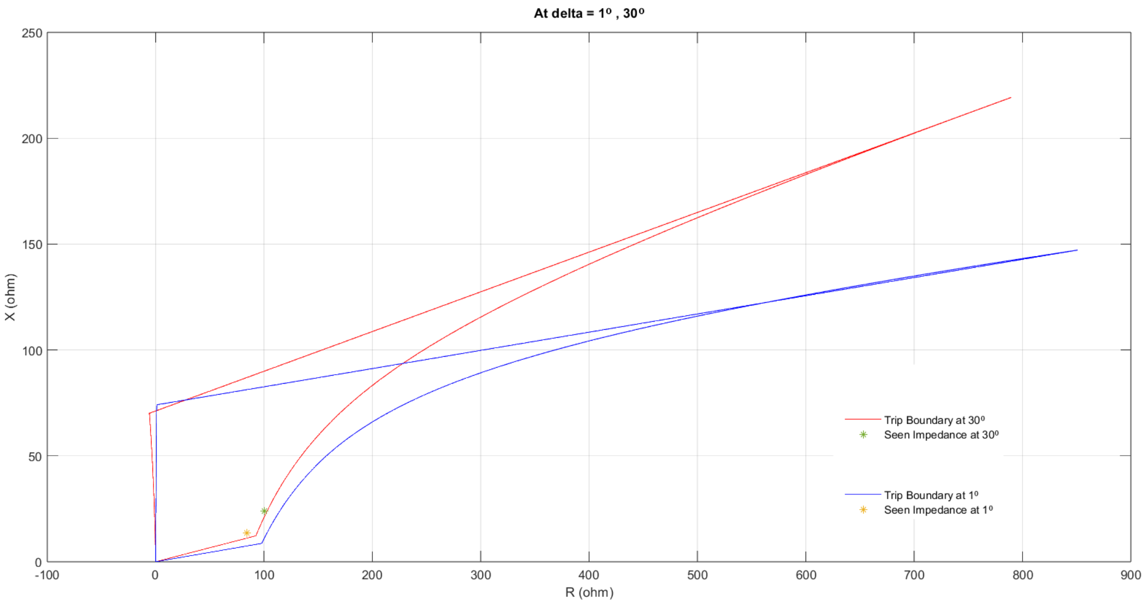
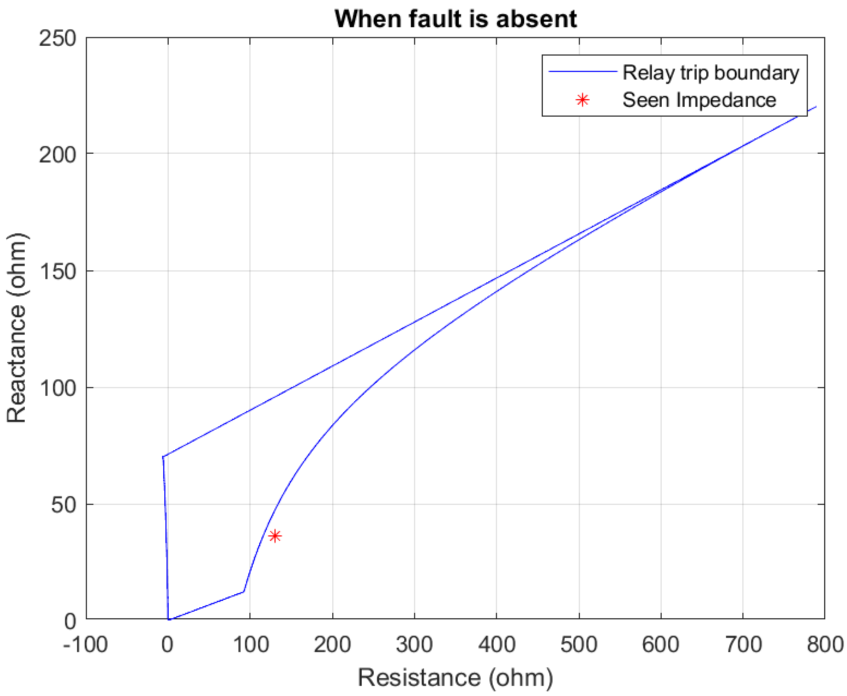


Figure 11.3.1. TBG for Delta = 30⁰ and 1⁰

11.4 No fault



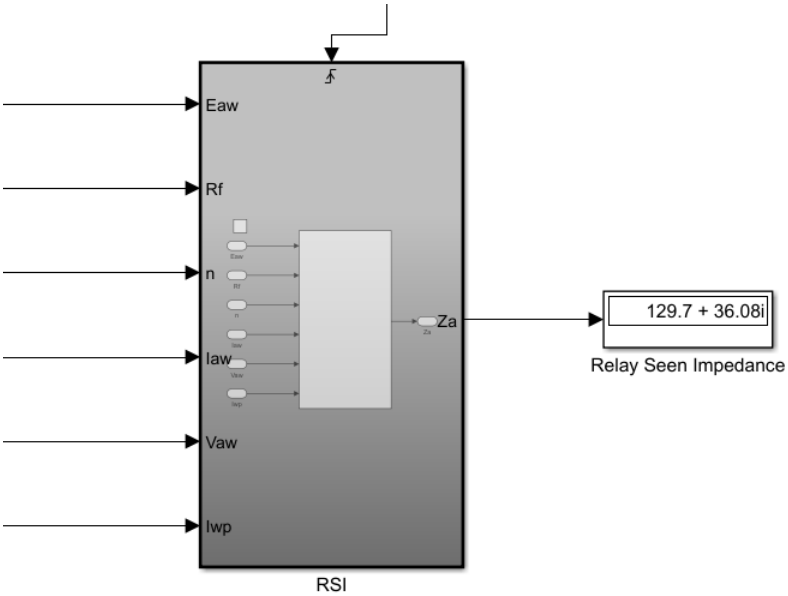


Figure 11.4.1. TBG & RSI at no fault

11.5 Summary

Here we have generated the trip boundary at various conditions. We have also obtained impedance seen by the relay for the various conditions. The adaptability of the distance relay could be observed from these graphs.

CHAPTER 12
PSCAD MODEL

PSCAD is a specialized piece of software used for modelling and assessing the operation of power systems. It stands for Power Systems Computer Aided Design. Engineers and researchers in the power sector frequently utilise PSCAD to build, evaluate, and optimise diverse electrical power systems.

The software offers a graphical interface that makes it simple for users to build intricate power system models. Generators, transformers, gearbox lines, and loads are just a few of the many parts that are included in the extensive library that may be utilised to construct these models. These parts can be modified to simulate a variety of settings and scenarios for power systems.

Advanced simulation features like electromagnetic transient simulation, steady-state analysis, and frequency-domain analysis are also available in PSCAD. With the aid of these technologies, engineers may assess a system's performance under various operating situations and spot any issues before they arise. A comprehensive and potent tool for power system modelling and analysis, PSCAD also interfaces with other tools for power system analysis, including MATLAB/Simulink and EMTP-RV. In conclusion, PSCAD is an important tool for power system engineers and researchers who need to simulate, develop, and optimise power systems in a secure and effective manner.

The mathematical model for the trip boundary generation has been implemented in PSCAD using the various Control System Modelling Functions (CSMF) available in the PSCAD library. The PSCAD Master Library's CSMF (Control Systems Modelling Functions) section offers a comprehensive selection of fundamental linear and non-linear controls elements. Almost any form of control system, no matter how complex, may be built using these components in combination to create larger, more complex systems.This PSCAD implement of the mathematical model could be used to generate the trip boundary. This model could be used to find the value of Za to calculate the trip boundaries and hence analyse the fault with respect to the trip boundaries.

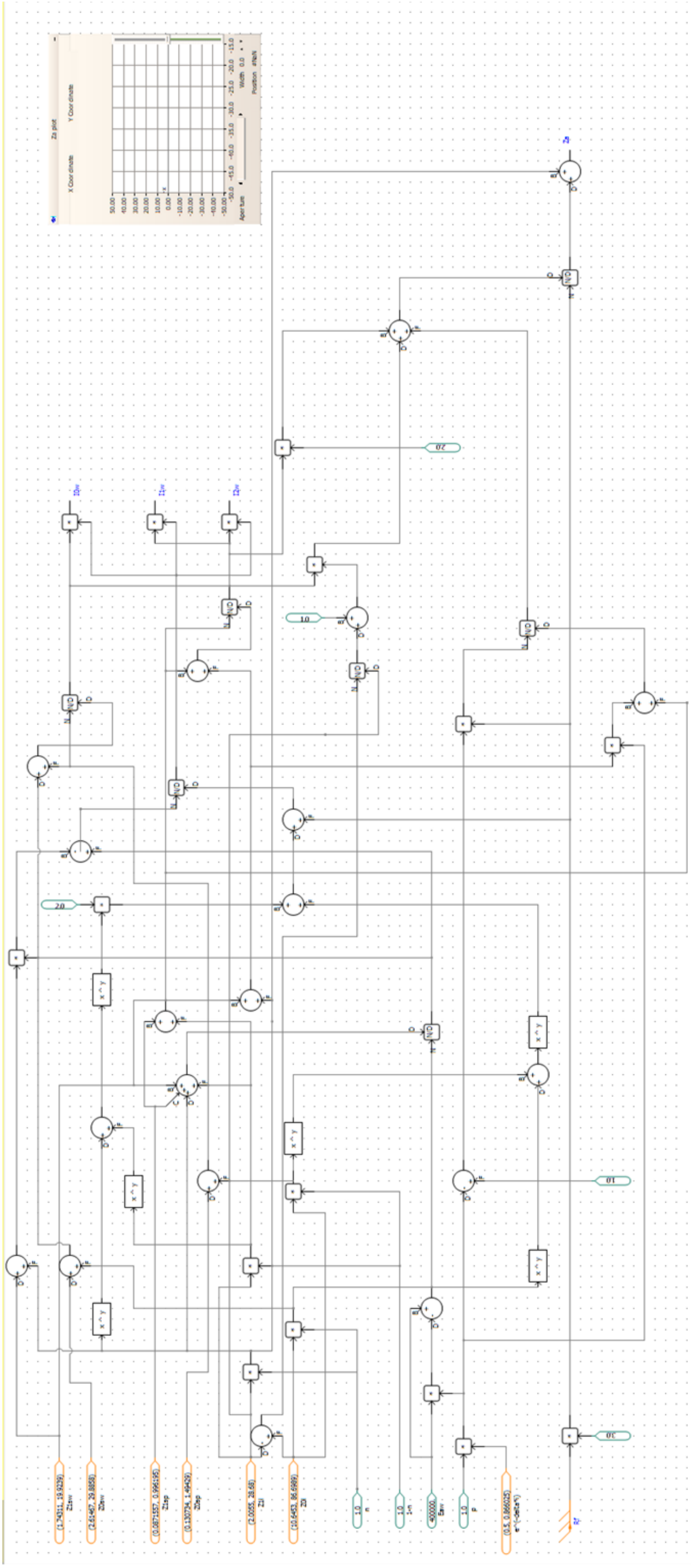


Figure 12.1 PSCAD Model

CHAPTER 13
CONCLUSION

Through this project, we have put forward a step in the direction of implementing adaptive distance relays in the real-world. Currently there are almost no adaptive relays available. With the adoption of smart grid technologies and the incorporation of more renewable energy sources into the grid, the need to include this technology becomes more urgent. We have demonstrated a method on how to generate a trip boundary and calculate the impedance seen by the relay, in an adaptive way. The method of having two separate computing blocks (the TBG and RSI in this case) have been developed here.

The project studied the numerous facets of adaptive distance relaying, including its operational principles, the algorithm employed, and the variables influencing its effectiveness. The benefits, drawbacks, and uses of adaptive distance relaying in various power system settings were also covered

Overall, the emphasis is on the value of adaptive distance relaying for safeguarding power systems and maintaining their dependable and effective functioning.

CHAPTER 14
SCOPE FOR FURTHER STUDY

A hardware-in-the-loop (HIL) model could be created using the results obtained from the PSCAD and Simulink simulations. This would involve connecting a physical relay to a simulated power system and testing its performance under various fault conditions. The results of this study could be used to validate the effectiveness of adaptive distance relaying and inform the development of future protection schemes.

This model provides a framework, algorithms found in different literature on the subject may be implemented along the same lines and research conducted on more efficient technologies. Further, Machine Learning techniques may be used to train an Artificial Intelligence (AI) model to respond to various conditions presented by a power system. Such a study would prove to be invaluable in future smart grid systems which would be safe, robust and secure.

REFERENCES

[1] K. Pradhan and G. Joos, "Adaptive Distance Relay Setting for Lines Connecting Wind Farms," in IEEE Transactions on Energy Conversion, vol. 22, no. 1, pp. 206-213, March 2007, doi: 10.1109/TEC.2006.889621.

[2] Jongepier, G., and van der Sluis, L., “Adaptive distance protection of a double circuit line,” IEEE Trans. Power Delivery, Vol.9, No. 3, pp. 1289–1297, July 1994.

[3] Kamel, A., Alaam, M. A., Azmy, A. M., and Abdelaziz, A. Y., “Protection coordination for distribution systems in presence of distributed generators,” Elect. Power Compon. Syst., Vol. 41, No. 15, pp. 1555–1566, November 2013.

[4] Xia, Y. Q., David, A. K., and Li, K. K., “High resistance faults on multi-terminal lines: Analysis, simulated studies an adaptive distance relaying scheme,” IEEE Trans. Power Delivery, Vol. 9, No. 1, pp. 492–501, 1994.

[5] Xia, Y. Q., Li, K. K., and David, A. K., “Adaptive relay setting for standalone digital distance protection,” IEEE Trans. Power Delivery, Vol. 9, No. 1, pp. 480–491, 1993.

[6] Jongepier, G., and van der Sluis, L., “Adaptive distance protection of a double circuit line,” IEEE Trans. Power Delivery, Vol. 9, No. 3, pp. 1289–1297, July 1994.