CONDITION MONITORING AND PROTECTION OF TRANSMISSION LINE USING PMU

A DISSERTATION

Submitted in partial fulfillment of the
requirements for the award of the degree of
MASTER OF TECHNOLOGY
in
ELECTRICAL ENGINEERING
(With specialization in Instrumentation and Signal Processing)

By

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MAY, 2016

CANDIDATE'S DECLARATION

I, hereby, certify that the work which is being presented in the dissertation entitled "**CONDITION MONITORING AND PROTECTION OF TRANSMISSION LINE USING PMU**" in partial fulfilment of the requirement for the award of the degree of **Master of Technology in Electrical Engineering with specialization in *Instrumentation & Signal Processing***, submitted to the Department of Electrical Engineering, Indian Institute of Technology, Roorkee, India, is an authentic record of my own work carried out during a period from May 2015 to May 2016 under the supervision of Dr. Manoj Tripathy, Department of Electrical Engineering, Indian Institute of Technology, Roorkee.

The matter presented in the dissertation has not been submitted by me for the award of any other degree of this or any other institute.

Date :

Place : Roorkee **(Navendu)**

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to best of my knowledge**.**

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ABSTRACT

Naive Bayes (NB) Classifier has been implemented for fault detection and type of fault classification in transmission line. The Naïve Bayes classifier is based on Bayes conditional probability theorem. Synchronized fault current is taken from two PMU placed at two alternate buses. The magnitude and angle of all the three phase current are considered for fault classification of transmission line. First the line on which fault has occurred has been identified using Naive Bayes classifier. Then type of fault is classified using maximum value of phase current. Since, PMU gives RMS value as output and the faulty phase shows maximum value of RMS current. So the maximum value of each phase current is used in Naïve Bayes classifier for fault classification. Ten different types of fault have been classified. It classifies the fault very accurately. The classifier is very simple to understand and use. It takes very less time for training and testing.

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CHAPTER 1

INTRODUCTION

1.1 General

For the bulk transfer of electrical power from generating station to electrical substation, transmission line is required. Transmission line is a very important part of power system. The length of transmission lines can vary from few hundred meters to several thousand kilometers and voltages (line to line) used to transmit can vary from 66kV to 765kV**.** Power transmission line is very long and it usually placed in open atmosphere**. P**robability of occurrence of fault is very high as compared to generator and power transformer.

There are various reasons for fault in transmission lines like falling of tree, lightning, birds, weather (wind, snow, and ice), natural disaster like earthquake and flood, faulty equipments etc. Fault can be of four types single line to ground fault, line to line fault, double line to ground fault and three phase fault. Three phase fault is most severe fault. Single line to ground fault is more common in transmission line.

Features of transmission line protection system are as follows:

- Circuit breaker which is closest to the fault should be tripped first.
- The operating time of relay should be as minimum as possible, so that faulty lines get disconnected from the healthy part as soon as possible.
- If primary relay fails to operate, then back up relay should operate just next to primary relay.

Various protection schemes are used for the protection of transmission line. These are listed as follows:

- Over current protection scheme
- Distance protection scheme
- Differential protection scheme viz pilot protection

Over current protection scheme

An over current (OC) relay works on the principle that it operates when current exceeds a pick up value. Only current is used as actuating quantity. When normal current flows through the operating current coil magnetic field induced in the current coil is not able to move the moving part of the relay. In this condition restraining force is greater than deflecting force. But in case of fault, level of current increases and deflecting force becomes greater than restraining force. The moving element of the relay start moving because of deflecting force more than restraining force and trip the circuit breaker.

Depending upon the time of operation, there are four types of over current relay these are as follows:

i. Instantaneous over current relay
ii. Definite time over current relay
iii. Inverse definite time over current relay (IDMT)
iv. Directional over current relay

Limitations of over current relay:

The operating time and reach of the OC relay depends on the fault current. Fault current at a point on the line depends on the type of fault and the source impedance. Higher the source impedance, lower the fault current so the operating time of the relay gets increase and the relay under reach. The fault current is a maximum for three phase fault compared to single line to ground fault at the same location. Therefore, as the fault changes from three phase to single phase the relay operating time increases.

Distance protection scheme

It works on the principle that when voltage to current ratio became less than the predetermined value, it operates. It measures voltage to current ratio between the fault point and relay location. It has two actuating quantities i.e. voltage and current. Deflecting torque is produced by current and restraining torque by voltage. In fault condition, current becomes very large whereas voltage becomes less, so the deflecting torque becomes high and relay operates. It is also called impedance relay since voltage to current ratio is impedance of the transmission line.

Types of distance relay

- Impedance relay- Used for protection of medium transmission line.
- Reactance relay- mainly used for protection of short transmission line.
- Mho relay- Used for protection of long transmission line.

Differential protection scheme

Differential relay is a unit type protection scheme. It operates for the fault within its zone of protection and it does not operate for the fault outside its zone of protection. It is based on the principle that the relay operates when the difference between similar electrical quantities taken from two ends of the protection zone, exceeds pick up value.

Limitations of differential protection/pilot protection:

Differential protection is used for short line only. Since, with the increase in length of transmission line, length of wire used for differential protection also increases which added cost of conductor to the protection system. Also in pilot protection communication channels are used to send data from local to remote station. But some delay has occurred in transmission of data through communication channels, so immediate action cannot be taken if fault has occurred and also accurate estimate of power plant cannot be determined.

To solve this problem synchronized data is being used. Phasor measurement unit is used to obtain the synchronized data. Nowadays communication delay has reduced significantly, so problem of communication delay gets solved.

1.2 Literature Review

Transmission line protection is a well-known problem which has been studied for a long time. Most important task in protection of transmission line involves detection of fault and its classification. This is then followed by finding location of fault on transmission line. Output obtained from these three steps are then used to make decision regarding protection. Various methods of fault detection have been proposed based on one terminal and two terminal methods. For fault detection and location, PMU synchronized measurements have been used in recent years [2], [3]. Most of these techniques use only local fault data. Also accuracy of one terminal and two terminal method of fault location are affected by fault resistance. Chih. Wen Liu et al. [9] have proposed fault detection for N terminal transmission lines. It works for any type of transmission line, but it needs to calculate (N-1) indices which increase the computational complexity. A method of fault detection and fault location based on eigen value and eigen vector is proposed in [4]. This technique calculates the line parameter on-line under the actual power system condition, and it detects the fault accurately. But it only considers the parallel transmission line. Kai-Ping Lien et al. [7] proposed a fault location scheme for transmission network. This scheme is based on the Gauss-Seidel numerical method. In this initial value of the variable is based on assumption. Y. Liao [10] has used voltage measurement for fault location, but this technique is used only for single circuit line. Also S.Brahma [6] uses voltage measurement for multi-terminal transmission line but does not consider power source impedance. According to Di Shi et al. [13], PMU data are expected to be highly accurate. However, this accuracy is not always achieved in actual field installations because it has been observed that in some PMU measurements, the voltage and current phasors are corrupted by noise and bias errors. Multiple measurements with linear regression (MMLR), is used for online calculation of transmission line parameter [15]. Chun Wang used synchronized fault voltages of two nodes of the faulted line and their neighboring nodes for fault location [8]. T.G. Bolandi et al. have given the concept of differential impedance based pilot relaying scheme, but they did not consider CT saturation effect on their study [18].

1.3 Objective of dissertation work

The dissertation work involves:

- Classification of the type of fault that occurs in transmission line. Different types of faults are: LL fault, LG fault, LLG fault and LLLG fault.
- The accuracy of classification of different fault types is then obtained using Naïve Bayes classifier

1.4 Organization of dissertation work

The work in this dissertation is organised in seven chapters.

CHAPTER 1 includes details about different types of techniques used for protection of transmission lines and literature survey.

CHAPTER 2 introduces PMU, its components, its purpose and its importance in protection philosophy.

CHAPTER 3 includes System modelling and simulation methodology. Modelling of 8 bus system has been carried out and various types of faults have been simulated by varying fault parameters.

CHAPTER 4 then describes Naïve Bayes classifier and the algorithm used for fault detection Naive Bayes classifier has been applied to classify faults on transmission line.

CHAPTER 5 gives the results of classification. By using 50% data for training highest accuracy of the order of 93% has been obtained.

CHAPTER 6 concludes the work done so far and and the future work that can been done has been discussed in CHAPTER 7.

CHAPTER 2

PHASOR MEASURMENT UNIT

2.1 Introduction

Phasor measurement unit (PMU) measures voltage and current on an electricity grid using Global Positioning System (GPS) for synchronization. Currents and voltages are taken from many feeders and buses at the substation. Phasors of currents and voltages are calculated using DFT technique. All PMU measurements are tagged with time in microseconds using Global Positioning System (GPS). The time stamped phasor is transmitted to a local or remote receiver in a file format defined in IEEE standard. Phasor Data Concentrator (PDC), its function is to collect data from several PMU, reject bad data, align time stamped data and create a coherent record of simultaneously recorded data from wider part of the power system. The next level of hierarchy is Super Data Concentrator (SDC). Its function is similar to PDC. It collects data from several PDC.

Block Diagram of PMU

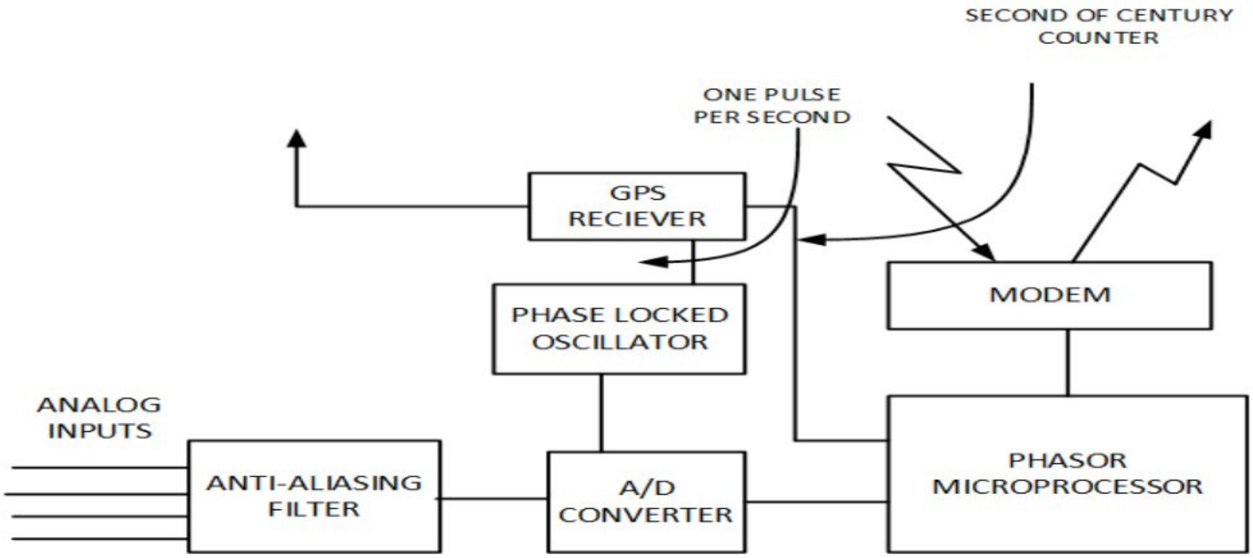


Figure 2.1[1] General block diagram of PMU

General block diagram of PMU is shown in figure 2.1. The analog current and voltage signal taken from current transformer and potential transformer respectively is fed to the anti-aliasing filter. The cut-off frequency for the filter should be less than half the sampling frequency. The sampling clock is synchronized with GPS clock pulse. A/D converter is used to sample the analog current and voltage signal. The sequence phasors of current and voltage are calculated by the microprocessor. The calculated phasors is then sent to the remote receivers by using communication channel.

Communication options for PMU

Phasor data is required to transfer from PMU to PDC or from PDC to SDC. A communication medium is required for this purpose. The type of communication medium can be used for data transfer depends upon type of data to be transferred, distance and latency.

Communication medium available are as follows:

- Leased telephone circuit
- Switched telephone circuit
- Power carrier line
- Fiber optics

Global positioning system (GPS)

The GPS satellites provide one pulse per second signal. The pulse is identified by the number of seconds since the time the clock began to count i.e. January 6, 1980. PMU standard uses UNIX time base with a “second of century” (SOC) counter which began counting at midnight on january 1, 1970.

File structure of PMU

Four types of file are defined by synchrophasor standard for data transmission. These are as follows:

i. Header files
ii. Configuration files
iii. Data files
iv. Command files

The first word of 2 bytes is for synchronization of the data transfer. The second word defines the size of total record, the third word identifies the data originator, and the next two words provide the "second of century" (SOC) and the "fraction of second" (FRACSEC) at which the data is being reported. The length of data words which follow FRACSEC depends upon the specifications provided in the configuration file. The last word is the check sum to help determine any errors in transmission.

2.2 Purpose of using PMU

Nowadays, interest has increased in the wide area monitoring, control and disturbance analysis, minimization of blackouts happened due to cascade tripping so there is growing interest in the microprocessor based relays. Phasor measurement unit is being used for this purpose. Power system state can be monitored in real time. With the help of PMU data, the sequence of events that causes blackout can be determined since the phasors which are received from PMU are time stamped using GPS. Time stamped phasor data is collected from various places at central location, so wide area can be monitored simultaneously. Power system state can be estimated precisely at frequent intervals, which enable dynamic phenomena to be observed from a central location. Appropriate actions are taken accordingly.

CHAPTER 3

SYSTEM MODELLING AND SIMULATION

3.1 System Modelling

3.1.1 Introduction

A 3 phase, 345kV transmission network system is considered in this work [7]. The system consists of eight transmission lines and eight buses. The transmission lines are modelled with distributed parameters. The RTDS/RSCAD simulator is used to model the system and generate fault data to test the performance of the proposed algorithm. Three PMUs are placed on buses 2, 4, and 7 in the sample system. The parameters of the simulated system are given in Table 3.1.

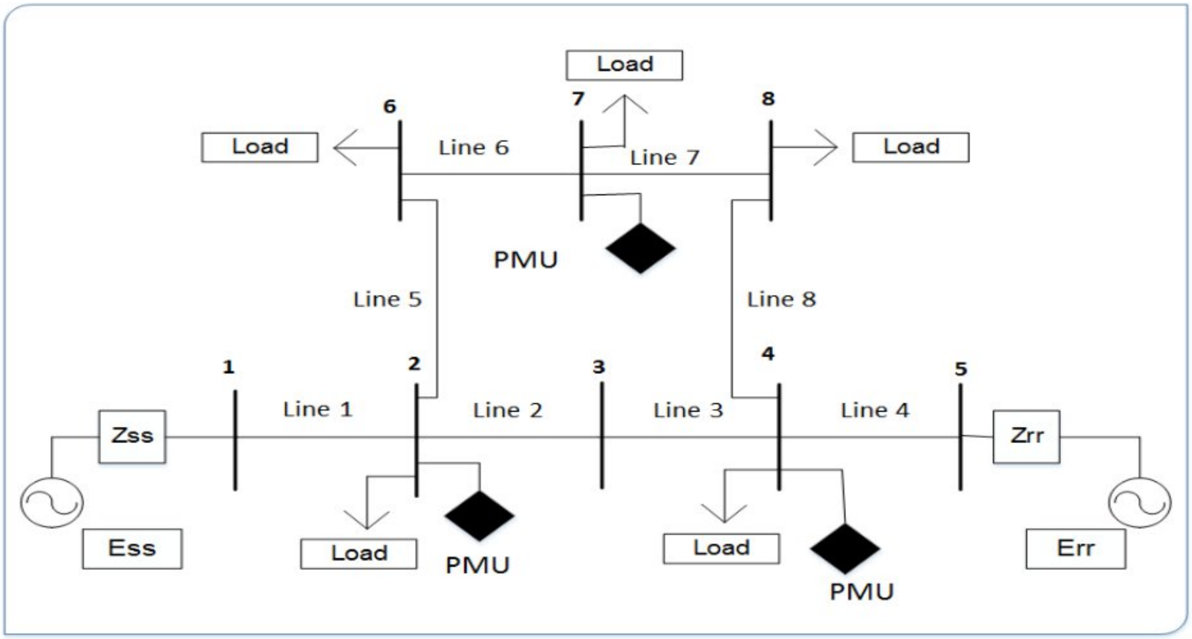


Figure 3.1 Sample network for simulation

3.1.2 Placement of PMU

- PMUs are placed on the buses with largest number of connected branches and with the second largest number of connected branches.
- Every two PMUs are spaced by one bus.
- Redundant PMUs are removed. .

TABLE 3.1 System Parameters

System voltage 345kV	System frequency 50Hz	
Source		
Ess=1.0<20° p.u. Zss1=0.238+j4.767 ohms Zss0=2.738+j10 ohms	Err=1.0<0° p.u. Zrr1=0.26+j5.458 ohms Zrr0=1.96+j6.925 ohms	
Transmission line parameter		
Line 2(100km), Line 7(100km)		
R1=0.0275(Ω/km) R0= 0.275(Ω/km)	C1=9.483(nF/km) C0=6.711(nF/km)	L1=1.345(mH/km) L0=3.725(mH/km)
Line 3 (100km), Line 8 (100km)		
R1=0.0385(Ω/km) R0= 0.4175(Ω/km)	C1=38(nF/km) C0=22(nF/km)	L1=0.5676(mH/km) L0=1.644(mH/km)
Line 1(50km), Line 4(80km), Line 5(100km), Line 6(100km)		
R1=0.0321(Ω/km) R0= 0.3479(Ω/km)	C1=38(nF/km) C0=22(nF/km)	L1=0.473(mH/km) L0=1.37(mH/km)
Load		
30 MW+ 20 MVar		

3.2 Simulation Methodology

3.2.1 Line classification

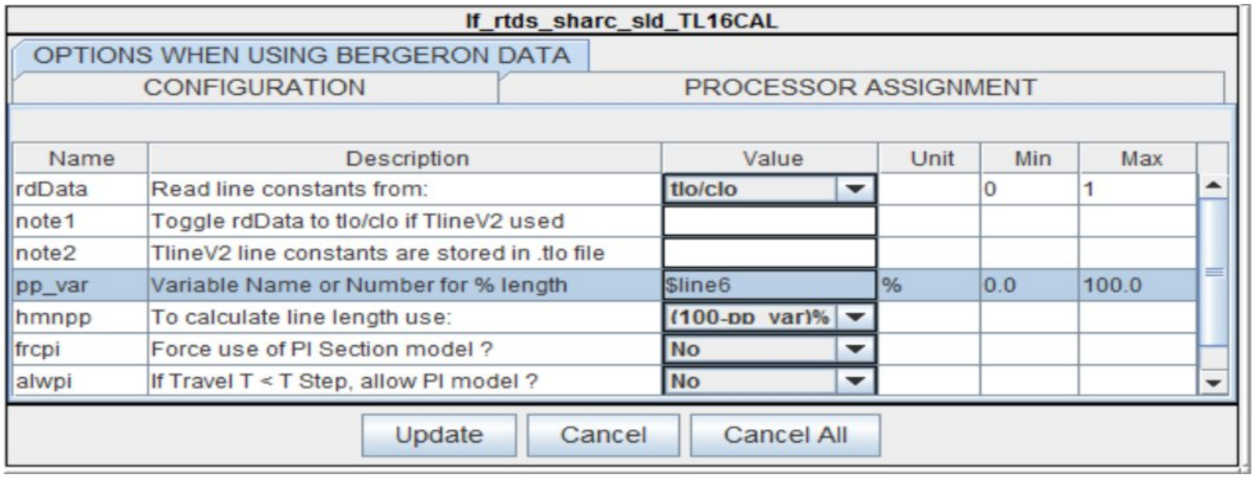
To classify the line in which fault has occurred, different types of fault has been created in two lines of the 8 bus-8-line transmission network. The line chosen for this purpose is line 2 and line 6. The line to ground fault (LG), line to line fault (LL) and three phase fault (LLLG) has been created on two lines of the simulation system by varying fault resistances and locations of fault. It has considered four different fault resistances. The way system parameter has been varied is described as follows:

- Fault locations (L): 20%, 50%, and 75%
- Fault resistances (R_f): 0.1, 10,30, and 50 ohms
- Fault types (F-type): AG, BG,CG,AB,BC,CA,ABCG
- Tested lines: Line 2 and Line 6

ABCG fault created at three different fault locations of each line and fault resistance considered is 50 ohms. Here, positive sequence current from each PMU is considered.

Total of 3(L) × 4(R_f) × 6(F-type) × 2(Tested lines)=144 cases has been created. For ABCG fault there a total of 6 cases have been created. So a total sum of 150 cases has been generated.

To create a fault at different location in transmission line a draft variable is used. A variable name is given to the draft variable as "$line6". Highlighted line in the figure 3.2 shows the variable name. In runtime, with the use of slider, length can be changed

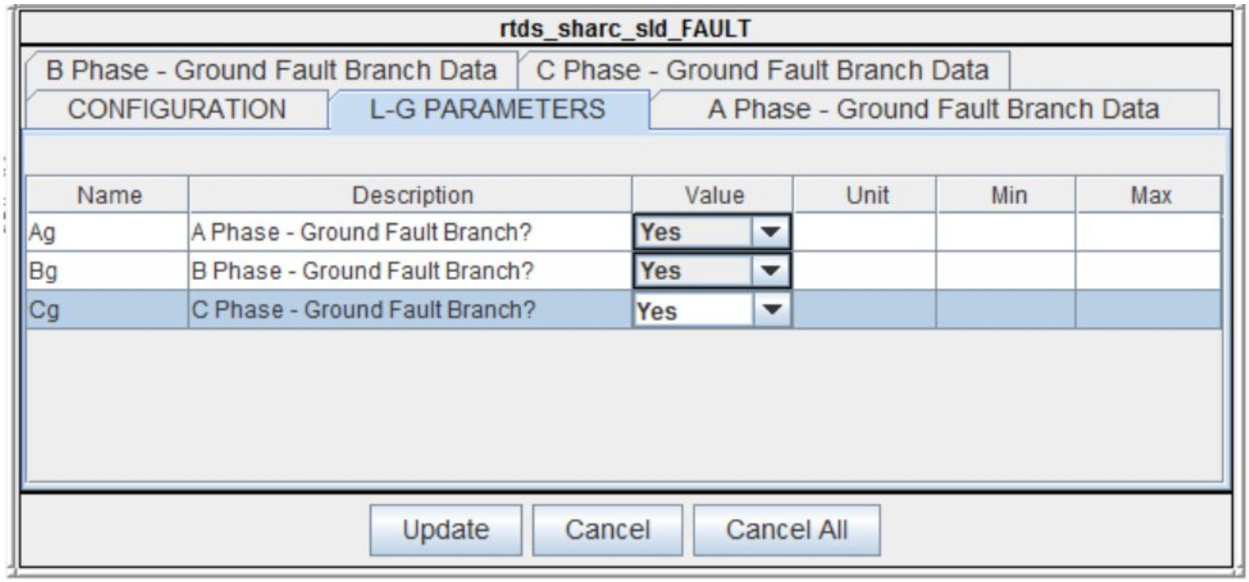


Name	Description	Value	Unit	Min	Max
rdData	Read line constants from:	tlo/clo		0	1
note1	Toggle rdData to tlo/clo if TlineV2 used				
note2	TlineV2 line constants are stored in .tlo file				
pp_var	Variable Name or Number for % length	$line6	%	0.0	100.0
hmnpp	To calculate line length use:	(100-pp_var)%			
frcpi	Force use of PI Section model ?	No			
alwpi	If Travel T < T Step, allow PI model ?	No			

Figure 3.2 Transmission line calculation block

Similarly, to change the fault resistance a draft variable is assigned to it and it also can be changed in runtime using slider.

For selection of different types of fault, fault block is used as shown in figure 3.3.



Name	Description	Value	Unit	Min	Max
Ag	A Phase - Ground Fault Branch?	Yes			
Bg	B Phase - Ground Fault Branch?	Yes			
Cg	C Phase - Ground Fault Branch?	Yes			

Figure 3.3 Fault block

To select any type of fault, ‘yes’ is chosen otherwise it is selected as ‘no’. To create AG fault only select ‘yes’ for AG and ‘no’ for BG and CG. In runtime fault is created by using push button. Duration of fault has been taken 0.1 sec.

3.2.2 Fault type classification

System parameters are varied to acquire many fault cases on line 2 of length 100km of the simulation system. The parameters include fault location (L), fault resistance (R_f), fault inception angle (FIA) and fault type (F-type). The parameter is varied in the following manner as:

- Fault locations: 20%,35%,50%, 65% and 80%
- Fault resistances: 0.1,10.0,30.0,50.0,75.0 and 100.0 ohms
- Fault inception angle: 0°,30°,45°,90°,120°,135°,180°,200°,250°,270°
- Fault types: AG, BG,CG,AB,BC,CA,ABG,BCG,CAG,ABCG
- Tested lines: Line 2

Total of 5(L) × 6(R_f) × 10 (FIA) × 10(F-type) =3000 fault cases have been generated.

To generate these many cases, script is used. It is available in runtime menu. A C- like programming has been written in the script file to run the fault controller.

Transmission line network of 8 buses and 8 lines as drawn in draft of RTDS/RSCAD software is shown in the figure3.4 and figure3.5 respectively.

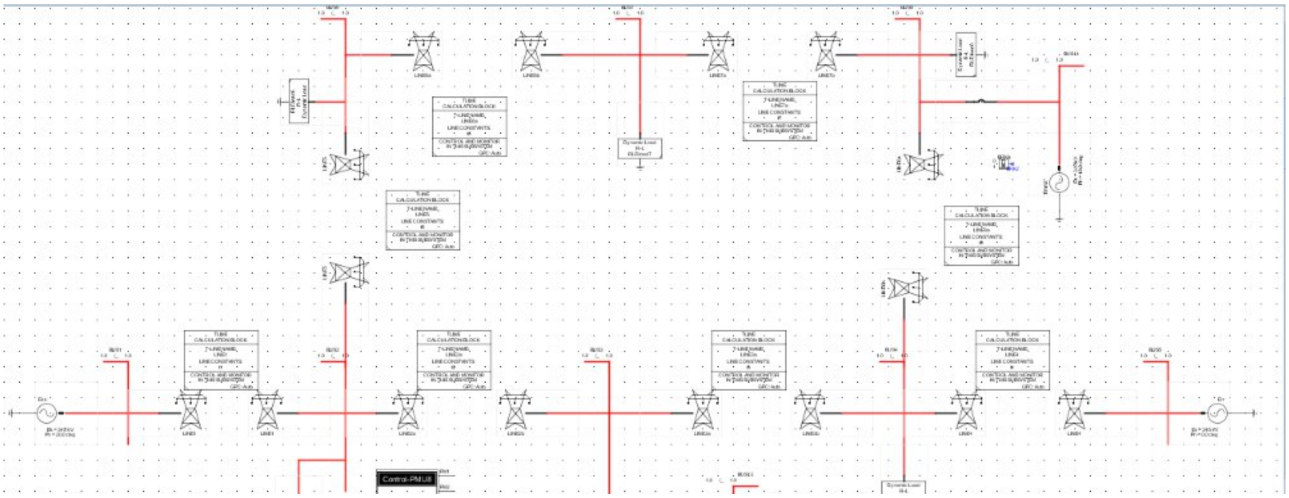


Figure 3.4 Circuit diagram of eight bus system (draft 1)

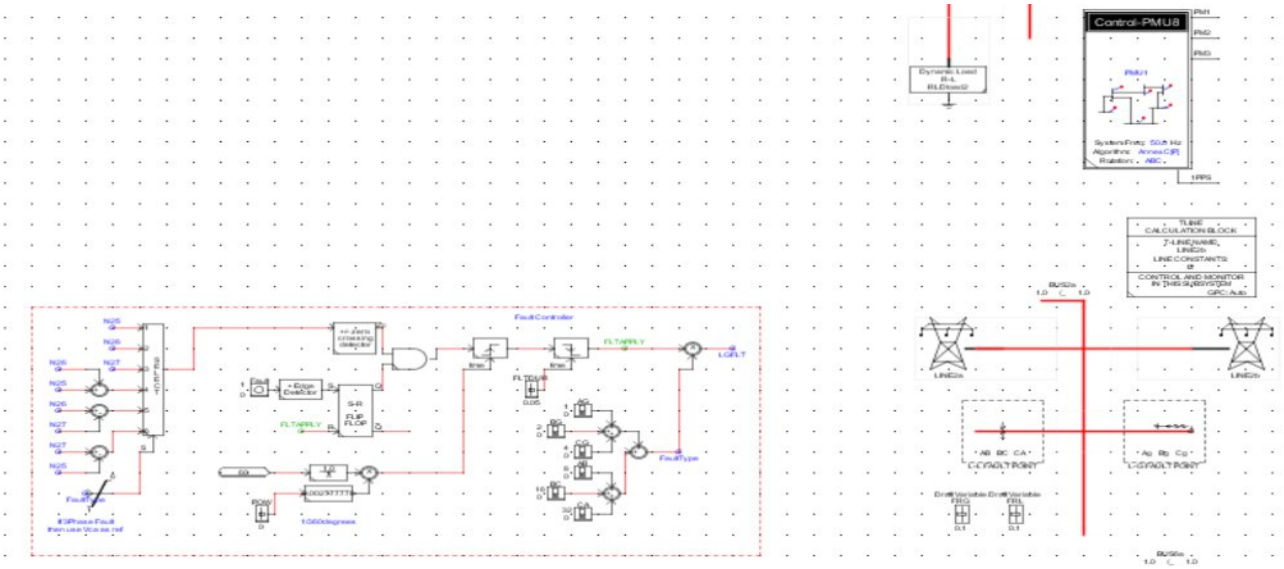


Figure 3.5 Circuit diagram of eight bus system (draft 2)

Fault controller

Fault controller as shown in the figure 3.6 is drawn in the draft of RTDS software. It is used to control the fault in runtime. It controls the type of fault, fault duration, fault inception angle etc. The control variable POW is used to control the angle in the runtime. “Select” block select the node voltage corresponding to the fault type. Push button named Fault is used to create fault. When push button is pressed then output is “1” and fault generated, after releasing it output becomes “0”. Here fault duration 0.05 sec is considered.

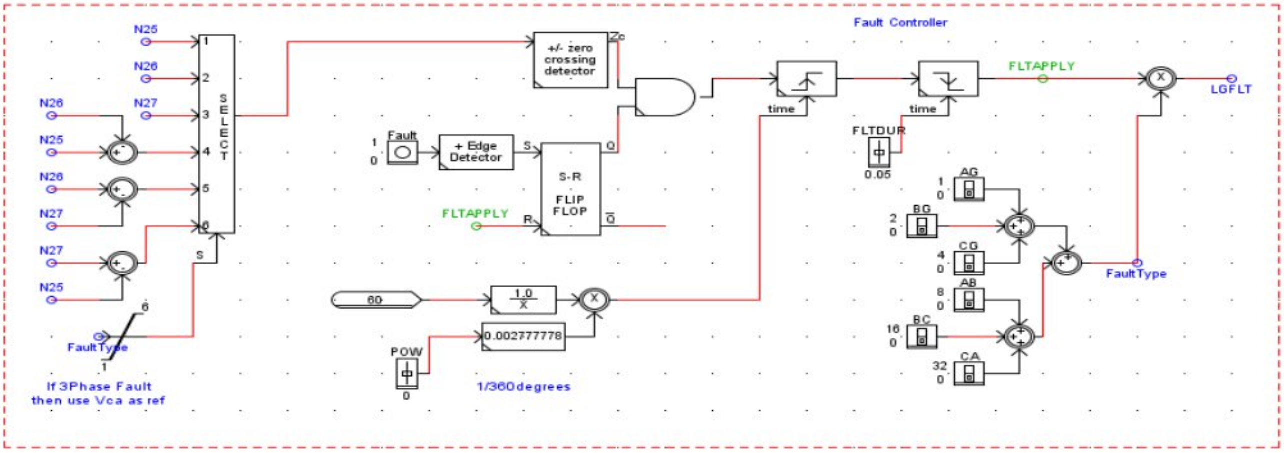
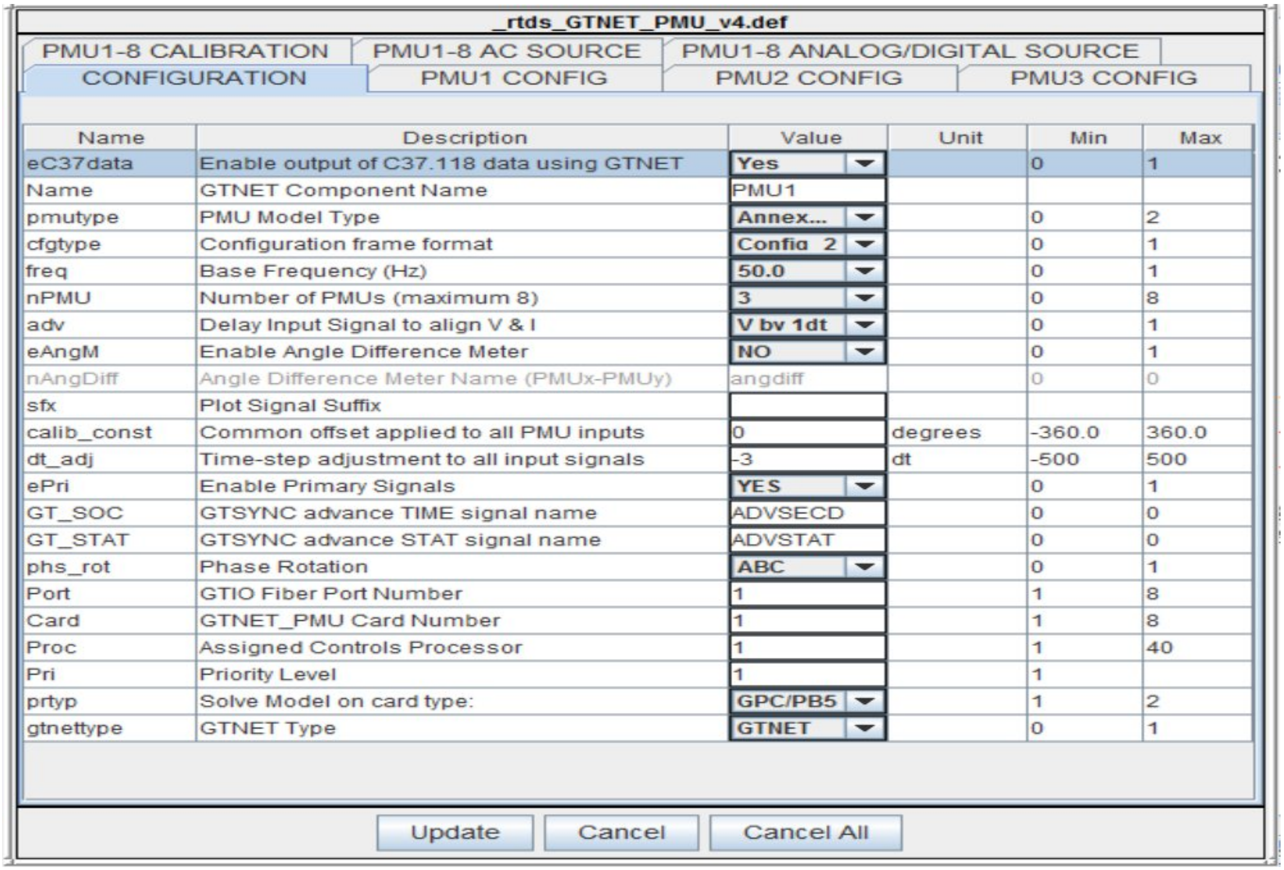


Figure 3.6 Fault controller

3.2.3 PMU in RTDS

PMU is used to collect fault data in line 2 of the given simulation system. Current and voltage is given as input to the PMU. For PMU 1, voltage signal is given as input from node voltages N4, N5 and N6 at bus 2 and current signals that are in the line 2 as CRT1SE, CRT2SE and CRT3SE for phase A, B and C respectively. Similarly, for PMU 2 voltage signal is fed from node voltages N10, N11 and N12 at bus 4 and current signals are CRT4ASE, CRT4BSE and CRT4CSE for A, B and C phase respectively.

One component of GTNET-PMU includes 8 PMUs. Each PMU work independently. Each PMU provides a total of 12 phasors that includes all the three phase voltage and current and their sequence components (voltage and current) in form of either magnitude and angle or real and imaginary. In this work, output has been taken in the form of magnitude and angle. PMU configuration is shown in the figure 3.7.



Name	Description	Value	Unit	Min	Max
eC37data	Enable output of C37.118 data using GTNET	Yes		0	1
Name	GTNET Component Name	PMU1			
pmutype	PMU Model Type	Annex...		0	2
cfgtype	Configuration frame format	Config 2		0	1
freq	Base Frequency (Hz)	50.0		0	1
nPMU	Number of PMUs (maximum 8)	3		0	8
adv	Delay Input Signal to align V & I	V by 1dt		0	1
eAngM	Enable Angle Difference Meter	NO		0	1
nAngDiff	Angle Difference Meter Name (PMUx-PMUy)	angdiff		0	0
sfx	Plot Signal Suffix				
calib_const	Common offset applied to all PMU inputs	0	degrees	-360.0	360.0
dt_adj	Time-step adjustment to all input signals	-3	dt	-500	500
ePri	Enable Primary Signals	YES		0	1
GT_SOC	GTSYNC advance TIME signal name	ADVSECD		0	0
GT_STAT	GTSYNC advance STAT signal name	ADVSTAT		0	0
phs_rot	Phase Rotation	ABC		0	1
Port	GTIO Fiber Port Number	1		1	8
Card	GTNET_PMU Card Number	1		1	8
Proc	Assigned Controls Processor	1		1	40
Pri	Priority Level	1		1	
prtyp	Solve Model on card type:	GPC/PB5		1	2
gtnettype	GTNET Type	GTNET		0	1

Figure 3.7 PMU configuration

The output of PMU is in the form of magnitude and angle. It calculates the RMS value of the signal using DFT technique. For the case of line to ground fault the current signal as shown in figure 3.8 is given as input to the PMU and the output from PMU for the same signal is shown in the figure 3.9.

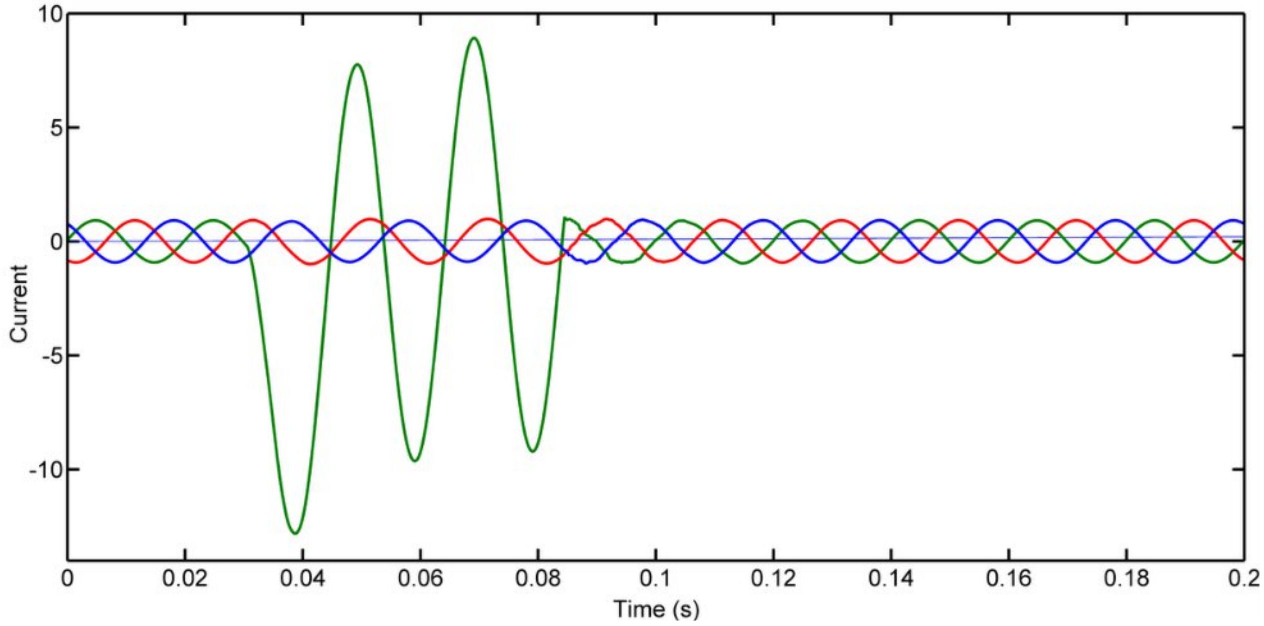


Figure 3.8 Line Current for LG fault

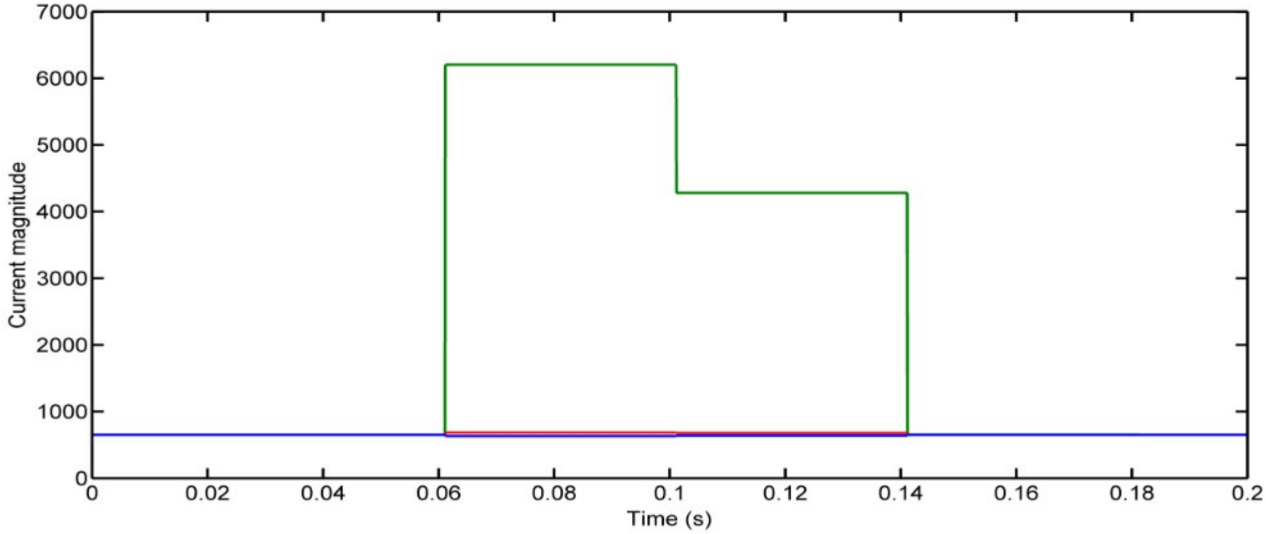


Figure 3.9 PMU output for LG fault

Similarly, for line to line fault output of PMU and line current is shown in figure 3.10 and figure 3.11.

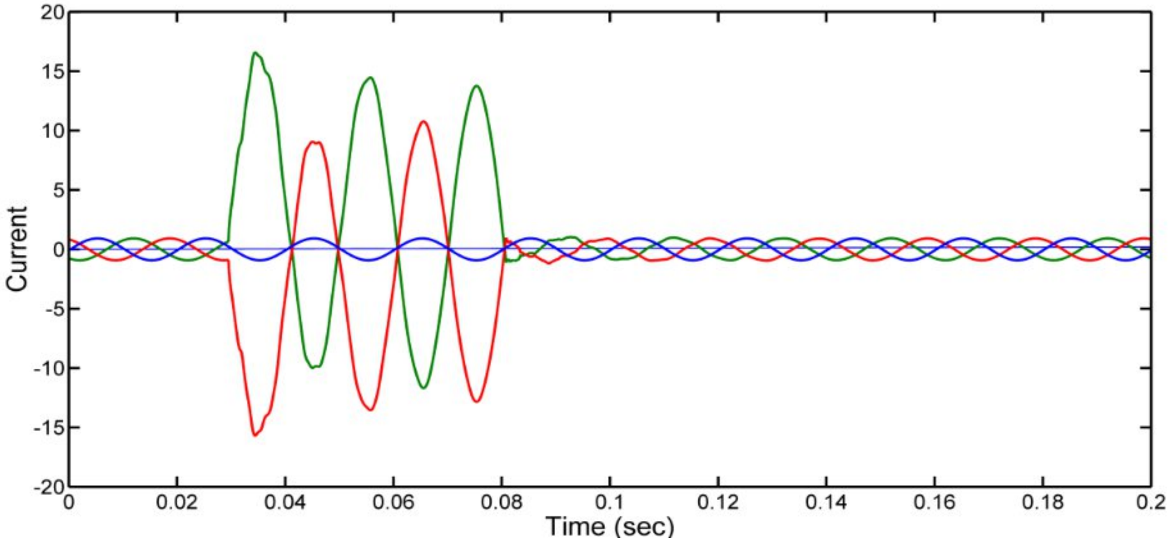


Figure 3.10 Line current for LL fault

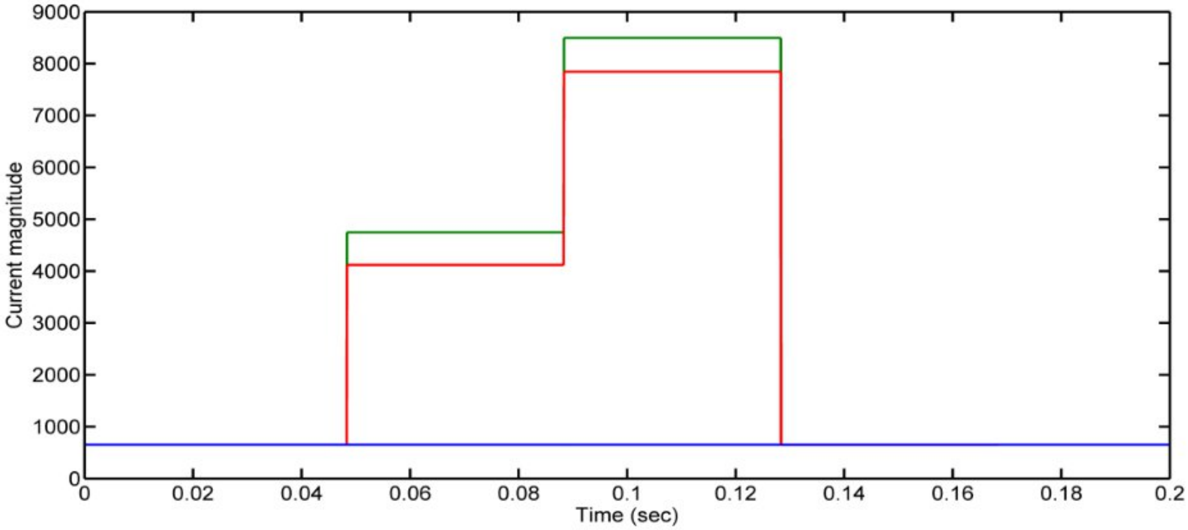


Figure 3.11 PMU output for LL fault

For three phase fault, the line current and PMU output is shown in figure 13 and figure 14 respectively. In case of three phase fault, all the phase current has almost equal maximum value at the same time.

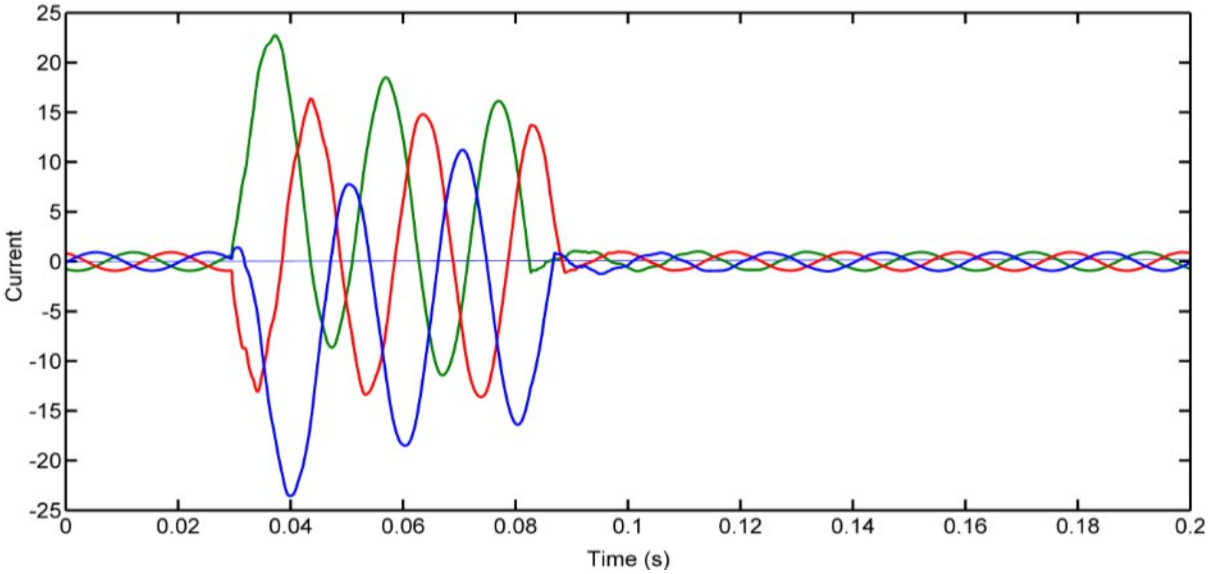


Figure 3.12 Three Phase Line Current

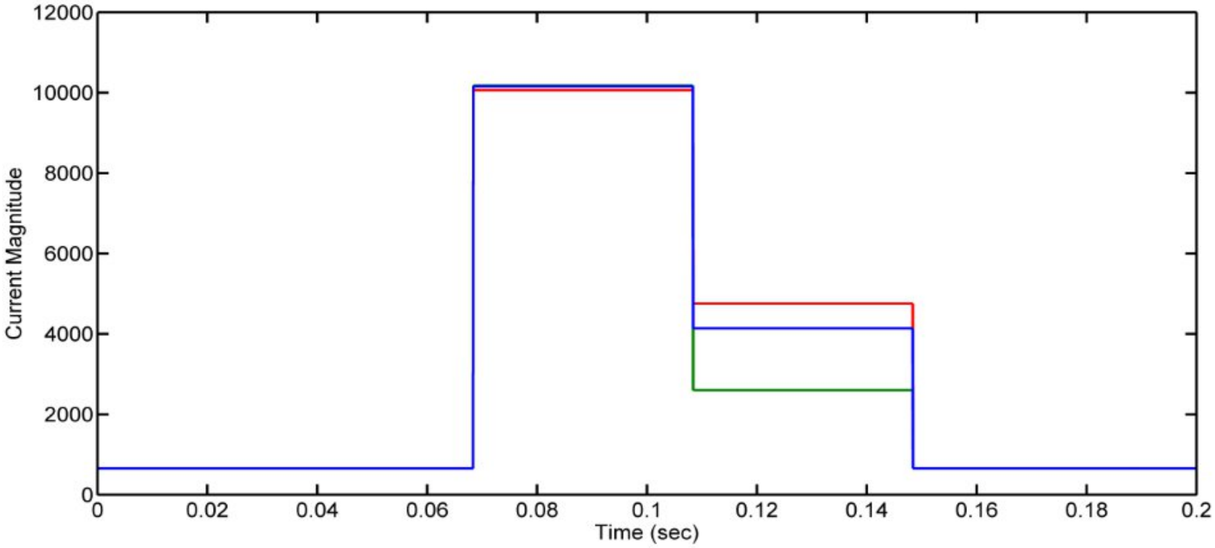


Figure 3.13 PMU output for three phase fault

CHAPTER 4

FAULT CLASSIFICATION USING NAIVE BAYES CLASSIFIER

4.1 Naive Bayes classifier

Naive Bayes Classifier is based on Bayes' theorem with strong assumption, that the features are independent of each other. It is easy to implement and fast since the naive assumption of class conditional independence reduces its computational cost.

X= $\{x_1, x_2, x_3, \ldots, x_n\}$ be a case from a dataset, whose feature values made on a set of n attributes. Let H be some hypothesis, such that the data X belongs to a specific class C_i i.e. $H = X \in C_i$. In Naive Bayesian classification, we calculate the probability that sample X belongs to class C_i, given that we know the feature values of X.

By Bayes' Theorem,

$$P\left(\frac{H}{X}\right) = \frac{P(H)\,P\left(\frac{X}{H}\right)}{P(X)} \tag{4.1}$$

Where,

$P\left(\frac{H}{X}\right)$ = Posterior Probability

$P(H)$ = Prior Probability

$P\left(\frac{X}{H}\right)$ = Likelihood

$P(X)$ = Evidence

$$P(X \in C_i | x_1, x_2, x_3, \ldots, x_n) = \frac{P(C_i)(x_1, x_2, x_3, \ldots, x_n | C_i)}{P(x_1, x_2, x_3, \ldots, x_n)} \tag{4.2}$$

It can be written as,

$$\text{Posterior Probability} = \frac{\text{Prior Probability} \times \text{Likelihood}}{\text{Evidence}} \tag{4.3}$$

The evidence part is constant if the values of the feature values are known and final Posterior Probability becomes as

Posterior Probability =Prior Probability × Likelihood (4.4)

$$=P(C_i)P(X/C_i)$$

By conditional probability theory and conditional independent assumption, the above equation can be written as

Posterior Probability$=P(C_i)P(x_1/C_i)P(x_2/C_i)P(x_3/C_i)\ldots\ldots$

$$=P(C_i)\prod_{k=1}^{n} P(x_k/C_i) \tag{4.5}$$

The equation (4.5) is used to calculate probability of each class given X.

The classifier then assigns the X to the class with the highest probability.

The classifier works in two steps:

- Training step: Use the training samples to estimate the parameters of a probability distribution, assuming features are conditionally independent given the class.
- Prediction step: For any unseen test sample the method computes the posterior probability of that sample belonging to each class. The method then classifies the test sample according to the largest posterior probability.

In the training step, it calculates the mean and standard deviation of each feature in the given class. Then it calculates the Gaussian probability using the formula given in equation 4.6

$$g(x,\mu,\sigma)=\frac{1}{\sqrt{2\pi\sigma}}\,e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{4.6}$$

Where, g= Gaussian probability

μ= mean,

σ= standard deviation

4.2 Fault classification algorithm

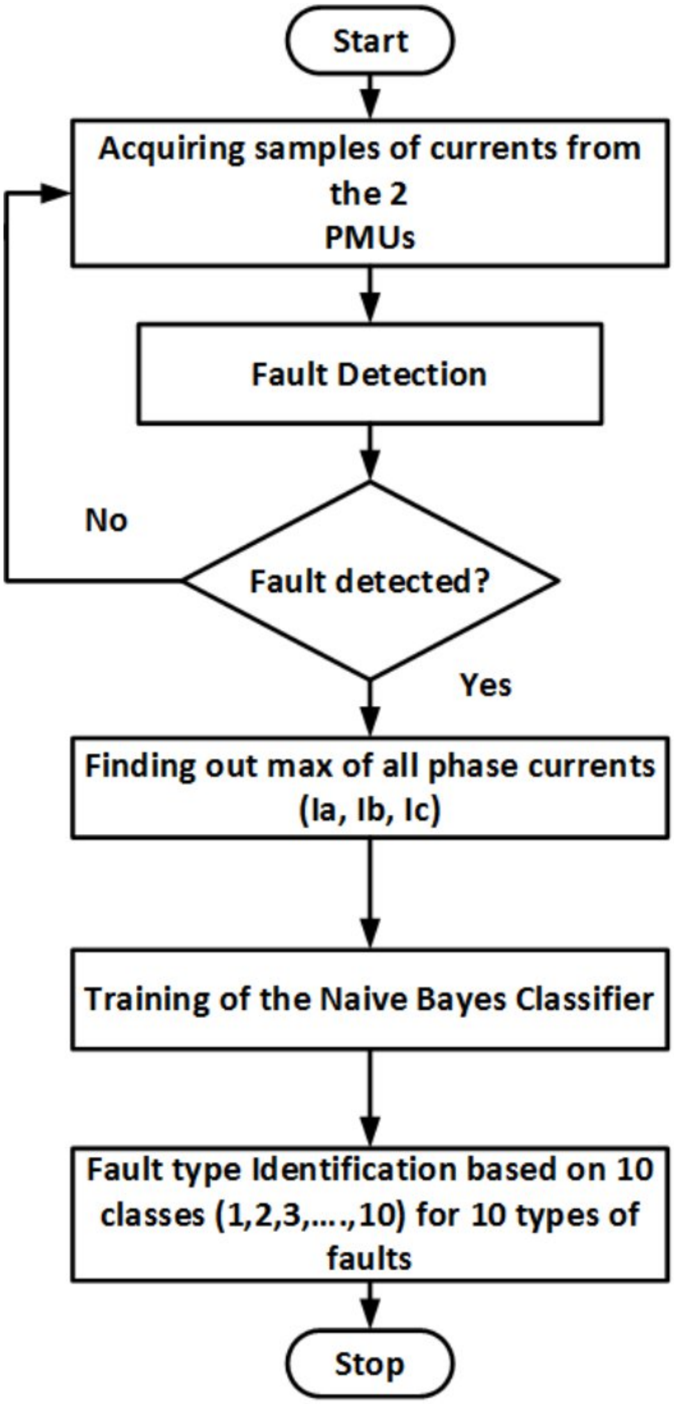


Fig 4.1 Algorithm of the technique

The algorithm of the proposed technique is shown above. Samples of current signals are acquired from the PMU 1 and PMU 2. The fault detection is used to discriminate between healthy and fault condition. Whenever a fault is detected, maximum of all the phase currents (I_a, I_b, I_c) are found out. These data are then sent to the Naïve Bayes classifier. Proper training of the classifier is carried out using 50 % of the simulated data. Main advantages associated with this classifier is that it is fast and space efficient. After the training process is completed, rest of the data available is used for testing. The Naïve Bayes finds out the probability of the previously unseen instance belonging to each class, then simply picks up the most probable class accordingly. The classifier is trained to classify 10 classes for 10 types of faults which include 3 line to ground faults, 3 types of double line faults, 3 double line to ground faults and LLLG faults. For example, if the classifier outputs class '1', it is case of AG fault and class '10' would mean three phase to ground fault.

CHAPTER 5

RESULTS AND DISCUSSIONS

Fault is created at different location of line 2 of the transmission network with various fault resistances and fault inception angle. The fault data obtained is first trained in NB classifier using 50% of the data since, 50% training and 50% testing gives better accuracy of fault classification. The accuracy of classification of fault is shown in the table 5.1.

Table 5.1 classification accuracy

Types of fault	**Accuracy**
AG	89.33%
BG	100
CG	89.33
AB	92
BC	100
CA	89.33
ABG	83.33
BCG	100
CAG	90.67
ABCG	99.33

Figure 5.1 Bar representation of accuracy of classification with 30% of training data

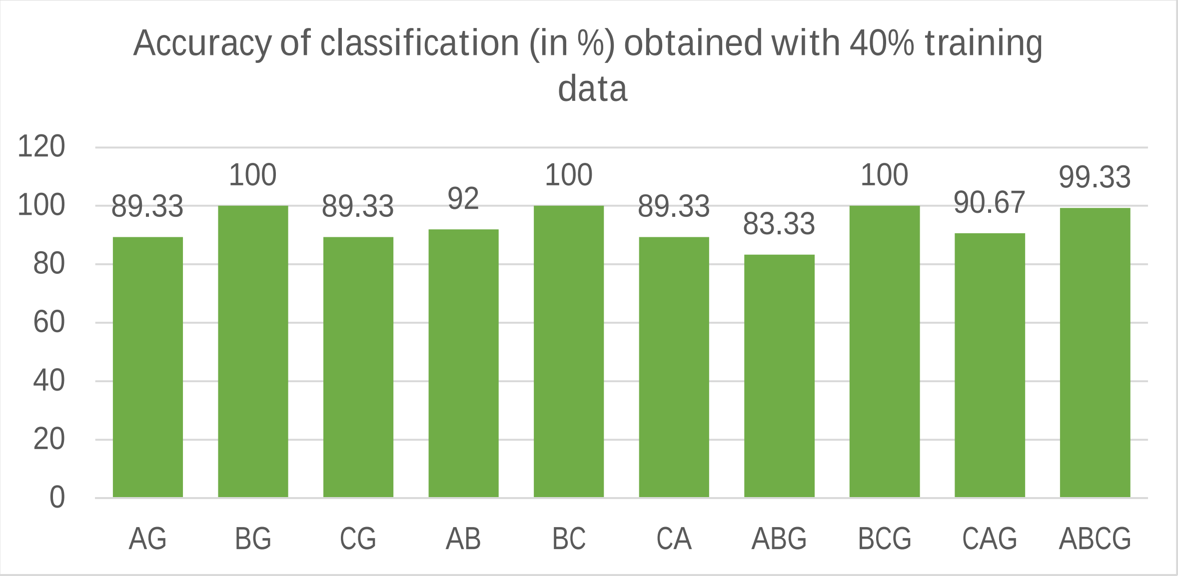


Figure 5.2 Bar representation of accuracy of classification with 40% of training data

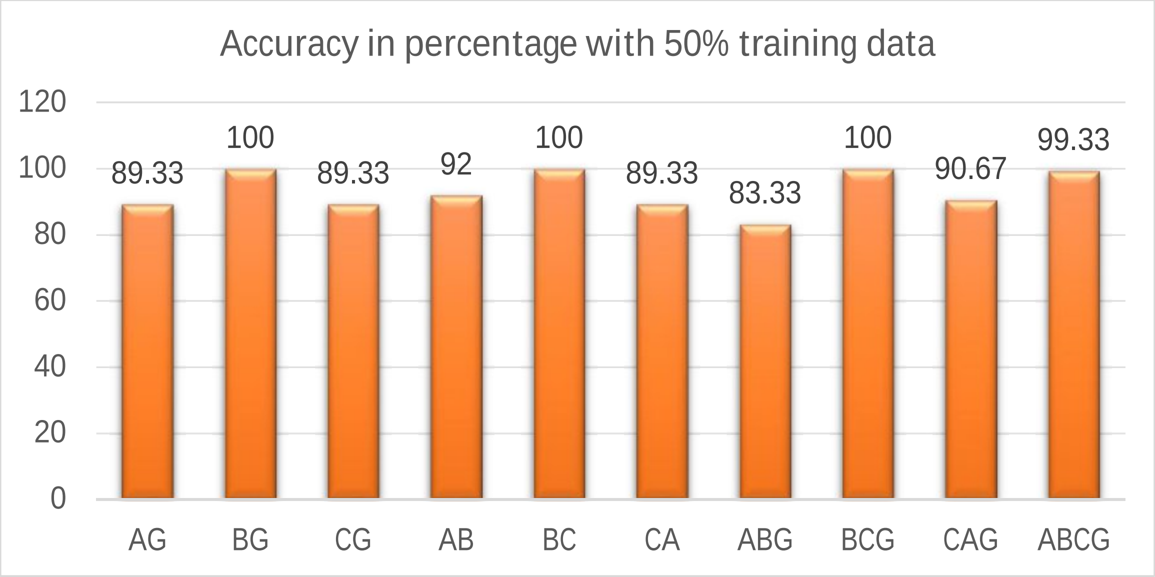


Figure 5.3 Bar representation of accuracy of classification with 50% of training data

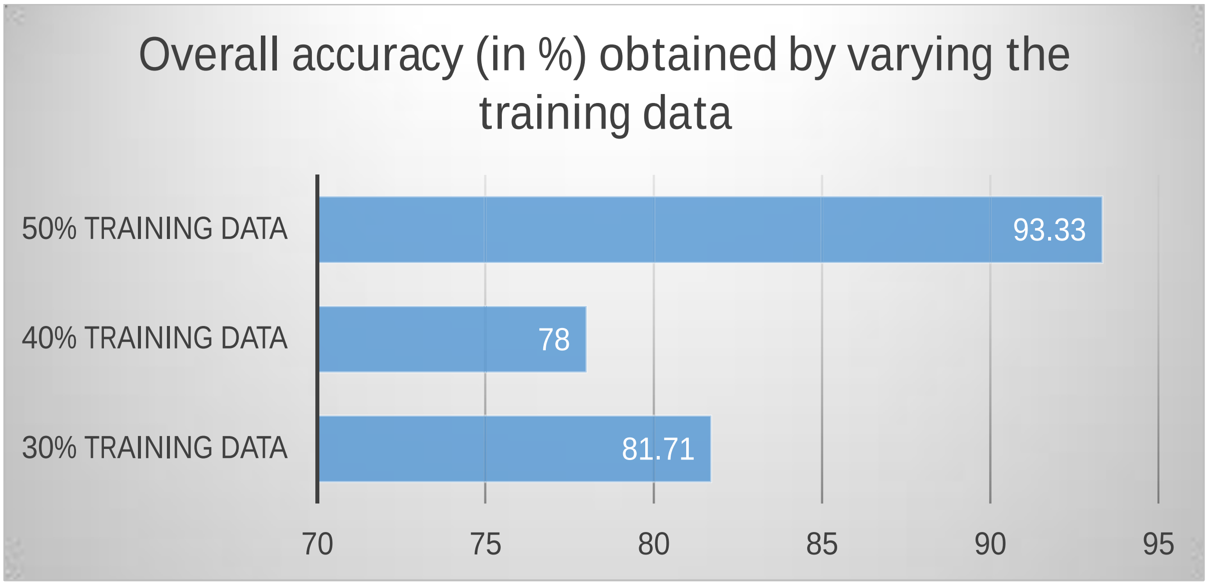


Figure 5.4 Bar representation of overall accuracy of classification

Training has been performed using 30% of data, 40% of data and 50% of the available data. Accuracy of fault classification has been presented in the above bar charts. Furthermore, the overall accuracy or the average accuracy of the 10 classes has been found out and has been presented in the bar chart. As can be seen form the bar chart maximum accuracy has been observed by using 50% of the data for training and 50% for testing.

CHAPTER 6

CONCLUSION

Here Naïve Bayes classifier which is based on Bayes conditional probability theorem is used to classify 10 different types of fault. Various fault cases have been generated by changing parameters of the 8 bus-8 lines transmission network. A total of 3000 cases have been generated by varying fault resistance, location of fault, fault inception angle and types of fault. A total of 50% cases i.e. 1500 is taken to train the NB classifier, and remaining 1500 cases is used for testing.

NB classifier classifies the different fault type efficiently with an overall accuracy of 93.33%. It can classify more than 2 types of class accurately. Here 10 types of fault is classified. For some types of fault, it classifies with an accuracy of 100% as for example for BG, BC and BCG. Three phase fault is classified with an accuracy of 99.33%. For other fault cases accuracy is around 89.33%.

It also classifies the line in which fault has occurred very accurately. The accuracy of line classification is 97.14% for line 2 and 85% for line 6.

So, Naïve Bayes classifier is found to be very simple to implement, and gives better accuracy.

CHAPTER 7

FUTURE WORK

- Data obtained from PMU can be classified using some other machine learning technique which can give better accuracy in fault type classification.
- Using data obtained from PMU, we can detect exact fault location with increased accuracy and minimum fault clearing time.

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