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**Regular paper**

# Fault Analysis of Microgrid With Grid-Connected and Islanded mode Using IoT-Wavelet Approach

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*Now a days microgrid is one of the most widely used method in power network to reduce system losses as well as improve the reliability in the field of electrical systems. Integration of power projects typically involves adding new distributed energy sources with and without compensating devices to an existing power system network. It is essential to design new protection scheme due to changes in the topology and dynamic behavior of the system. Now fast fault detection algorithmic approaches are necessary to integrate different types of generating sources and loads under smart environment. The protection scheme must provide physical monitoring as well as parametrical with the help of new technologies. Internet-of-things(IoT) is one of the source to monitor electrical systems under various environmental conditions of the system. Wavelet (WT) basically investigates the fault transient signals of different frequency and divides the waveform into different approximate and detailed coefficient values, which provides the important knowledge about the classification and location of fault. The detection of faulty-line and the location of fault by implementation wavelet detailed coefficients of Bior1.5 mother wavelet. This proposed method provides fault analysis of IoT based protection of microgrid with Grid-connected and Islanded Mode Using Wavelet Approach under various types of faults.*

Keywords: Wavelet Transform, Distributed Generation, Fault Detection, Idle mode, Internet of things (IoT).

## 1. Introduction

The task of the power transmission system is to transfer electric power from generating stations to load distribution centres and then consumer premises through substations and other utilities. The electrical power system should serve all its customers and inter connect partners economically and reliably. Transmission lines are transfer bulk amount of power from one location to the other location of the country. The conventional solution approach can be described asupgrading system infrastructure by erecting new lines, substations with associated equipment. Abnormal conditions are detected and prevented by protective relaying scheme and it will operate automatic switching mechanism to clear the fault by isolating faulty equipment from the existing network. The conventional line protection [1] is characterised by the ratio of two input quantities respectively proportional to the voltage and current at particular relay point. The basic measurement of impedance in comparators circuit. Now a day this type of protection may not suitable due to large detection time as well as isolation of faulty element and also it has several drawbacks [2,3] like to unwanted operation during power swings and heavy loading conditions which may leads to tripping stream and spread blackouts. Hence, it is necessary to think about alternative protection instead of distance protection scheme. In [4], now digital communication-based relays to designed for different operating condition of the system is pro- posed to detect the fault in the terminal and zones.

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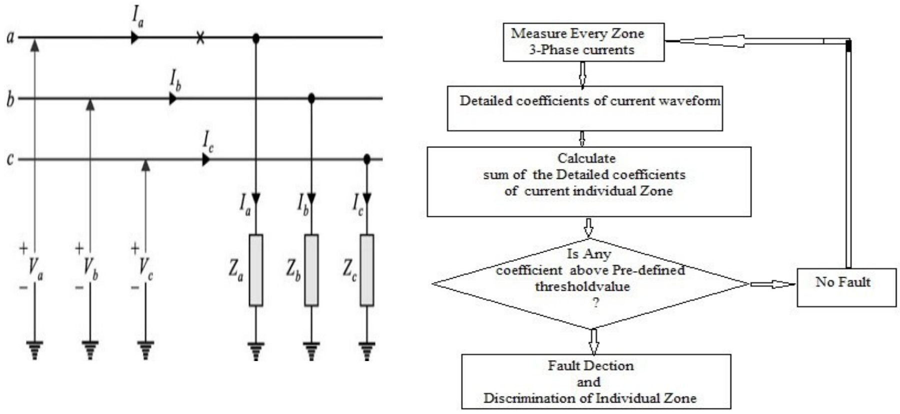
For the benefit of the mechanical protection Internet-of-Things (IoT) has emerged as one of the upcoming technologies for a smart grid network. As the IoT connected power network enable to develop more prominent protection scheme not only electrical as well as mechanical challenges in the existing grid network such as in design, erection commissioning, operation and maintenance [5]. Cyber security [12,13] triggers numerous problems in the system have been addressed and discussed in [6,7] about availability, integrity and confidentiality. Wired communication temporarily solves the problem but it gives problem due to interference communication channels. Few technologies related to broad band, GSM, GPRS ZigBee which cover up to the range of few kilometres due to the lack of data. If embedded IoT in the power system, can use the following communication models and protocols effectively like SCADA, DMS, GIS, CIS, OMS, etc. [8]. The applicable fast and secure communication method is Optical fibre but is very expensive [9]. since these devices are online hence making the smart grid protect to significant attacks.

A micro-grid comprises of three main components which are micro- generators, distribution and different loads. The formation of micro-grid can be Single or multi terminal with $1\varphi/3\varphi$ system and it is connected to low or medium-voltage for distribution of electric power, and can operate under normal and island modes [10]. Micro-grid protection has complicated challenges in design of protection scheme and which can respond main and micro-grid faults. The level of protectionis depending on fault current magnitudes in the system [11,12]. The protection scheme must face the problem comparing with existing power systems is that the fault current flow is unidirectional for radial system, but in the case of micro-grid the current flow is bidirectional flow [13]. The distribute energy sources are frequently used in power sector industry. The selection of protective element is complex due to coordination required between grid side over-current protection and distance protection at transmission line discussed in [14], but these types of systems can capable to suppress challenges of electrical protection system. Considering the available information, a half cycle based moving window average technique for wind source integrated tapped transmission line [15].

Now a day, the system must capable to reduce transient oscillations due to frequently changing loads and protect the system from the faults. The past transmission system is unable to manage the control of load fluctuations and unwanted disturbances. The design of new method not only increase the cost as well as decrease in efficiency, but it also increases the complexity of the system. Therefore, attention is required for the stability and security of the utility grid as well as micro-grid. For the protection of existing system various approaches are investigated and found some of the alternative mechanisms are formulated such as reactive power compensation by installation of power electronics based devices to increase security of the power system. The proposed method requires faster response of power system parameters, reduce power loss and stability improvement.

The protection system can perform two major tasks mainly fault classification and forecast of fault location. Primary importance for discrimination and location of the faulted. This helps to safeguard the connected equipment as well as operating personnel and also immediate restriction of redundant power loss. Mostly unsymmetrical and symmetrical type of faults occur in transmission known as Single-line ground (SLG), Double-line-ground (DLG), Double-line (DL) and Three-phase-ground (TPF) and also open-circuit(OC) faults. classification follows short circuit conditions of different phases: SLG-AG, BG and CG faults, DLG-ABG, BCG and CAG faults, DL-AB, BC and CA faults, LLL & LLLG faults are derived and discussed with figure-1 and figure-2. After getting faults in the system utmost care should be taken for restoration of system stability. The fault detection and location is major task to protect power system components for resuming normal power flow. A micro-grid protection based algorithm is described in [16] with the help of transient current wave form using wavelet detailed coefficients. The proposed research work concentrates on protection analysis of microgrid under grid connected and isolated mode with the help of Iot monitoring and wavelet based multi-Resolution-Analysis (MRA) [17] is used with the calibration of coefficients of Bior-1.5mother-wavelet. Nowadays, the digital relays are working fast as well as accurate detection and isolation of the faulty element when compared to previous methods. The following sections discuss about IoT Based protection of Microgrid with Grid-Connected and Islanded Mode Using Wavelet Approach.



(a) General system (b) Fault Detection Algorithm

Figure 1: General System and fault detection algorithm

## 2. Fault Analysis with symmetrical components

Normally power system network may fall under one-phase, Two-Phase, Three-Phase short circuit faults namely SLG (Single-Line-Ground), DLG(Double-Line-Ground), DL(Double-Line) and 3Phase faults categorised as unsymmetrical and symmetrical faults. The analysis of faulted network can be carried by make use of Positive, Negative and Zero sequence components and their interconnections based on the type of fault in the system. The following steps to consider for the analysis of faults.

1.Draw the single line diagram with fully labelled up to the faulty point with polarity marking and current flow directions.

2.Identify the known boundary conditions of voltage and current with respect to fault.

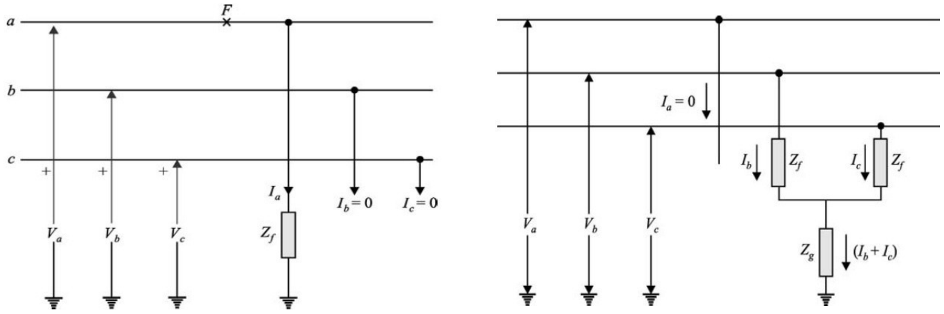
3.Convert voltage and current quantities from phase frame (a-b-c) system to sequence frame (1-2-0).

4.Determine the proper connection of sequence network satisfy the current and voltage relationships.

5.Interconnect sequence network according to the type of fault.

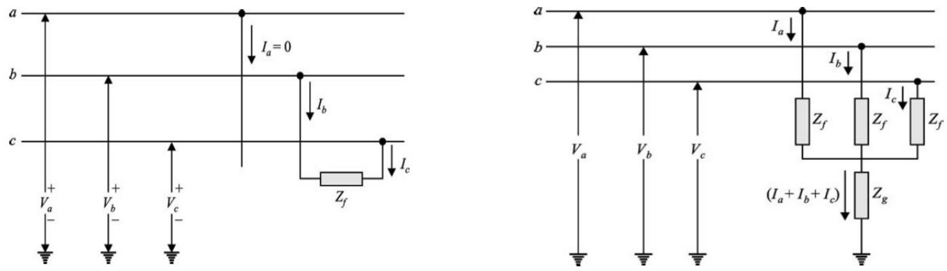
The sequential currents are represented as required phase currents are

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{1}$$



(a) SLG Fault

(b) DLG Fault



(c ) DL Fault

(d) TPG Fault

Figure 2: Line diagram representation of Transmission Fault analysis

### 2.1 Single-Line-to-Ground-Fault

The single-line-fault with proper labelling is illustrated in figure The initial conditions assumedas follows

$$I_b = I_c = 0 \tag{2}$$

$$V_a = Z_f I_a \tag{3}$$

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix} \tag{4}$$

$$I_0 = I_1 = I_2 = \frac{1}{3} I_a \tag{5}$$

$$I_0 = \frac{V_a}{Z_0+Z_1+Z_2+3Z_f} \tag{6}$$

The fault current $I_a$ calculated as

$$\boldsymbol{I_a = 3I_0 = \frac{3V_a}{Z_0+Z_1+Z_2+3Z_f}} \tag{7}$$

**2.2 Line-Line-Fault**

let us consider line-to-line fault is shown in figure
$\boldsymbol{I_b = -I_c}$ and $\boldsymbol{I_a = 0}$ ; $\boldsymbol{V_b - V_c = I_b Z_f}$

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} 0 \\ I_b \\ -I_b \end{bmatrix} \tag{8}$$

The sequence current computed as follows

$$I_{a1} = \frac{V_a}{Z_1+Z_2+Z_f} \tag{9}$$

$$I_b = -I_c = \frac{-j\sqrt{3}V_a}{Z_1+Z_2+Z_f} \tag{10}$$

**2.3 Line-Line-Ground-Fault**

A double line to ground fault is shown in figure. The phase-a current is assumed as $\boldsymbol{I_a = 0}$ and $\boldsymbol{V_b = V_c = (I_b + I_c)Z_f}$

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{11}$$

The fault current is calculated using equation-12

$$I_1 = \frac{V_a}{Z_1 + \frac{Z_2(Z_0+3Z_f)}{Z_2+Z_f+Z_0}} \tag{12}$$

**2.4 Three-Phase-Ground-Fault**

The three phases are short circuited known as symmetrical fault the vector sum of the faultcurrent is zero i.e. $\boldsymbol{I_a + I_b + I_c = 0}$. As the fault is symmetrical

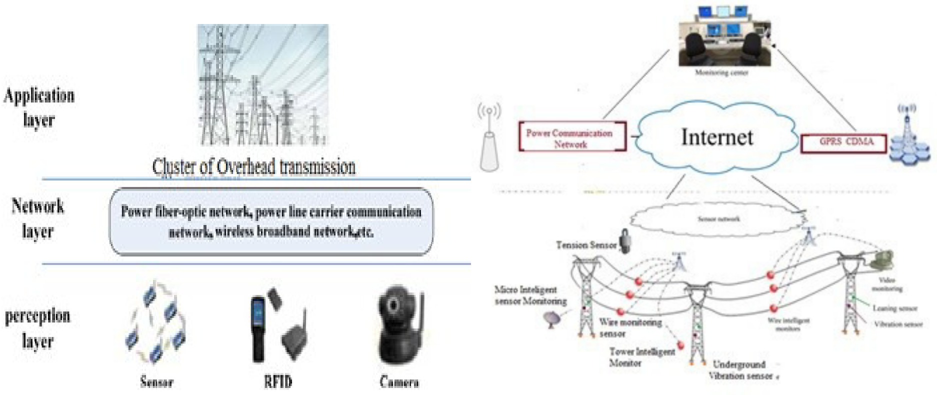
$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{3}\begin{bmatrix} Z_f & 0 & 0 \\ 0 & Z_f & 0 \\ 0 & 0 & Z_f \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{13}$$

The fault currents are calculated as follows

$$I_a = \frac{V_a}{Z_1+Z_f}; I_b = a^2 I_1; I_c = aI_1 \tag{14}$$

## 3. Transmission system protection methods

At present scenario only electrical based protection schemes are not suitable for entire powernetwork. Modern power systems require state-of-art methods to protect physically as well as electrically by the analysis of system performance. The protective system must observe natural calamities and electrical load fluctuations by make the utilisation of IoT application and fault detection algorithms [15]. Internet of Things (IoT) gives the basement for Smart City supports for instance Smart Health, Smart Transport, Smart Home, SG etc [18].



(a) IoT Architecture (b) IoT Protection

Figure 3: IoT Based Protection model

### 3.1 Basic IoT based Protection

The perception layer can gather required information through sensors, RFID and camera for monitoring the electrical devices which are required to send information to network layer for the protection of power transmission network [19,20]. The network layer includes fibre-optic communication channels for transmitting data from one end to other end; power line carrier communication is required for transmitting electrical data and wireless networks for remote data collection.

Application layer collect the information from various available sources and then make the protection scheme becomes real time system. IoT perform processing, integration and analysis of data, thus intelligent control services and decision making such that the protection schemeis improved.

This Iot system contains various sensors are generating premature warnings to the watching centres about physical and mechanical conditions of tower as well as conductor and also threats regarding of high voltage towers. The vibration sensors monitor underground vibrations discussed in [20]. IoT based transmission system protection incorporates mechanical and electrical safety of power lines from the problems of natural disasters, unsophisticated threats to construction, natural disaster and growing trees as illustrated in figure-3.

### 3.2 Wavelet based network protection

Wavelet transform (WT) is popular tool for research to detect transient faults by analysing various types of signals and separate approximate and detailed coefficients using basic mother wavelet, which gives tremendous information regarding fault classification and location [21]. A power system with microgrid protection algorithm is described in [16] Multi-resolution- Analysis (MRA) through transient current signals with mother wavelets of faulty signals with the comparison threshold value. The proposed algorithm is described in figure8.

## 4. Modelling and simulation of System under study

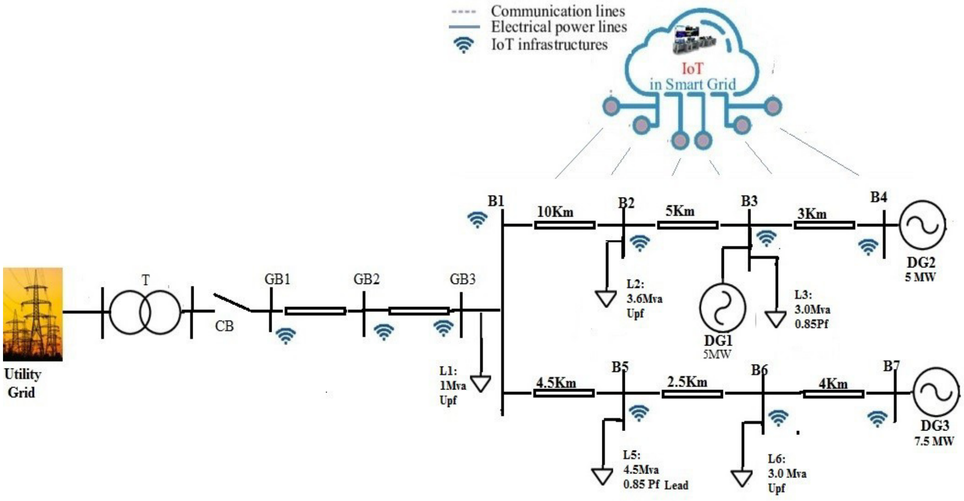


Figure 4: Proposed system model-main parameters

DG1: 7.5 MVA, 4.16 kV-DG unit at bus 3. L1:1 MVA, PF=1

DG2: 5 MVA , 4.16 kV -DG unit at bus 4 L2:=3.6 MVA, PF=1

DG3: 5 MVA , 4.16 kV DG unit at bus 7 L3:3.0 MVA, PF=0.85 lag

Line-12=10 km, Line-23=5 km, Line-34=3 km L5:4.5 MVA, PF=0.85 lead

Line-15=4.5 km, Line-56=2.5 km, Line-67=4 km L6:3.0 MVA, PF=1

$Z_{1,2} = 0.173 + j0.432\Omega/km$ $Z_0 = 0.346 + j1.800\Omega/km$

The proposed test system under study is Canadian bench mark distribution network as shown in figure-4.The system comprises of 9-bus microgrid connected system connected to grid with three synchronous DGs are connected at bus numbers 3,4 and 7.The total system divided in to eight zones as illustrated in figure-4 and system technical parameters are represented in Table-I Fig.4 shows the layout of Iot based transmission system and its main parameters are represented as follows: three phase, three-wire, 34.5 kV, 60 Hz test microgrid simulated using MATLAB. The utility grid is represented by a voltage source with the short-circuit capacity of 900 MVA. This microgrid can include a combination of the following DG units:

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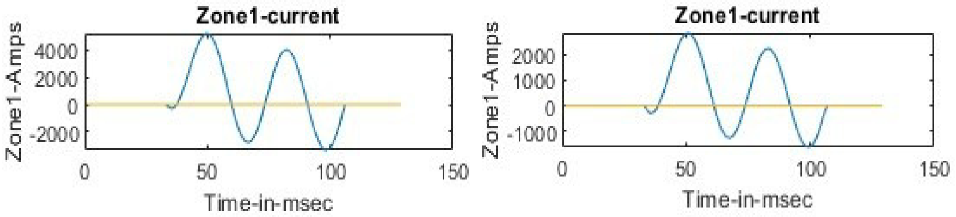
## 5. Simulation results

The fault cases are considered every zone of ten different types of faults. There are three maincases to

Study: 1) Type of fault – SG, SLG, DLG, TLG faults

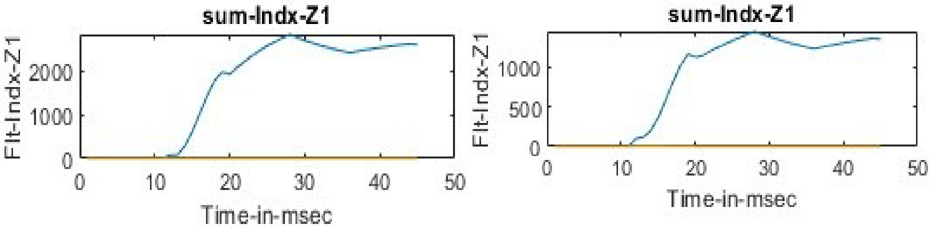
2) Total transmission divided into 8 Zones.

3) Fault inception angles (from $0^0$ to $180^0$ in increment of 15 degrees



(a) Grid Connected mode (b) Grid Idle mode

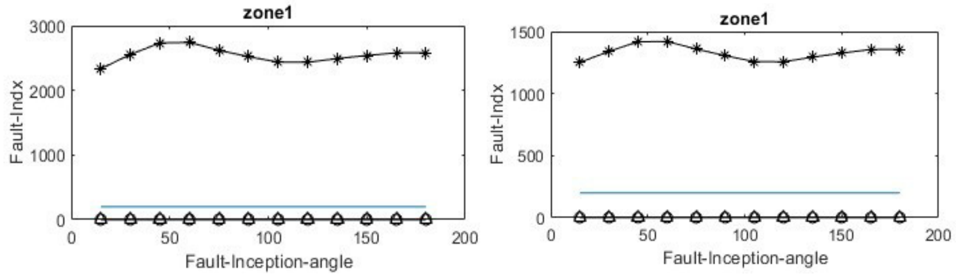
Figure 5: Current wave-forms of 9-Bus system in Zone-1 at LG-Fault



(a) Grid Connected mode (b) Grid Idle mode

Figure 6: wavelet based fault index of 9-Bus System in Zone-1 at AG-Fault

The Proposed work report detection& discrimination and location of fault in various zones by utilisation of sum-of-the-Detailed coefficients of current signal of the system. The detection of fault is observed with the analysis of fault index values. The faulty phases and healthy phases are detected with the comparison of predefined threshold value which describe the detection and discrimination of fault.

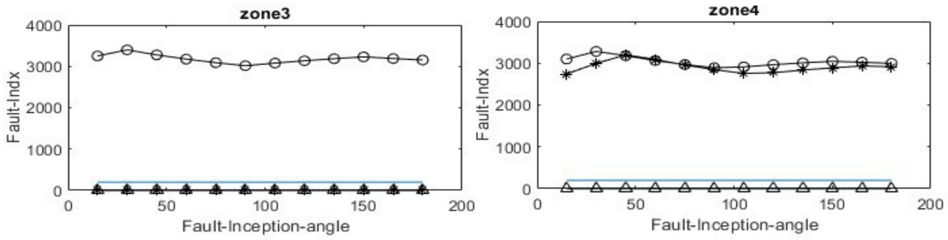


(a) Grid Connected mode (b) Grid Idle mode

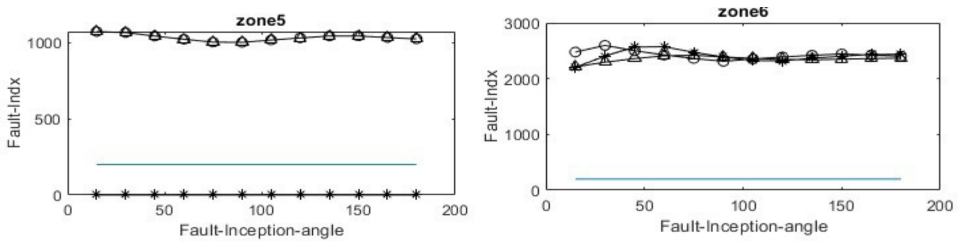
Figure 7: FIA variation of fault index of 9-Bus System in Zone-1 at AG-Fault

Then the Zone current signal has sampling rate 144 kHz of Z1 to Z8 during the fault to analyse the data after selecting bior1.5 mother wavelet. For system study total 10 types of faults in each Zone. For the differentiating grid connected and idling mode of system is described by actual current wave forms. It is observed that grid connected made has highest value when compared to idle mode and indicating that the impact of fault is higher at normal grid connected mode as shown in figure-5.

The time required to find the fault is less than 12 milliseconds in the case of wavelet multi resolution with sum of the detailed coefficients algorithm where as in the case of conventionalapproach by observing current waveform analysis the duration to identify the fault is more than 30 milliseconds and it is found that the proposed algorithm require lesser time compared to normal conventional method which can be identified from figure-6.



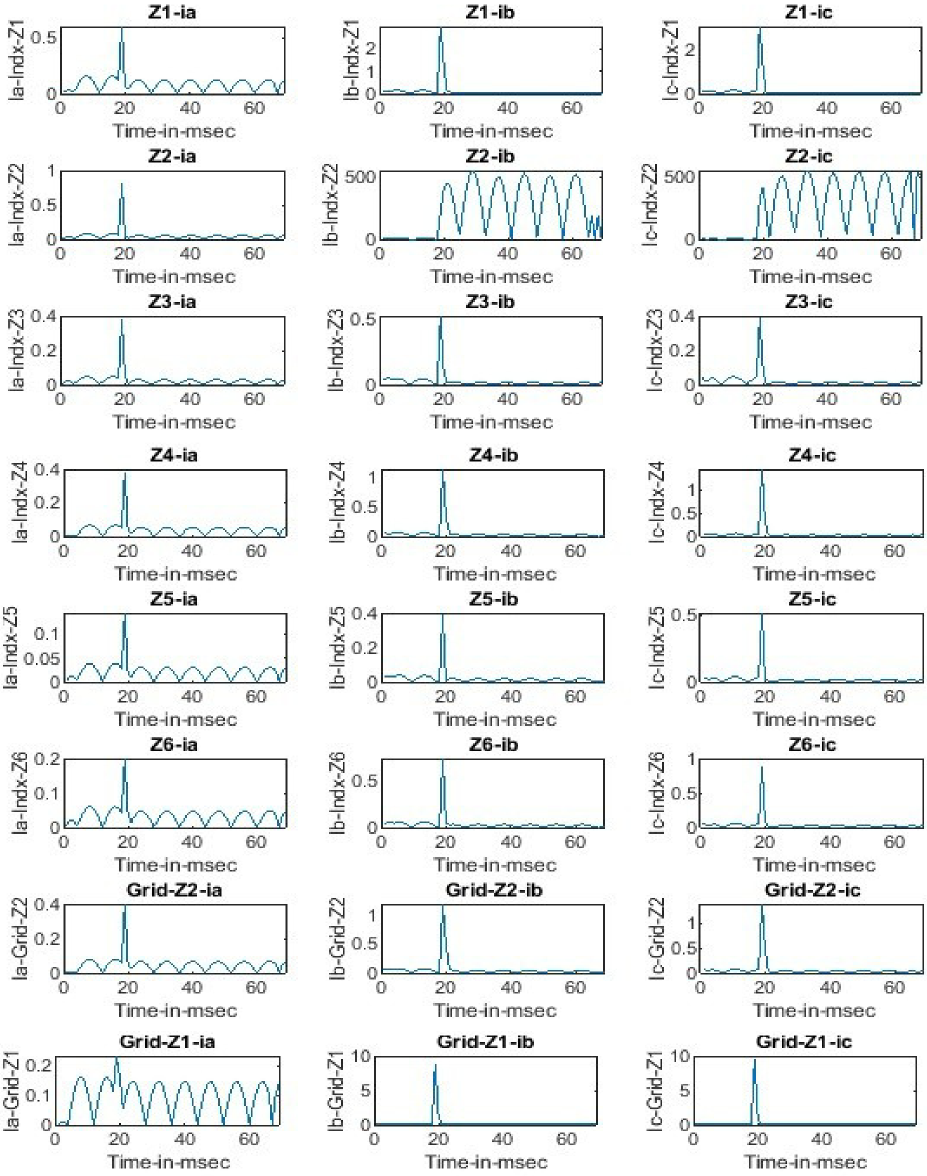
(a) Zone 3: SLG Fault (b) Zone 4: DLG Fault



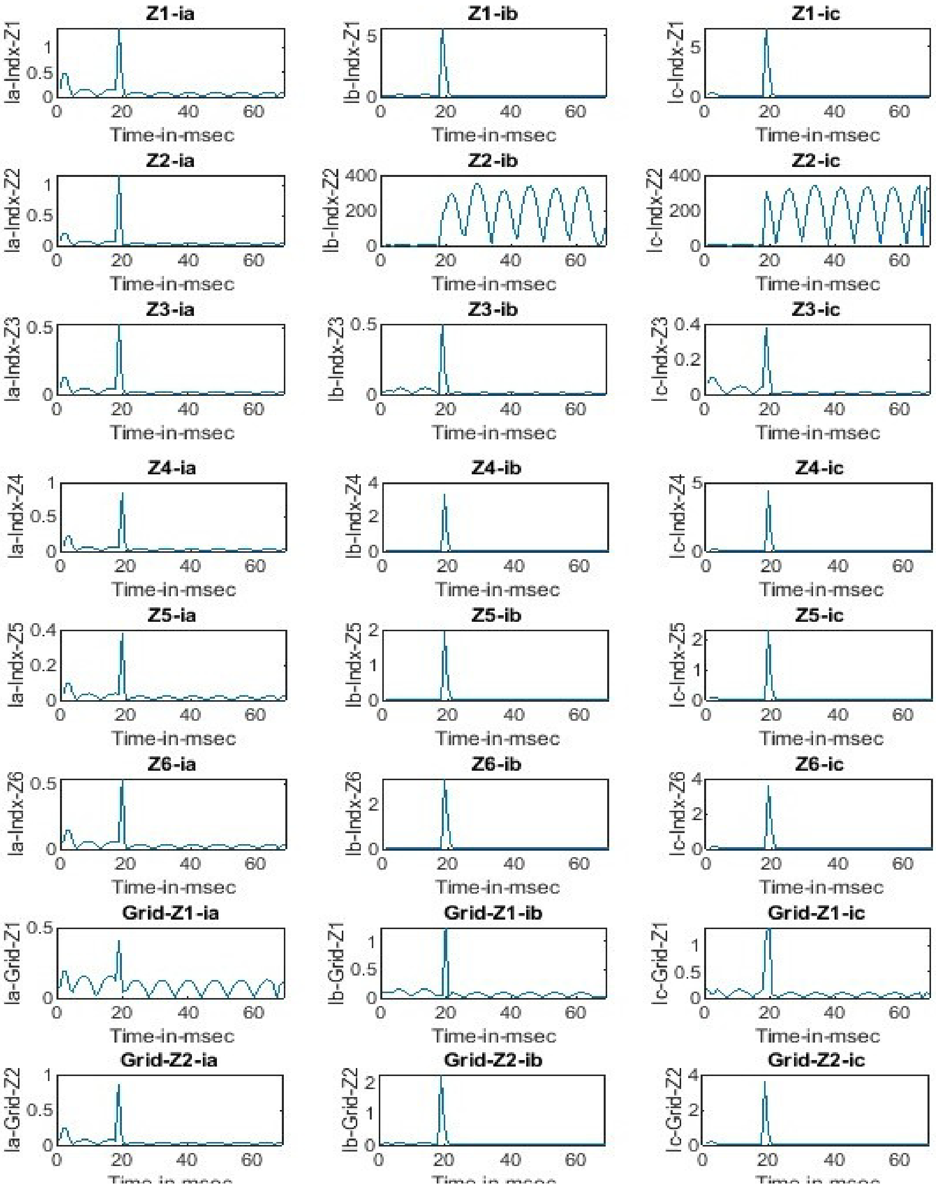
(c) Zone 5: DL Fault (d) Zone 6: TPG Fault

Figure 8: Impact of Fault Inception Angle under various Faults and Zones

The impact of fault inception angle at Zone-1 is observed from figure-7 and the system fault analysis is described in Table-I. It is observed that highest detailed coefficient values at phase-a and indicating that the phase-a to ground fault.



(a) Grid Connected mode

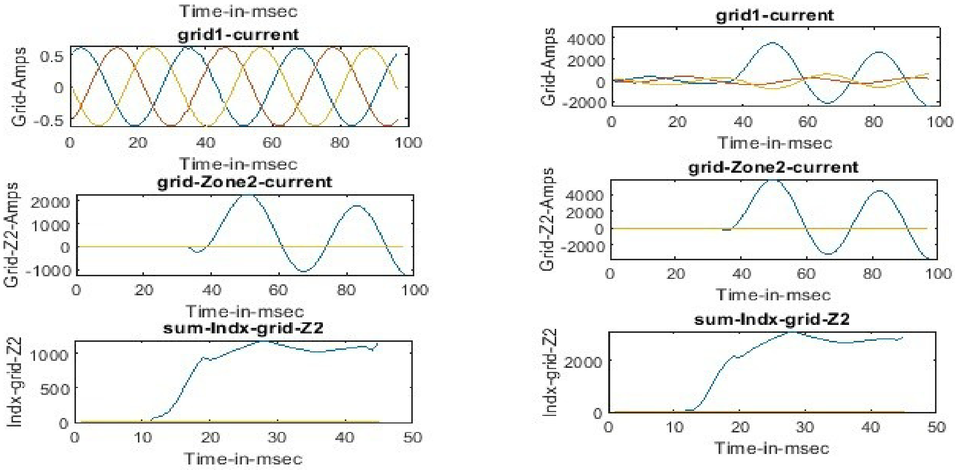


(b) Grid Idle mode

Figure 9: Detection of fault in Zone-2 at BCG-Fault

Table 1: LG-Fault at Zone-1: Analysis of fault Index at Zone-1 under grid connected and Idle mode

| FIA | Fault Index at Zone-1 Grid connected | | | Fault Index at Zone-1 Grid Idle mode | | |
|---|---|---|---|---|---|---|
| | $I_A$ | $I_B$ | $I_C$ | $I_A$ | $I_B$ | $I_C$ |
| 15 | 2335.73 | 0.7819 | 0.7674 | 1251.59 | 0.7240 | 0.7171 |
| 30 | 2554.79 | 0.7817 | 0.7675 | 1339.77 | 0.7239 | 0.7172 |
| 45 | 2733.89 | 0.7817 | 0.7672 | 1417.64 | 0.7238 | 0.7173 |
| 60 | 2741.11 | 0.7818 | 0.7671 | 1419.77 | 0.7238 | 0.7174 |
| 75 | 2620.26 | 0.7819 | 0.7669 | 1359.03 | 0.7237 | 0.7175 |
| 90 | 2520.51 | 0.7820 | 0.7669 | 1305.38 | 0.7236 | 0.7176 |



*(a) Grid Connected mode* *(b) Grid idle mode*

Figure 10: wavelet based fault index of 9-Bus System in Zone-1 at AG-Fault

Table 2: LG-Fault at Zone-1: Analysis of fault Index at utility Grid side under grid connected and Idle mode

| FIA | Fault Index at Zone-1 Grid connected | | | Fault Index at Zone-1 Grid Idle mode | | |
|---|---|---|---|---|---|---|
| | $I_A$ | $I_B$ | $I_C$ | $I_A$ | $I_B$ | $I_C$ |
| 15 | 2603.08 | 0.4050 | 0.3996 | 1017.07 | 0.3687 | 0.3667 |
| 30 | 2854.04 | 0.4045 | 0.3992 | 1094.62 | 0.3685 | 0.3669 |
| 45 | 3059.76 | 0.4045 | 0.3991 | 1161.92 | 0.3685 | 0.3670 |
| 60 | 3068.05 | 0.4046 | 0.3990 | 1163.98 | 0.3685 | 0.3670 |
| 75 | 2929.16 | 0.4046 | 0.3990 | 1113.27 | 0.3684 | 0.3670 |
| 90 | 2814.76 | 0.4047 | 0.3990 | 1069.23 | 0.3684 | 0.3671 |

The detection of fault can be identified in the entire network is illustrated in figure-9. It is observed that larger index values compared to all indices of the network which can be specified that the fault is BC-To-Ground fault in zone-2. The impact of fault inception angle can be notedfor Zone-3 of BG Fault under grid idle mode, Zone-4 of ABG fault under grid connected mode and Zone-5 of CAG fault under grid connected mode illustrated in figure-8.

The analysis of wavelet-based fault analysis of idle and connected mode of grid under AG-fault in zone-1 is represented in figure-10. The fault analysis Table-II values reported that wavelet multi resolution analysis carried effectively for the detection and discrimination of faults.

## 6. Conclusions

This paper proposes protection scheme of Transmission system with the assistance of IoT and itsapplications, so that it can provide strong real protection scheme. IoT can solve real problems mechanical and physical problems with effective manner and also promoting the development of new protection algorithms. WT is one of the research tool to analyses the faults in transient signals at different frequencies by decomposing the waveform into coefficients of bior1.5 mother wavelet, which presents more prominent information regarding the class of fault and location in existing system by time and frequency domain. The Proposed algorithm has been tested for the detection of faults under various types of faults at different fault inception angles using wavelet multi resolution analysis with bios1.5 mother wavelets detailed coefficients with the help of IOT Application.

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