Arc Fault and Flash Signal Analysis and Detection in DC Distribution Systems Using Wavelet Transform

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Abstract— An arc fault may be a discharge of electrical energy through the air. Under normal operation two conductors are connected and therefore the flow of electrons passes through the essentially zero resistance path. If the connection is corroded or impure, it'll have resistance and heat is generated. Over time the warmth will wear down the contact and result in small arcs between connections. These arcs begin as low current faults, but given enough time they need the potential to breakdown to another phase or ground conductor resulting in a dangerous high current fault. the most focus of this paper is on detection of arc fault and flash in DC distribution systems and DC grid which may causes fire hazard, personnel shock hazard and damage other system elements or appliances. A notable complication to their detection is that arc in dc system isn't periodic, and thus might not have easily perceptible amplitude or frequency signature for pattern recognition based detection technique. during this paper, a replacement approach using Wavelet transform(WT) base spectral energy calibration for arc fault analysis and classification with Fuzzy Logic Controller in dc systems is projected. WT provides a time and frequency approach to research target signals with multiple resolutions. during this approach we were design a cassie arc model for representation of practical arc condition. The arc voltage was analyzed using wavelet analysis which feature of wavelet then utilized for design fuzzy rule base data. the tactic of detection associate arc fault involves solar PV output voltage analysis and so feature identification. this whole system was implemented and tested in MATLAB simulink 2017 atmosphere.

Keywords—Arc fault analysis, discrete wavelet transform, detection, Fuzzy logic, Fault location, DC distribution system.

I. INTRODUCTION

Since the different DC microgrid installations are increasing currently so study on precise safety feature is improving more significance. Besides the execution of skill development of mechanism & fixing , moreover thorough inspection of safety &stability of control methodology has received selected performed not just for bulky scale, except for little microgrids. Mainly because of immense value of worldwide photovoltaic installations & hence, rising use of battery systems within previous year numerous examinations are administered about explanations of statement fire incidents [1] & begins research course & standard provision [2].

Fig. 1: Damage to a PV system attributed to an arc

Arc fault are significant downside in electrical mechanism [1-3]. The energy since associate arc fault will achieve to 1000 W in the main in style of light-weight &warmth [4]. In cables installations, same heat will ignite hearth [5]. Many plane incidences are often clarified through arcing faults [6].

The arc's explosion is every so often due to: isolation fault cable aging, pollution of oil or dangerous mechanical contact together via vibration [7]. UL1699b normal outline many examinations to urge this fault.

Very less research is devoted to recognition of DC arcs [8] as compared to AC arcs. The present progress of DC distribution within automotive, region or natural phenomenon plants provoked us to possess an interest notably in DC arcs with aim of increasing a depend able discovery methodology for safety of installations. Consistent with definition, a DC arc isn't as periodic within AC condition. So, it becomes complicated to detect mainly in sequential configurations thanks to such isolated & sheath characteristic. Parallel arc square measures appreciate a fast circuit of the foremost power supply.

This reaches high worth & typical grid protection procedure area unit sufficient to shield installation. This condition of serial arcs, this cannot top face importance while not arc. Electrical defense devices like fuse or circuit wave square measure incompetent during case results of this does not increase.

Some researchers have based their technique of detective work DC faults on vary in applied math nature of this. Another research square measure supported the rise of this occurrence spectrum at the beginning of arc or technique victimization multiple higher frequency bands.

The aim of study is meant conclusion algorithm of discrete wavelet transform& fuzzy logic, this engaged to an arc forecast fault position in DC delivery system. The wavelet transform approach is effective for analysing arc fault in dc systems which supply a more readily detectable signal & best presentation. Additionally, with wavelet transform, a signal data is used for arc zone classification using Fuzzy logic controller.

This study is planned follows: Section II showing brief summary of various techniques of arc fault detection and location. Section III presents a proposed methodology of work. A MATLAB simulation model existing in section IV, & its simulation results are showed in section V. Conclusion is presented in final section VI.

II. LITERATURE SURVEY

Classification of arc fault detection methods used for arc fault detection. For the aim of low impedance arc fault detection (i.e. parallel arcing) conventional protection devices like fuses, relays and CBs are utilised to apply sufficient protection coverage. High impedance, low fault current arc fault detection (AFD) methods are typically characterised as either nonelectrical or electrical. The subsequent sections describe these methods in more detail.

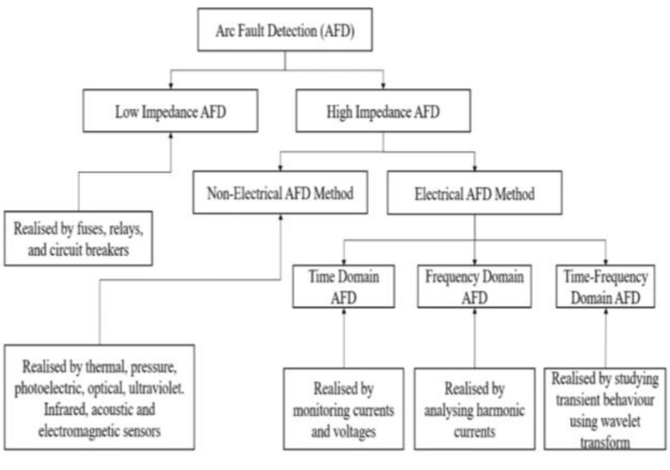


Fig.2: Classification Of AFD methods

Non-Electrical AFD Methods -Non-electrical AFD methods utilise special sensors which identify a measurement (pressure/thermal) [9] rise or a specific emission of light (infrared) [10] for detection. The acoustic signature [11] present within the arc, also makes a special case for detection in high powered arcs. There are several limitations of mechanical detection methods, including the very fact that the specialised sensors have high installation and maintenance costs. These limitations mean that non-electrical based AFD methods are unsuitable for series DC arc fault detection.

Electrical AFD Methods -Electrical AFD methods are defined as approaches supported algorithms that use feature extraction to analyse specific components to determine the presence of a fault. Observations made with variation in current, voltage and their electrical derivatives forms the idea for fault detection. Supported the domain of the feature extraction technique used, electrical FDI methods are often further categorised into the time domain, frequency domain and time-frequency domain [16].

Time Domain -This AFD methods involves the analysis of differential current/voltage [12], imbalance of three phase current [13], voltage imbalance along a feeder [14] and arc fault energy [15]. Methods that employ voltage monitoring across a feeder for the aim of detection and location of series faults, require voltage sensors installed across multiple measurement sites on one conductor. The supplementary weight increase attests that these approaches not particularly fitted to aircraft applications. Time domain arc FDI limitations mainly arise from the method of determining thresholds and defining features that actively distinguish between true arcing and events that produce similar load characteristic profiles such as load inrush and switching transients.

Frequency Domain -Numerous AFD methods have been proposed in the literature based on analysis of voltage and current frequency spectra. The Fast Fourier Transform (FFT) efficiently translates the time domain signals to the frequency domain. The Discrete Fourier Transform (DFT) possess the capability to decompose signals into spectral components. The harmonic voltage and or current data are often analysed to supply discrimination between normal transient and fault conditions for the purpose of arc fault detection. Kojori et al. [17] propose a real-time analysis method of load current through the implementation of a moving/sliding DFT window that performs steady state component monitoring. An amplitude variation profile within the DC component is deemed to be conclusive of an arc fault being present. The variation within the information is extracted by counting the number of maxima over a period in comparison with a set threshold. The technique combined with the measurement variations observed on load current distortion was found to extend the accuracy of the fault detection.

Although many frequency domain based AFD methods are proposed within the literature, their main disadvantages dwell the fact that the FFT does not have the capability to associate the time at which the harmonic frequencies are present. FFT proves to be a perfect platform for stationary and continuous fault conditions. However, for highly transient signals like series DC arc faults the absence of time information may limit the accuracy of the purely frequency domain based methods.

Time-Frequency Domain -Time-Frequency Domain arc FDI methods determine how the frequency behaviour changes with time. These often employ the Short Time Fourier Transform (STFT), through the utilisation of a gliding window that provides the determination of the sinusoidal frequency and the phase contents of a local section of a signal, with variation in time.

Chen and Xiong [18], utilise STFT to detect the varying characteristic frequency bands produced by arc noises. The disadvantage related to STFT is the compromise that has to be undergone when the prioritisation of time resolution vs. frequency resolution may be a factor. A shorter window length lends itself to fast transient signals, providing a better resolution in locating time domain behaviour whereas a longer window length provides a higher frequency resolution but the information is averaged across a longer time frame and potentially smearing out non-stationary behaviour.

The Wavelet Transform (WT) can provide the frequency of a signal as well as the time associated with each frequency. For cases related to highly transient and non-stationary signals, WT proves to be ideal. The WT features a leverage over the STFT as the analysing 'window' is variable in size. The overall challenge associated within WT based detection methods is the evaluation of generated wavelet coefficients for the purpose of determining the presence of a fault. Advanced detection systems utilise intelligent techniques applied with WT features to figure out the probability of fault presence.

III. PROPOSED METHODOLOGY

A. Discrete Wavelet Transform

Wavelet transform may be a linear transformation which permits precise time and localization of dissimilar frequency components of known signal. Fault identification strategy is achieved through by employing discrete wavelet transform. The Wavelet transform utilize little windows at high frequencies &long at low frequencies. Wavelets are mainly efficient in almost like functions with irregular changes like fault signals in power system. Wavelet transformation is effective tool for fault detection &feature distraction with correct alternative of mother wavelet which uses the dilation and translation property. during this study dyadic-orthonormal wavelet transform with Daubechies 3 (db3) has utilizes to take out arc fault details. during this proposed methodology Cassie arc model utilized from MATLAB tool box for arc generation. The Cassie arc model is connected at different locations and which is taken into account as slandered arc model for dc grid system for different locations. Then voltage of the dc grid are going to be measured at the end of line and then measured voltage will be transfer to discrete wavelet transform using Daubechies mother wavelet for signal energy calibration. The mother wavelet Daubechies is engaged to decompose input into a low-frequency &high-frequency components. With dyadic wavelet filters, only lower frequency fraction is then decomposed. And these decomposed signals of energy are going to be utilized for decision making.

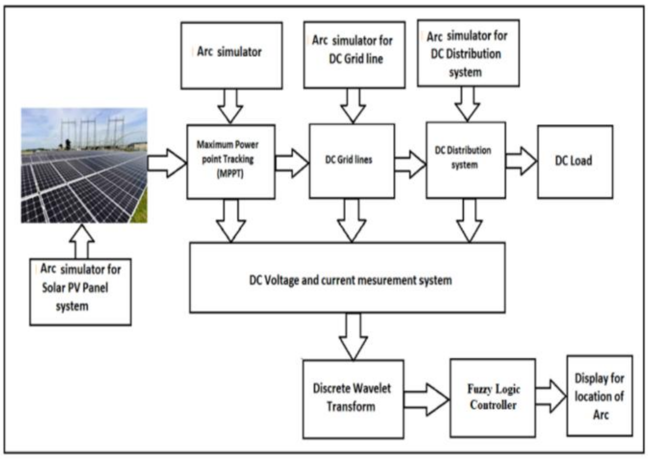


Fig. 3: Block diagram of proposed methodology

B. Fuzzy Logic

The process executed in fuzzy-set advance is showed in block illustration. Without use of Boolean logic, the method can use a fuzzy membership function &rules, to cause regarding data. Crisp values are first converted into fuzzy values to be ready to use them to apply rules formulated by linguistic expressions. Then, the fuzzy system again converts the linguistic conclusion back to a crisp value. These steps are described as below.

a. Fuzzification: The method of converting crisp input values into (linguistic variables) fuzzy sets able to utilized them for computing the truth-values of basis of each regulation in rule base

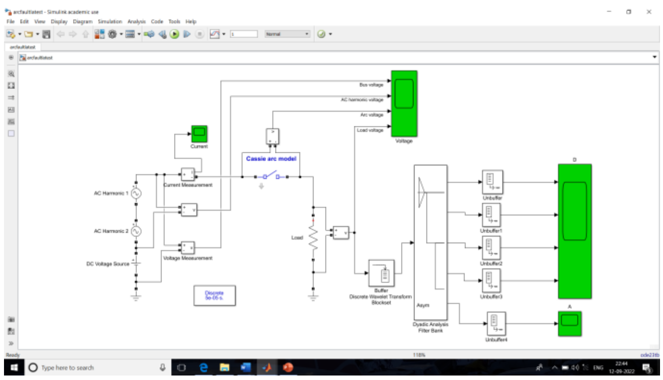
b. Inference: truth-value for idea of every logic rule computed & practical to conclusion measurement of each rule. This direct to at least one fuzzy set to be allocated to each output inconsistent for each rule.

c. Composition: All of fuzzy sets assigned to each output variable are collective together to form single fuzzy sets for each output variable.

d. Defuzzification: It converts fuzzy values into crisp values getting from fuzzy interference engine. The fuzzy processor block characterized heart of all fuzzy logic process. It estimates total truth position of set of rules which illustrated system during a fuzzy direction.

The fault location decision algorithm can be assembled supported on fuzzy logic toolbox in MATLAB. Before the choice algorithm process, a structure of fuzzy logic contains of 4 inputs &1 output. For next stage, triangle shaped membership function is employed to create a function for input variable. Additionally, a term of number of fuzzy sets has 5 terms &linguistic variables has 3 levels like medium, low, & high designed for triangular membership purpose. The output variables of fuzzy are designed as particular range of values which corresponds to location of fault. The fuzzy interference rules are based on principles of fuzzy logic in the form of IF-THEN rules. The IF rule is named condition, which is fuzzy input while THEN is understood consequent, which is fuzzy output. Process in fuzzy logic controller which will be act as classifier for arc flash location on dc grid. This complete system will be design in MATLAB Simulink software. So we have planned to design such system in future in MATLAB Simulink software.

IV. MATLAB SIMULATION MODEL



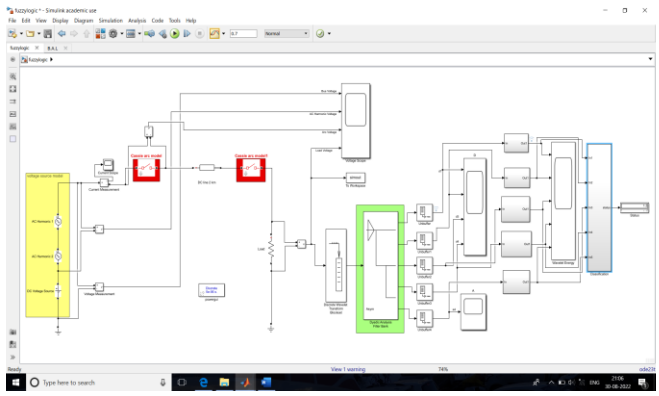


Fig. 4: MATLAB simulation model of proposed approach

The arcing condition is simulated through black box modelling which is utilized to illustrate arc communication with electrical network. The black box models use voltage &current traces from a circuit breaker test, simultaneously with select disparity equation, to form a mathematical model for preferred arc under research. Majority published work using black box models is based on well-known Cassie &Mayr models.

TABLE I. MATLAB SIMULATION MODEL PARAMETER SPECIFICATION

SR. NO.	Name Of Simulink Block	Parameter Specifications
1.	DC source voltage	DC voltage = 100V
2.	AC Harmonics 1	Peak voltage = 10 V; Phase = 0^0; Frequency = 2 KHz; Sample time = 0
3.	AC Harmonics 2	Peak voltage = 10 V; Phase = 00; Frequency = 120 Hz; Sample time = 0
4.	Cassie arc model	tau = 1.2μsec; Uc = 500V; g(0) = 1000 Sec; Time constant = 1 nsec
5.	Load	Nominal voltage Vn = 1000V; Active power = 10KW
6.	Buffer	Output buffer size = 64 Channel
7.	DWT (Dyadic analysis filter bank)	Filter (mother wavelet) =Daubechies; Wavelet order =3; Number of level = 4

The mathematical model is tune to line of measured data by resources of a correct collection of arc parameters including time constant &cooling power, that normally taken as a function of arc current &voltage. An example circuit with series arcing is made in Simulink, as shown in figure 4, which is predicated on Cassie arc model block set developed. The Cassie arc model is written as a differential equation.

$$\frac{1}{g}\frac{dg}{dt} = \frac{d\ln g}{dt} = \frac{1}{\tau}\left(\frac{u^2}{U_C^2} - 1\right)$$

Where
g conductance of the arc;
u voltage across the arc;
i current through the arc;
Uc constant arc voltage;
τ arc time constant.

The source voltage of bus system contains of a dominant 1000 V dc component with small-amplitude ac mechanism at 120 &2000 Hz, which characterize single-phase double frequency power ripple &power electronic switching noise, correspondingly. The constant series arc starts at 0.5 s.

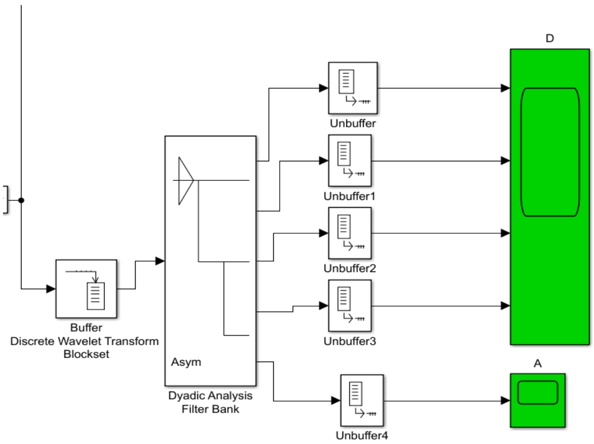


Fig.5. Wavelet multi-resolution analysis subsystem MATLAB Simulink model

Figure 5 illustrate wavelet multi-resolution analysis MATLAB Simulink subsystem blocks which give wavelet multi-resolution analysis of load voltage.

A.Fuzzy logic controller

Figure 6 shows the fuzzy logic controller toolbox window in which wavelet multi-resolution output Detail D1 coordinator input was designed for fuzzy logic controller input as triangular membership function. Similarly for Detail

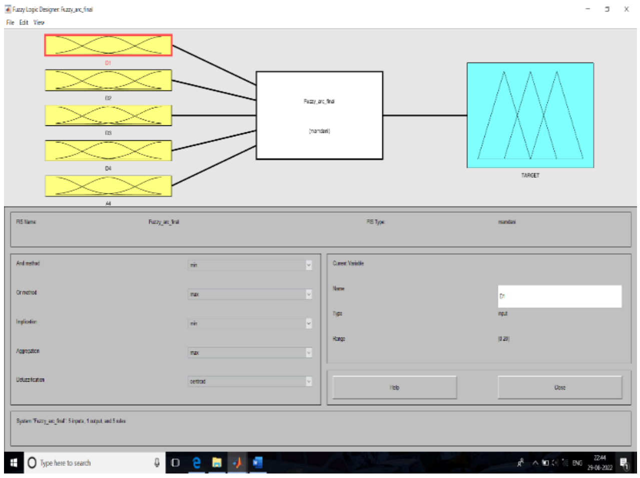


Fig.6. Fuzzy logic designer in MATLAB simulink

Coordinator D2, D3, D4 AND Approximation A4 coordinators input values are define and design. The values for triangular membership function are define in table II, III, IV, V and VI for detail D1, D2, D3, D4 and Approximation A4 signal respectively.
Figure 7 illustrate triangular membership purpose view for set values for detail D1 signal.

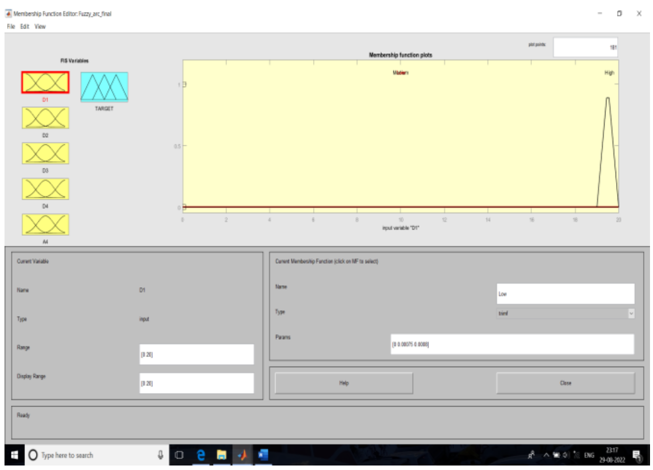


Fig.7. Fuzzy membership purpose for Detail D1 input

B. Fuzzy rule base

Figure 8 shows fuzzy rule editor during which rule base design for fuzzy logic controller. Based on fuzzy rule base fuzzy logic controller is work and provides decision for arc flash zone classification.

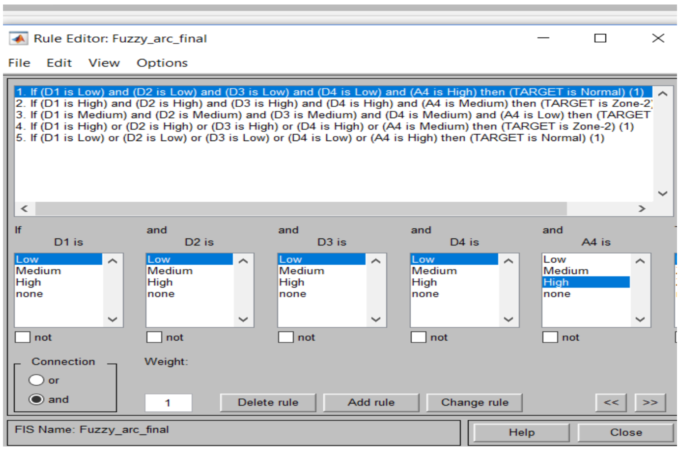


Fig.8. Fuzzy rule editor in MATLAB

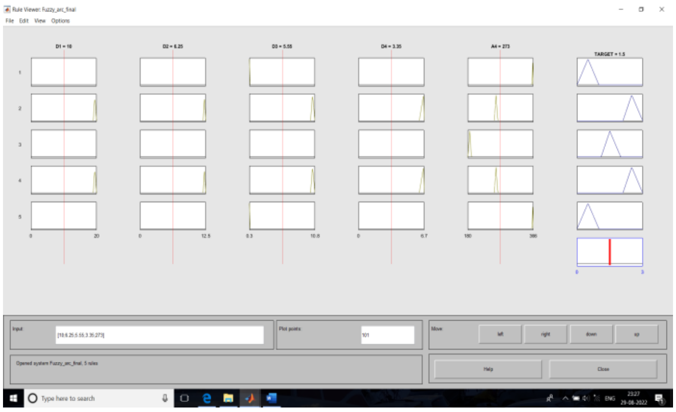


Fig.9. Fuzzy rule base for fuzzy controller

V. MATLAB SIMULATION RESULTS

A. Expected results from fuzzy logic controller

Table II shows the particular output will be provided by fuzzy logic controller. The particular output is in range of target membership function which is design in fuzzy logic controller toolbox.

TABLE II. EXPECTED FUZZY LOGIC CONTROLLER RESULTS FOR DIFFERENT ARC FLASH ZONE

Sr. No.	Fault Type	Range of fuzzy decision	Actual decision by fuzzy controller
1.	Normal Condition	0 to 1	0.51
2.	Zone 1 arc	1.1 to 2	1.5
3.	Zone 2 arc	2.1 to 3	2.5

B. Result from Voltage scope

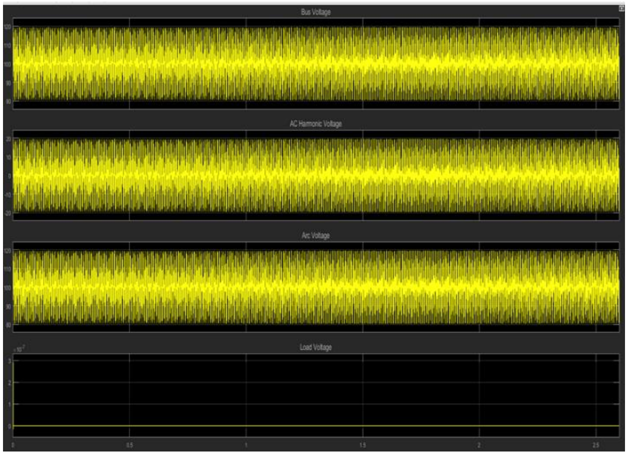


Fig.12. During Normal Condition

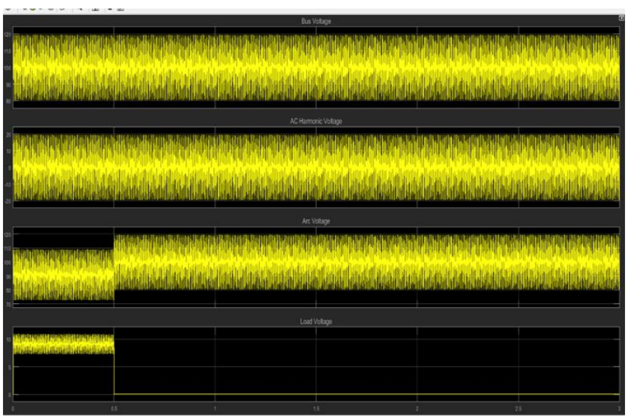


Fig.13. During Abnormal Condition

C. Result from Wavelet multiresolution analysis

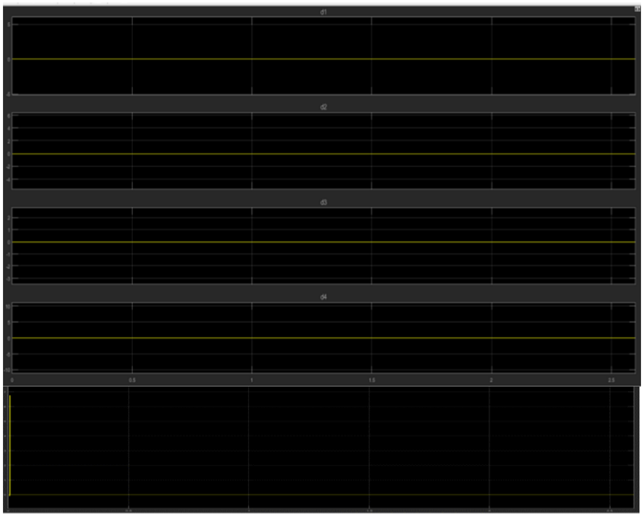


Fig.14. During Normal Condition

Figure 14. shows wavelet multi-resolution analysis window which shows detail and approximate coordinator data during normal operation of dc cable. In this case arc is not strict or not consider for operation. So that in this case detail coordinator data that is D1, D2, D3, D4 &Approximation A4 is constant data throughout operation. Daubechies mother wavelet is used for multi-resolution analysis of wavelet transform.

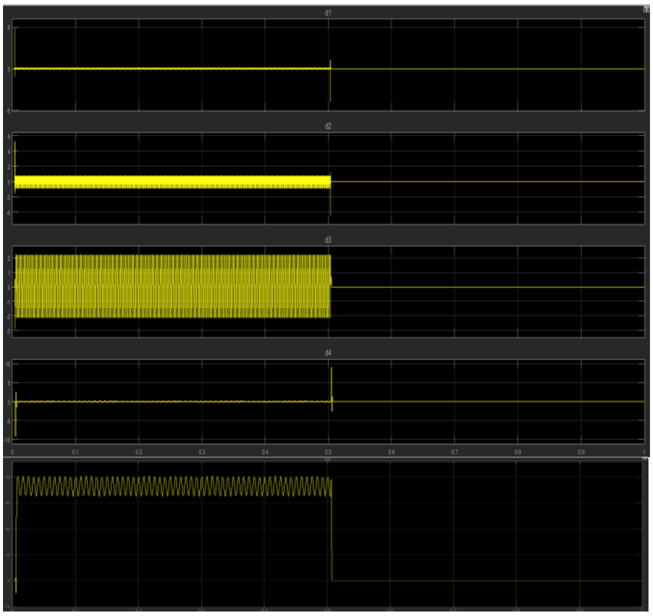


Fig.15. During Abnormal Condition

Figure 15. shows the wavelet multi-resolution analysis window which shows the detail and approximate coordinator data during arc flash occurs operation of dc cable. In this case arc is initiated in zone 1 of DC cable. So that in this case detail coordinator data that is D1, D2, D3, D4 & estimate A4 is constant before arc initiated while arc is initiated at time 0.5 sec time then coordinator data changes. Daubechies mother wavelet is used for multiresolution analysis of wavelet transform.

VI. CONCLUSION

This study showed novel approach on arc analysis to identify and locate fault on dc distribution system based on grouping of discrete wavelet transform & fuzzy logic. The basic possibility of applying WT has been accessible. The presence of switching harmonics& ambient electrical noise can hide arc signal, creating discovery of an arc hard. Perhaps, WT is extremely efficient with detecting proper immediate signal changes. The outcomes propose that WT approach is not just able of analyzing arc fault in dc systems but that it provides more simply detectable signal & good presentation. In addition with wavelet transform, this technique extends and calibrates wavelet spectral energy of wavelet multiresolution signal like detailed and approximate signal. That signal data is then useful for arc zone classification using fuzzy logic controller. Fuzzy logic controller is design in MATLAB fuzzy logic toolbox and association function also design in MATLAB fuzzy toolbox. Then controller data is fed in MATLAB Simulink model for dc arc zone classification.

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