Modeling and Simulation of Faults in Distribution Network System Using MATLAB/Simulink

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Abstract: *This study presents the detail integration of faults in distribution network systems (DNS). Simulation and modeling is carried out using MATLAB/Simulink software package. The suggested model is user friendly and can be used as a common platform for both control and power system engineers. The proposed model is very simple, fast and precise. A detailed modeling technique is presented. Ede distribution Business Hub of Ibadan Electricity Distribution Company (IBEDC) of Osun Region, South West, Nigeria is used for the modeling. This network contains two feeders that is: Ede Township feeder and Ede Cottage feeder. The designed model is used to validate the results of reliability appraisal from the data of IBEDC to justify the need to transform from the long century present traditional grid to smart distribution grid. The results of simulation shows from the waveform display that various contests facing centralized traditional distribution grid need modern technologies to shift to decentralized smart distribution grid for smooth distribution of power system to ensure an improved quality and reliability.*

Keywords: *Fault, DNS, Simulation and modeling, MATLAB/Simulink, IBEDC, reliability appraisal.*

I. Introduction

The economic growth and development of a country depends greatly on the reliability and quality of the electric power supply [1]. The last decade in Nigeria witnessed huge investment in expanding the generation capacity and increasing the transmission lines. However, regardless of the significant function of Electric power distribution system in the conveyance of electricity, the system have generally grown in an unplanned manner resulting in high technical and commercial losses in addition to poor quality of power[2]. As stated by Ogujor, [3], the Nigerian electric power distribution system (EPDS) as a developing one is horizontally characterized by very long radial circuits, undersized distribution conductors and various other factors that affect reliability. The power distribution network is characterized with a number of distribution substations positioned over a huge geographical area which is susceptible to faults occasioned by wind storms, lightning, rain, insulation breakdown, overloading and short circuits. According to Car, distribution lines experience faults more frequently than the faults experienced by other power system facilities [4].

II. Distribution System Faults

Distribution networks of an electric power system connect bulk sources of energy to customers' services. Distribution lines are generally operated in radial mode with loads tapped along the lines; which could be single or three-phase taps. The substation transformer steps the voltage down to 415V. It is projected that 80% of all interruptions occur due to failures in distribution systems [5, 6, and 7]. Faults situation are unexpected strange change to the normal circuit arrangement [1] that results in energy being dissipated in manner other the serving of the intended load [8]. The circuit quantities, current and voltage, will alter, and the circuit will pass through a transient state to a steady state. In the transient state, the initial magnitude of the fault current will depend upon the point on the voltage wave at which the fault occurs. The decay of the transient condition, until it merges into steady state, is a function of the parameters of the circuit elements [1]. The different types of faults that occur in a network can be classified in threemajor groups [1, 10]: short circuit faults; open circuited faults and simultaneous faults. Simultaneous faults are a combination of the two groups described above. The most dangerous phenomenon is normally the high current that occurs at a short circuit. The magnitude of the fault current is dependent on what type of fault that occurs [1]. The faults have different possible origin which includes electric, climatologic and human activity or error.

Short Circuit Faults

Short circuit is the unplanned or intentional conductive linking through a relatively low resistance or impedance between two or more points of a circuit which are generally at different potentials [1, 6, and 10]. When short-circuit take place in an installation served by a distribution network (far from the generator), a short circuit current consisting of two components-the transient aperiodic component and steady state sinusoidal component will flow [6]. The aperiodic components decay towards zero. On three-phase power systems, there are ten separate possible shunt faults types [9] which involves single phase, two phase and three phase. These are categorized in the following four groups [7]:

(i)   Single - phase - to - ground faults
(ii) Two - Phase - to - ground faults
(iii) Phase - to - phase faults
(iv) Three - phase faults.

Single-phase-to-ground faults
The following three types of single-phase-to-ground faults as shown Fig. no.1 occurred in Electrical Power Distribution System [1, 7]: a) Phase R-to-ground fault;   b) Phase B-to-ground fault and
 c) Phase Y-to-ground fault.

Two-phase-to-ground faults
The following three types of Two-phase-to-ground faults are defined [11] as shown in Fig.no. 2.
a)   Phase R and phase B-to-ground fault;
b)   Phase B and phase Y-to-ground fault and
c)   Phase Y and phase R-to-ground fault.

Phase-to-phase faults
The three types of phase-to-phase faults that can be experienced on three phase lines as shown in Fig. no. 3 are as follows [11].a) Phase R-to-phase B fault; b) Phase R-to-phase Y fault and c) Phase B-to-phase Y fault.

 Three phase short circuit faults
   According to [12], a 3-phase short circuit faults also known as symmetrical or balanced fault implies that all three phases of the power system are simultaneously short-circuited to each other through a direct or "bolted" connection. These faults can be with or without ground as shown in Fig. no. 4. The three phase faults give the highest short circuit currents and play pivotal role in short circuit calculations for the selection of protective devices [1].
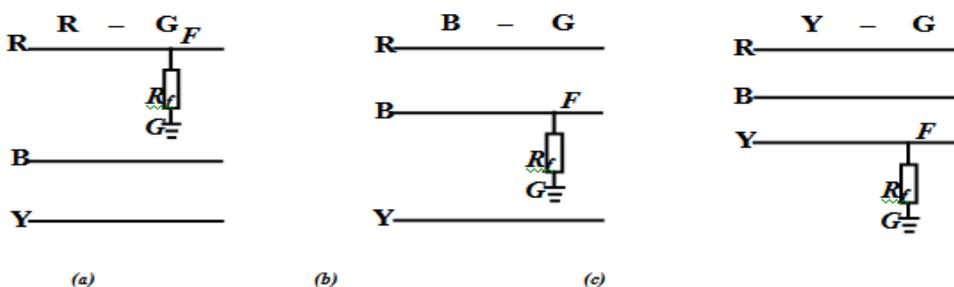

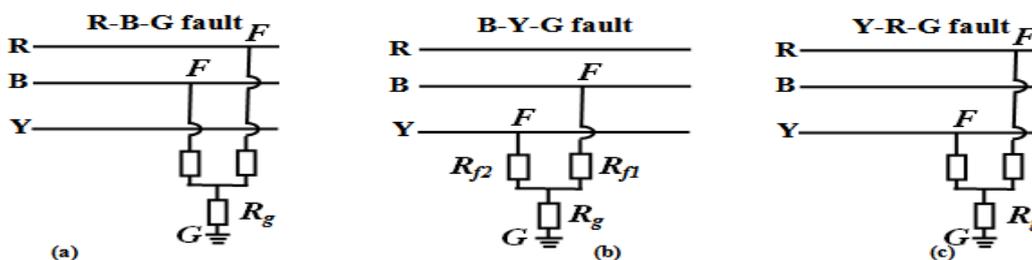Figure no. 1:Single-phase-to-ground faults experienced on three-phase lines

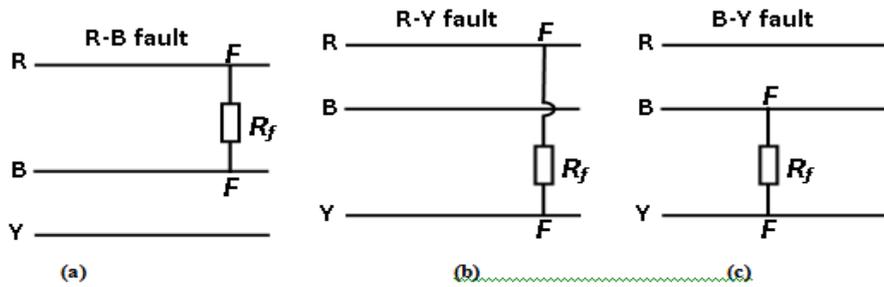Figure no. 2: Two-phase-to-ground faults experienced on three-phase lines

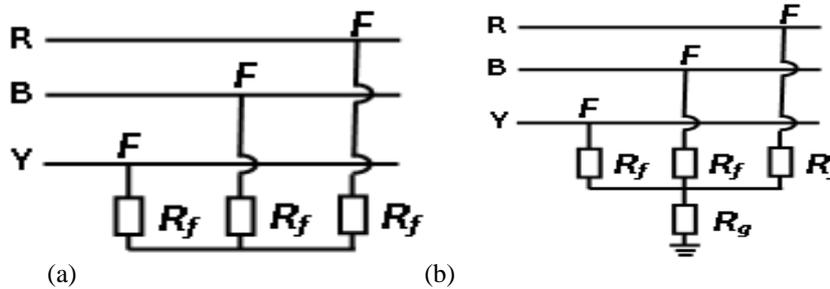**Figure no. 3:** Phase-to-phase faults experienced on three-phase lines

Figure no. 4: Three Phase faults experienced on three-phase lines

III. Methodology

The environment in which we build our simulation model was MATLAB. The name MATLAB stands for matrix laboratory. *MATLAB*, developed by MathWorks Inc., is a software package for high performance numerical computation and visualization. The combination of analysis capabilities, flexibility, reliability, and powerful graphics makes *MATLAB* the premier software package for scientific researchers. *MATLAB* provides an interactive environment with hundreds of reliable and accurate built-in mathematical functions [13, 16].

These functions provide solutions to a broad range of mathematical problems including matrix algebra, complex arithmetic, linear systems, differential equations, signal processing, optimization, nonlinear systems, and many other types of scientific computations. The most important feature of *MATLAB* is its programming capability, which is very easy to learn and to use, and which allows user-developed functions. It also allows access to FORTRAN algorithms and C codes by means of external interfaces. There are several optional toolboxes written for special applications such as signal processing, control systems design, system identification, statistics, neural networks, fuzzy logic, symbolic computations, and others. *MATLAB* has been enhanced by the very powerful Simulink program [13, 16].

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multi-rate, i.e., have different parts that are sampled or updated at different rates. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. With this interface, you can draw the models just as you would with pencil and paper (or as most textbooks depict them). Simulink includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors [14]. You can also customize and create your own blocks Models are hierarchical.

This approach provides insight into how a model is organized and how its parts interact. After you define a model, you can simulate it, using a choice of integration methods, either from the Simulink menus or by entering commands in MATLAB's command window [14]. The menus are particularly convenient for interactive work, while the command-line approach is very useful for running a batch of simulations (for example, if you are doing Monte Carlo simulations or want to sweep a parameter across a range of values). Using scopes and other display blocks, you can see the simulation results while the simulation is running. In addition, you can change parameters and immediately see what happens, for "what if" exploration. The simulation results can be put in the MATLAB workspace for post processing and visualization. And because MATLAB and Simulink are integrated, you can simulate, analyze, and revise your models in either environment at any point. [13, 16].

Simulating faults in Simulink MATLAB

The model has been produced with a toolbox of MATLAB/SIMULINK called Sim Power Systems. To be able to simulate a fault in any point of any line, it is essential to model every line with two blocks, the first

will have the distance equal to the distance from the commencement of the line to the fault and the second will have a distance equal to the total length of the line minus the fault distance. Loads were coupled at the nodes to reproduce a real-life environment. Generally electric lines are modeled with the sequential impedance and the parallel admittance. As the lines are short, the parallel are omitted. All the required parameters to build the model of the line are known: topology (as shown in table no. 1), section lengths, section unitary impedances, transformer nominal powers. Faults were simulated at different positions on the 415V overhead lines as shown in figure 5. The parameters of the line were adjusted at constant intervals.

The simulated faults as shown in figure no. 5 are:
a) Single phase short circuit fault with ground;
b) Phase - phase short circuit fault;
c) Two - phase short circuit fault with ground and
d) Three - phase short circuit fault with ground;

IV. Analysis and Discussion of Results

From the above results, it is obvious that the behavior of the system was successfully described using the suggested simulation methodology. It is also important to mention that this simulation method provides the ability to change the different system parameters to create new environment and hence, new simulation scenarios. This new simulation methodology proves the ability of the Simulink MATLAB to be a useful and flexible approach to study the effect of integration of faults into existing DNS. Below is the detail algorithm use to carry out modeling of faults in DNS.

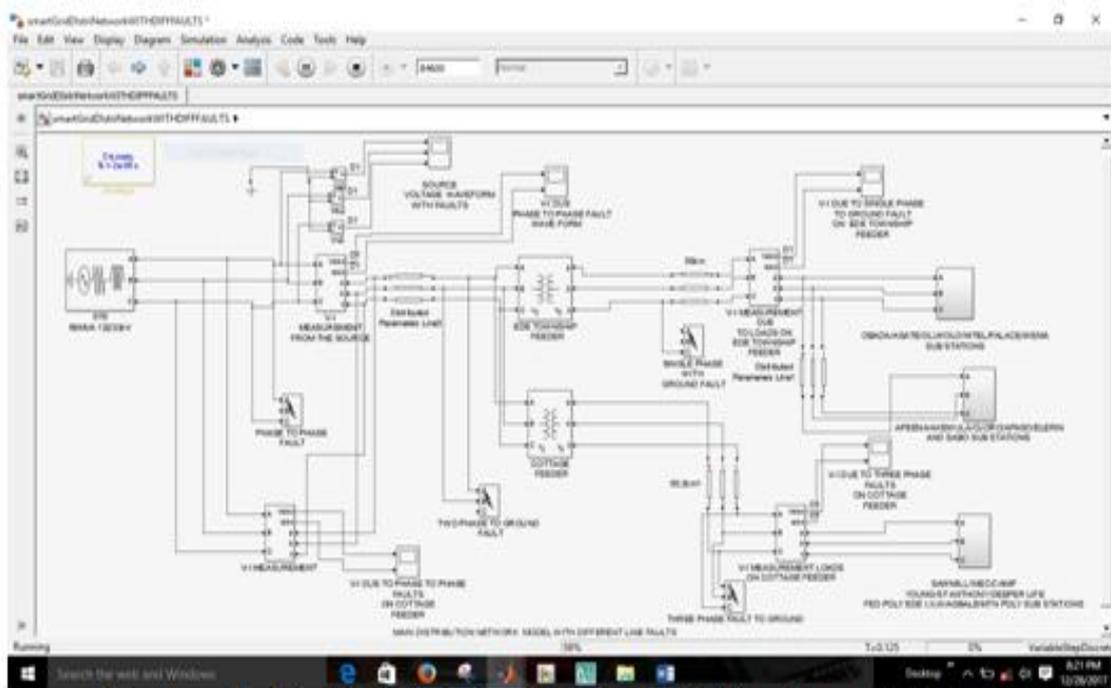Algorithm for Modelling on MATLAB/Simulink is detail in [16].

Figure no. 5: The distribution network system with different types of line faults

Table no. 1: Parameters Used For Modeling Distribution Network (Source: Osun Region Of Ibedc)

S/N	ITEMS	BOOK DESCRIPTION	PARAMETERS USED FOR MODEL
1	5T5 60MVA 132/33kv	Step down transformer at the National Control Center (Osogbo Nigeria)	➢ Phase to phase voltage(v) =132kV ➢ Phase angle of phase A =0° ➢ Phaseangle of phase B = -120° ➢ Phase angle of Phase c = 120° ➢ Frequency = 50Hz ➢ 3 phase Short circuit level of base voltage (VA) = 100MVA ➢ Base voltage (V_{rms} phase to phase) = 25kV ➢ $\times/r = 7$ ➢ Generator type Swing
2	Ede town feeder & cottage feeder	The main feeder serving some of the town (distribution network)	➢ Parameters on each feeder ➢ Normal power: 15MVA frequency : 50Hz

			➤ Winding 1 parameters V_1 ph-ph(V_{rms}) = 1.32×10^5 V R_1(pu) = 0.014882 L_1 (pu) = 0.49608 ➤ Winding 2 parameters V_2 ph-ph (V_{rms}) = 33×10^3 R_2(pu) = 0.43736 L_2(pu) = 1.4579 ➤ Magnetization resistance R_m(pu) = 500 ➤ Magnetization inductance L_m(pu) = 500
3	Distributed Line parameters	The transmission line between the power source(NCC) to the various loads on distribution network(destination)	➤ Number of phase(N) = 3 ➤ Frequency (f) = 50Hz ➤ Resistance/unit length(Ω/Km) = [N×N]matrix [0.01273 0.3864] ➤ Inductance/ unit length(H/km) = [N×N] matrix [0.9337 ×10^{-3} 4.1264×2×10^3] ➤ Conductance /Unit length (f/km)[N×N]matrix [12.74 × 10^9 7.751×10^9] ➤ Length of line(km) = 20 & 50.2 respectively 20 & 50.2 respectively
4	V.I measurement block	Ideal for 3 phase voltage and current measurements	➤ Voltage measurements = phase to ground ➤ Base power(VA) = 100MVA ➤ Normal voltage measurement(pu) (V_{rms} phase to phase) = 500MV
5	Distribution transformer (Typical Substation)	the transformer step down the voltage to consumable voltage (415V)	➤ Note; All measurement in (pu) ➤ Normal Power (VA) = 5×10^3 ➤ Frequency: 50Hz ➤ Winding 1 parameter V_1 (ph-ph) V_{rms} = 11kV R_1(pu) = 0.51529 L_1 (pu)1.9843 ➤ Winding 2 parameters V_2 (ph-ph) V_{rms} = 0.415kv R_2(pu) = 0.0984021 L_2(pu) = 3.2801 ➤ Magnetization resistance R_m(pu) = 500 ➤ Magnetization inductance L_m(pu) = 500
6	Phase to Phase Fault	The block model represent The fault with phase to phase fault characteristics	➤ Fault resistance(Ω) = 0.001 ➤ Transform status [1 0] ➤ Translation [1/60 3/60] ➤ Snubber Resistance [Ω] =1×10^6
7	Two phase to ground fault	The block model represent the fault with two phase to ground characteristic	➤ Fault resistance(Ω) = 0.001 ➤ Transform status [1 0] ➤ Translation [1/60 3/60] ➤ Snubber Resistance [Ω] =1×10^6
8	Single Phase With Ground Fault	Fault model with single phase to ground fault characteristic	➤ Fault resistance(Ω) = 0.001 ➤ Transform status [1 0] ➤ Translation [1/60 3/60] ➤ Snubber Resistance [Ω] =1×106 ➤ Snubber capacitance Cp (farad) =inf
9	Three Phase To Ground Fault	Three phase fault characteristics	➤ Fault resistance(Ω) = 0.001 ➤ Transform status [1 0] ➤ Translation [1/60 3/60] ➤ Snubber Resistance [Ω] =1×106 ➤ Snubber capacitance Cp (farad) = inf .
10	Typical Load On the Network	The model represent the load on each of the substation it represents the resistance, capacitive and inductive load on the network	➤ Normal voltage ph to ph =11kV ➤ Normal frequency =50Hz ➤ Active power 10×10^6 W ➤ Inductive reactive power 2.5×10^6Var. ➤ Capacitive reactive power =100 Var ➤ Type of load = constant z

V. Results of Faults Simulation

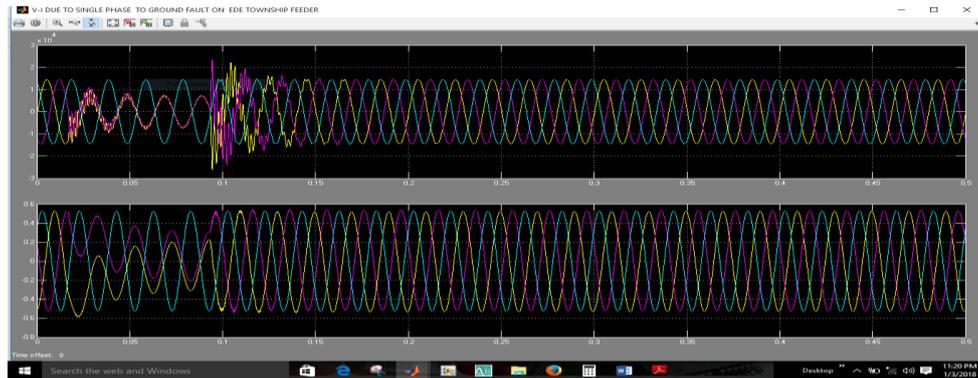The waveforms for the various categories of faults are shown in Figures no. 6 to no. 10.

Figure no. 6: Waveform Results of V_{abc} and I_{abc} of modeled Single phase with ground fault
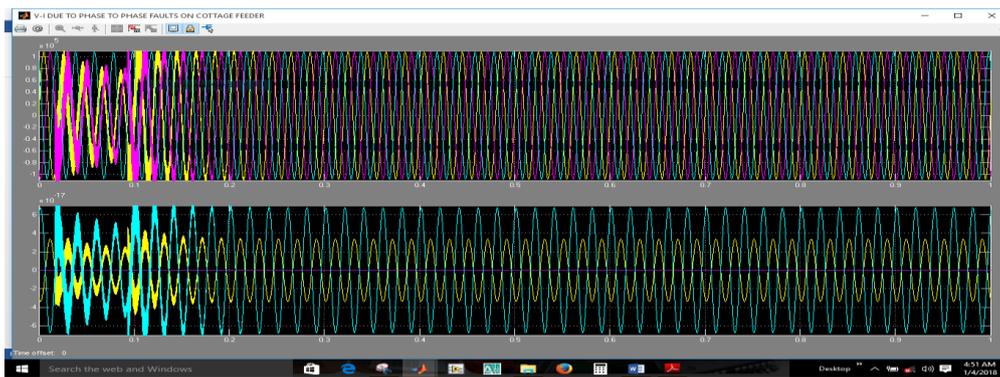

Figure no. 7: Waveform Results of V_{abc} and I_{abc} of modeled phase to phase fault
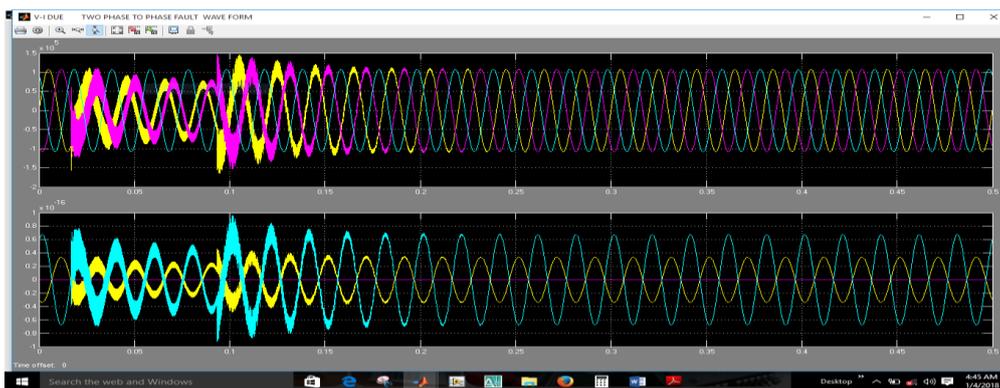

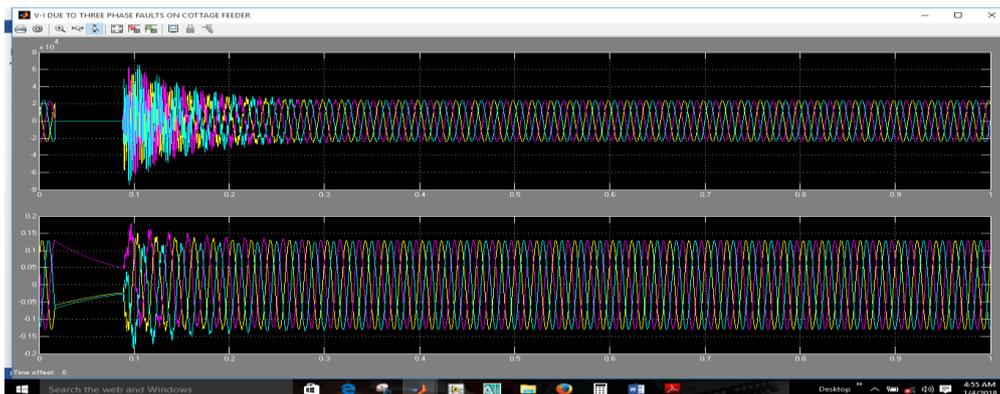**Figure no. 8:** Waveform results of V_{abc} and I_{abc} of modeled two phase with ground fault

Figure no. 9: Waveform results of V_{abc} and I_{abc} of modeled three phase with ground fault
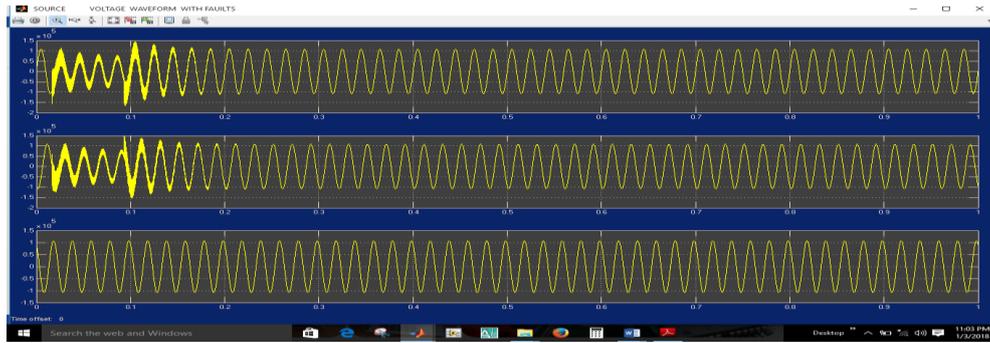
Figure no. 10: Waveform result of source Voltage with fault

VI. Discussion of Results

Single Phase Fault to ground

      The single phase fault to ground lead to distortion on one of the three phases as shown in Figure no. 6, however, this is prominent on yellow phase. Although, the effect is not so adverse. The single phase fault on the yellow phase result to some interruptions on the phase, it also has some effect on the other phase. However, over certain time lag, the fault is cleared off and waveforms become normal as shown on the simulation result obtained.

From Figure no. 6:
1 division = 0.025 s
1 complete cycle = 10 divisions
1 cycle = 0.025 * 10
= 0.25s.
Duration of interruption R_i = 60 * 0.25
= 15
No of Customer served N_t = 38185
No of interrupted Customers N_i = 1:4 = 38185/5
= 7637
Sum of Customer Interruption Durations = 15x 7637
= 114555
SAIDI = $N_i R_i / N_t$
= 114555/38185 = 3.0
SAIFI = 5
CAID = 3.0/5 = 0.6
ASAI = 1- [(114555/ (38185*24)]
= 0.88

Two Phase to Ground Faults
From Figure no. 7:
Duration of interruptions = 0.2x60
= 12
No of interrupted Customers N_i = 38185/6
= 6364
Sum of Customer interruption = 12 * 6364
= 76368
SAIDI = 76368/38185 = 1.999995
SAIFI = 6
CAIDI = 1.999995/6
= 0.3333
ASAI = 1-[(76368/38185*24)]
= 0.916

Phase to Phase Faults
     From Figure no. 8:
Duration of interruption = 0.15 * 60 =9.0
No of interrupted customers = 38185/8 = 4773

Sum of Customer interruption = 9*4773 = 42957
SAIDI = 42957/38185 = 1.125
SAIFI = 8
CAIDI = 1.125/8 = 0.0134
ASAI = 1-[(42957/38185 * 24)]
 = 0.9531

Three Phase to Ground
From Figure no. 9:
Duration of interruption = 0.18 * 60
 = 10.8
No of interrupted customers N_i = 1:3
 = 38185/4 = 9546
Sum of customer interruption = 10.8 * 9546
= 103096.8
SAIDI = 103096.8/38185
 = 2.7
SAIFI = 4
CAIDI = 2.7/4 = 0.675
ASAI = 1-[(103096.8/ (38185*24)]
 = 0.8875

Source Voltage waveform with fault
　　　　Figure no. 10 shows waveform of the source voltage from National Control Centre (NCC). The waveforms are observed not to smooth neither are they accurate. We observed some sparks and distortion. This indicates that the overall power quality from the source have been distorted as a result of interruptions due to the combination of different types of line faults on the system. This has validated results obtained in appraisal of reliability using data from IBEDC, Osun region in [15] on 33kV Ede Water Works feeder. Practically this is what happen on the distribution network. This justify the need to make the system return to approximately ideal state All the above waveforms are results of the modeled Ede feeders that are modeled on MATLAB/Simulink to validate the results obtained with data gathered from Osun region of IBEDC, South West, Nigeria in [15].

For Figure no. 10; 33kV Water Works Feeder;
No of Customer served = 58513
Duration of interruptions = 2.0 * 60
= 120
No of interrupted customers N_i = 58513/20
 = 2925
Sum of interruption customers = 120* 2925
= 351000

SAIDI = 26325/58513
 = 5.9987
SAIFI = 20
CAIDI = 5.9987/20
= 0.29993
ASAI = 1-[(351000/ (58513*24)]
= 0.7500.

VII.　Conclusion
　　　　In this paper, a new simulation methodology of faults incorporation into distribution networks was presented. MATLAB/Simulink was used as the tool to build the simulation environment. The strength of this simulation method falls in the ability to study the effect of different kind of faults on the system behavior. The other advantage of this method is its flexibility in building different kind of faults and ability to appraise the gravity of effect on network systems and assist to validate the results of reliability appraisal using real data from IBEDC. This simulation methodology could be used to build different fault types and opens the doors to use the MATLAB in this new field.

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