OPTIMAL SITING OF PROTECTION RELAY FOR DISTRIBUTION SYSTEM

Nidharshan R#1, Madhavaraja RS $2, Mahima G*3, Dr.J.SenthilKumar^4

[1,2,3] *Dept of EEE, Bannari Amman Institute of Technology*

[4]*Assistant Professor Level III,Dept of EEE, Bannari Amman Institute of Technology*

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Abstract — ***In today's contemporary world, ensuring the dependability and security of electrical power supply is a top priority. However, the increasing complexity of power systems makes it difficult for protective measures to satisfy these key objectives. Fortunately, relays have evolved as a critical component capable of performing complex processing tasks quickly and precisely. The time-current characteristics of overcurrent protection devices are critical in distribution systems. These qualities are carefully chosen and designed to guarantee that, in the case of a breakdown, protection devices activate in a specified time sequence. To solve this, a three-load distribution system has been methodically constructed and extensively simulated under various failure scenarios. The simulation results show that the system successfully regulates the relays, allowing them to respond quickly andprecisely during fault circumstances. As a consequence, even when faults occur, the system constantly supplies power, ensuring the dependability and security of the electrical supply inside the distribution network.***

Keywords— relay, three phase fault, circuit breaker, distribution system, domestic load, high tension load.

1. INTRODUCTION

Electricity generation typically begins at power plants with voltages ranging from 11-25 kV. To transmit electricity efficiently across long distances, it is transformed to higher voltages, such as 200 kV or 400 kV, and conveyed through a high-voltage transmission network of wires. These transmission lines connect to load centers, primarily cities, through a sub-transmission network consisting of 132 kV (or occasionally 66 kV) lines.

Upon entering a 132 kV (or 66 kV) substation, the voltage is lowered to 33 kV or 11 kV, which is suitable for the subsequent distribution through 11 kV and lower power line networks. The power delivery equipment within the transmission and distribution system is organized into various levels. At these load points, transformers reduce the voltage from 11 kV to 415 kV, providing the final connection to individual customers. Customers receive power at either 240 V (single-phase supply) or 415 V (three-phase supply) via 415 V feeders, also referred to as Low Tension (LT) feeders.

These feeders can be either underground cables or overhead wires, and it is essential for a 415 V feeder to have a relatively short length, typically ranging from 0.5 to 1 km, to ensure low voltage at the consumer's end. The development of power supply infrastructure and transmission and distribution networks initially prioritized urban areas and towns, predominantly catering to the needs of households and businesses during the early stages of the needs of households and businesses during the early stages of the country's powerdevelopment.

In the field of power systems, the validation of power protection equipment settings and performance is imperative, especially when considering various fault scenarios. Swift identification and correction of issues in the power system's location are vital to ensure a continuous and uninterrupted power supply to the load. Efficient coordination and reliable equipment protection play pivotal roles in mitigating potential problems. A significant focus of research within this domain revolves around conducting simulations and analyses pertaining to overcurrent relay coordination in both radial and parallel feeder networks. This research aims to enhance the effectiveness of protective measures and ensure the seamless functioning of power systems.

2. LITERATURE SURVEY

[1] Pritam V. Warbhe and colleagues have detailed a modeling strategy for overcurrent relays using MATLAB/SIMULINK. This approach involves classifying overcurrent relays into categories such as fast, definite time, inverse time, and inverse definite minimum time (IDMT) based on their time characteristics. A significant aspect of this technique involves comparing the response times between ideal and calculated results of the overcurrent relay. It also assesses the relay's performance in response to operational conditions and fault currents, including the time it takes to trip the relay.
In a separate study, Muhammad Shoaib Almas and his team

[2] have presented a model for overcurrent relays using Sim Power Systems in MATLAB/Simulink. They have incorporated thismodel into a test case, and the entire system is subjected to real- time simulation using Opal-RT's eMEGAsim real-time simulator. This analysis aims to evaluate how the relay functions when exposed to various faults. Furthermore, hardware-in-the-loop validation of the model is conducted, employing the overcurrent protection feature in the Schweitzer Engineering Laboratories Relay SEL-487E.
Acharya Sandesh and colleagues

[3] contribute to the field by addressing the coordination of overcurrent relays within radial and parallel feeder networks, focusing on the time-current characteristics. Their research involves conducting experiments in an electrical laboratory to establish observations and configurations for radial and parallel feeder networks. This hardware implementation study also includes an examination of the time it takes for overcurrent relays

to operate, with a comparison to simulation results and findings from the ETAP software.

[4] Yin Lee Goh and team discuss the development and investigation of an overcurrent relay implemented using DSP, specifically the TMS320F2812. Prior to the DSP implementation,the overcurrent relay is modeled within MATLAB/Simulink. Thestudy provides a comparative analysis of simulation results and hardware execution based two different implementation methods.

Finally, Dr. Shakuntla Boora and colleagues [5] have developed a MATLAB-based simulation model for the analysis of symmetrical and unsymmetrical faults in three-phase systems. This model is used to assess the impact of various types of faults on system variables such as voltage and current. Additionally, this research is focused on the efficient and compact application of this simulation model for renewable solar power systems

III METHODOLOGY

Distribution system planning is a critical aspect of ensuring that the increasing demand for electricity is met through technically sound and cost-effective expansions. Unfortunately, distribution system planning has often been neglected. Electrical utilities require a fast and cost-efficient planning tool to evaluate the implications of various proposed alternatives and their impact on providing affordable, reliable, and safe electrical power to customers. The primary objective of distribution system planning is to address the rising demand for electricity, considering factors like growth rate and high load densities. Distribution system planners must accurately assess load capacities and their geographical distribution. The proposed system involves both single-line and double-line distribution systems, accommodating three different types of loads: High Tension load, and domestic loads connected in series and parallel combinations. Each load is equipped with circuit breakers and relay logic. This system is implemented using various blocks and simulated using MATLAB Simulink tool. The data feed for the simulation is given in Table 1.

Table 1. Simulation System Data

S. No	Part No	Description	Power	Voltage	R	X
1	G1	Generator	55MVA	11kV	0.89	16.58 mH
2	T1	Transformer	250MVA	11kV/132kV	500	500
3	CB	Circuit Breaker	-	-	0.01	inf
4	TL	Transmission Line	100 km	132kV	0.013	4.12mH
5	T2, T4	Transformer	250MVA	132kV/33kV	500	500
6	T3	Transformer	250MVA	132kV/44kV	500	500
7	T5	Transformer	250MVA	33kV/2kV	500	500
8	T6	Transformer	250MVA	33kV/415V	500	500
9	HT 1	HT Load	100kW	33kV	-	10
10	DL 1	Domestic Load 1	100kW	415	10	100
11	DL 2	Domestic Load 2	100kW	415	100	10

While expansions in the high-voltage transmission system (110kV and above) have been based on systematic load flow and system studies, sub-transmission and distribution system extensions (66kV and below) have often been driven by immediate needs, lacking proper planning and system studies to establish optimal network configurations, substation locations, and backup network adequacy. Consequently, distribution networks have grown in an unplanned and disorganized manner. It is worth noting that a significant portion of total losses, approximately 70%,occurs in the primary and secondary distribution system, whereastransmission and sub-transmission lines account for only 30% of these losses. Distribution losses currently stand at 15.5% of generation capacity, with a target level of 7.5%. Achieving this target necessitates proper planning of the primary and secondary distribution system, focusing on loss reduction, improved revenue collection, enhanced customer satisfaction, and other measures.

4. IMPLEMENTATION

Distribution systems can be highly intricate, featuring diverse feeder arrangements, substation connections, and varying load conditions. Simulink, with its adaptability, empowers the creation of complex network topologies and dynamic representations of these systems. This enables engineers to model fault scenarios, including both short-circuit and open-circuit faults, in distribution systems. Simulink's fault analysis feature serves as a valuable tool for assessing the impact of these faults on system performance, protection schemes, and the time taken to clear faults. Simulink also offers the capability to conduct load flow analysis, which is essential for evaluating voltage profiles, losses, and power flows in distribution networks across different operational conditions. This analysis is fundamental for network planning and optimization. Engineers can employ Simulink to design and test voltage regulation strategies, which play a crucial role in maintaining voltage levels within acceptable limits in distribution systems and determining effective voltage regulation. The proposed system utilizes the Simulink toolbox within the MATLAB 2016a software package. The simulation models provide a comprehensive representation of the power system, featuring three distinct distributed loads with varying voltage and power levels. Figure 1 illustrates the simulation model for a single-line distribution system with a fault occurring on the High-Tension Load (HT), while Figure 2 showcases the simulation model for a double-line distributed system with a fault on the domestic load's first line.

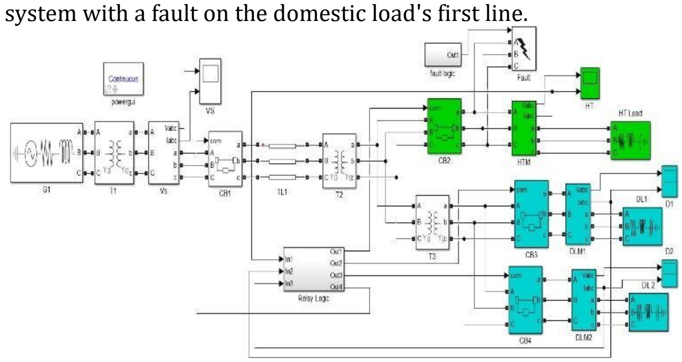

Fig.1 Simulink Model of Single Line Distribution System

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The proposed system has been realized using the Simulink toolbox within the MATLAB 2016a software package. The simulation models are designed to elucidate the power system, incorporating three distinct distributed loads characterized by varying voltage and power levels. Simulink, as a versatile and robust platform, offers a means to model, simulate, and analyze distribution systems effectively. It serves as a valuable tool for engineers and researchers, aiding in the comprehension of system behavior, optimization of operations, and the development of innovative technologies aimed at enhancing the efficiency and reliability of electrical energy distribution.

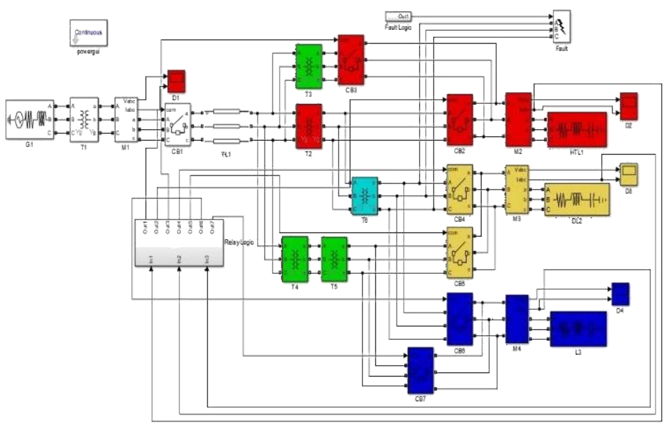

Fig.2 Simulink Model of Double Line Distribution System

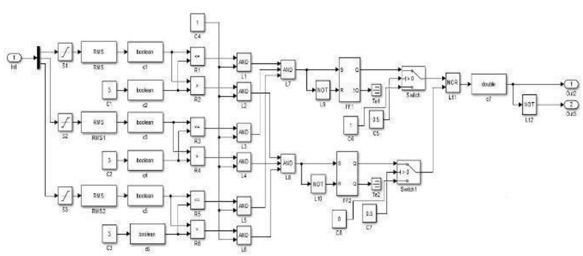

Fig.3 Simulink Model of Relay Logic

In Fig. 3, we can observe the relay logic circuit responsible for controlling the operation of circuit breakers situated near the load lines. The logic is defined to process the three-phase load current, received as input through input port 1. To manage these currents, the three-phase signal is individually split into single-phase line currents using a demultiplexer block. Each analog input current is then passed through a saturation block, which converts the varying current into a fixed range of values. Subsequently, these values are directed to an RMS converter block, which transforms the signal from saturation into its equivalent root mean square value.

The output of the RMS conversion yields a double value, which is further converted into Boolean values through a data conversion block for subsequent digital computations utilizing gates and relational operators. These Boolean values are then compared with the constant maximum values representing the individual phase load currents. The resulting values are then fed into memory elements blocks, generating continuous pulses for the relay logic controlling the circuit breaker's operation.

This process is repeated for both the ON and OFF conditions separately. The output from the SR flip-flop is directed to the switch selector, and the final relay activation signal is transmitted to the circuit breaker in the form of a double value through the outport block. This same logic and circuitry are replicated for all other circuitbreakers linked to different loads within the distribution system.

RESULTS AND DISCUSSION

The proposed distribution model has been successfully simulated using the MATLAB 2016a software, with a simulation time interval of 10 milliseconds. In the initial circuit model, a programmed fault condition is simulated, spanning a time period of 4 milliseconds, specifically occurring from 0.7 to 1 millisecond. This simulation encompasses the programmed generation of a three-phase fault and the implementation of circuit breakers using relay logic blocks.

Figure 5.1 provides a visual representation of the Simulink model for the three-phase distributed system with the fault conditions. The simulation extends over 10 milliseconds, with the programmed faults occurring between 1 to 2 milliseconds, as stipulated by the logic conditions. It's important to note that the fault current and voltage disturbances have a direct impact on the source voltages since the loads are directly connected to a single-source network.

Figure 4 offers an insight into the source voltage and current waveforms across the entire simulation period. Meanwhile, Figure 5 and Figure 6 depict the source voltage and current waveforms during the fault condition and in the aftermath of the fault condition.

Notably, the High Tension (HT) load line is also programmed to experience three-phase faults, and the resulting fault currents and voltage spikes have significant implications for the entire load system, affecting both the distribution network and the generating station.

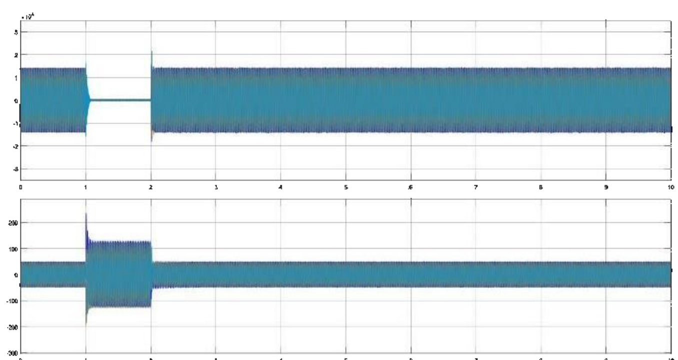

Fig.4 Source Voltage and Current Waveforms for Single Line Network

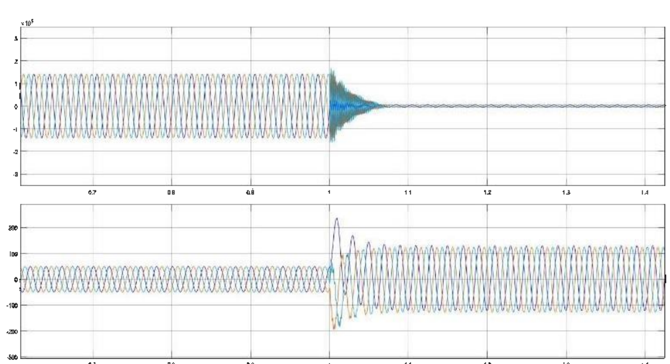

Fig.5 Source Voltage and Current during Fault Condition

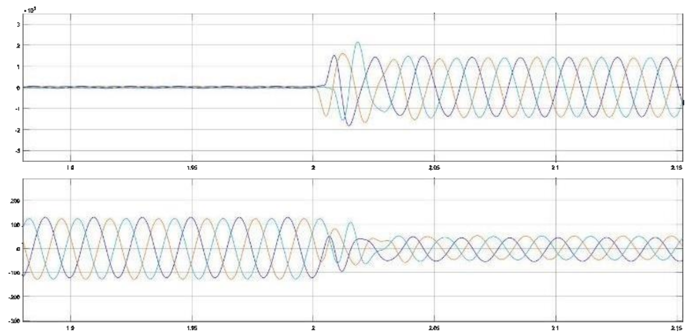

Fig.6 Source Voltage and Current after FaultCondition

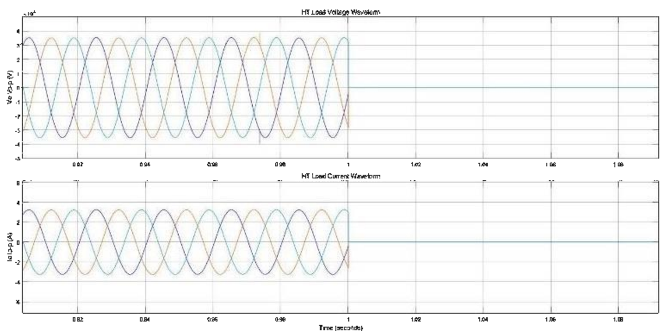

Fig. 7 HT Load Voltage and Current during FaultCondition

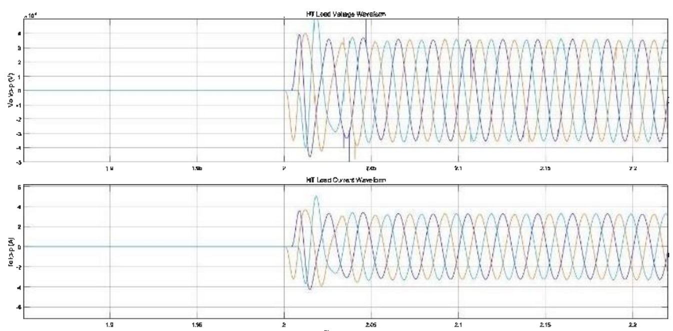

Fig. 8 HT Load Voltage and Current after FaultCondition

Fig.7 represents the load voltage and current during the fault condition across the HT load. Fig.8 shows the load voltage and currentafter the fault occurrence at the HT load.

The load voltage and current waveforms as shown from fig.7 and fig.8 have various levels of voltage spikes occurring in HT load with normalized current values. Due to this fault in the HT load, that has the impact on the low power domestic load lines also, this is because all the loads share the common single bus generation system.

The load voltage and current waveforms of domestic loads are shown from fig. 9 and fig. 10. The above simulation results infer that even a single three phase fault occurs in any one of the distribution load systems has the impact on the other loads and generation systemalso. This problem has to be addressed so the simulation model is reframed with the double protection scheme for the distributed load system.

This proposed system ensures that the other loads connected to thesingle bus system is isolated from the faulted load and it also has the advantages that the load power will be continuous even if any fault occurs on any one of the load systemsand the proposed system has the advantage that it is vulnerableeven if fault happened.

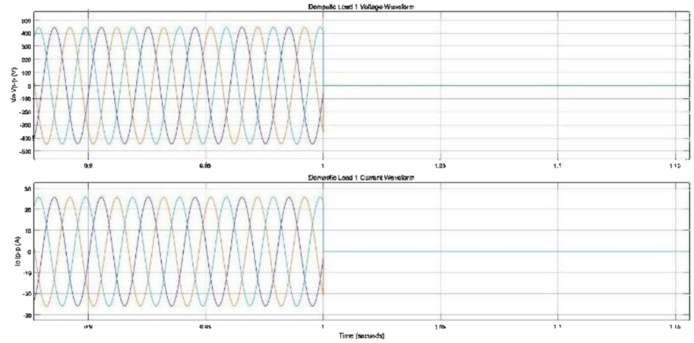

Fig. 9 Domestic Loads Voltage and Current during FaultCondition

The proposed system introduces an additional double line for the load distribution network, ensuring uninterrupted power supply to the loads without causing transients in the other connected loads on the same bus system. This system's fault tolerance is a key feature, leading to enhancements in the voltage and current profiles of the generating station. However, it's important to note that the proposed system does come with a drawback - it exhibits poor voltage regulation, and there are moreinstances of voltage spikes.

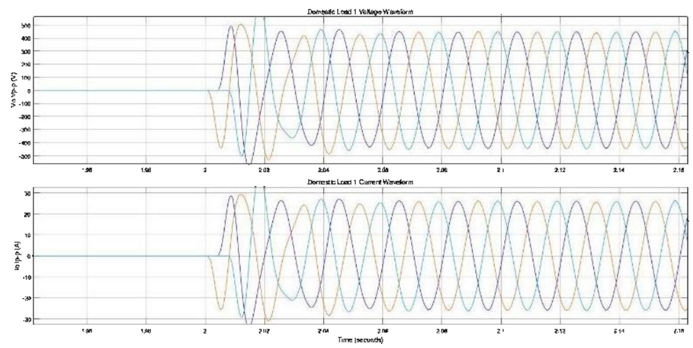

Fig. 10 Domestic Load 2 Voltage and Current after FaultCondition

Compared to a single-line distribution network, the source voltage and current profiles have shown significant improvements in the proposed system, offering continuous power to the loads, even in the presence of a faulted load line. The power is routed through auxiliary circuit breakers equipped with dedicated transformers designed to bypass power during fault conditions, which are managed by the primary circuit breaker. In order to provide a visual representation of the system's performance, the load voltageand current waveforms for the source side, High Tension (HT) load,and domestic loads are presented in Figures 11, 12, 13, and 14, respectively.

Table 2 provides a comparative analysis of simulation results for both the single- and double-line distribution systems, highlighting the key differences and benefits of the proposed system

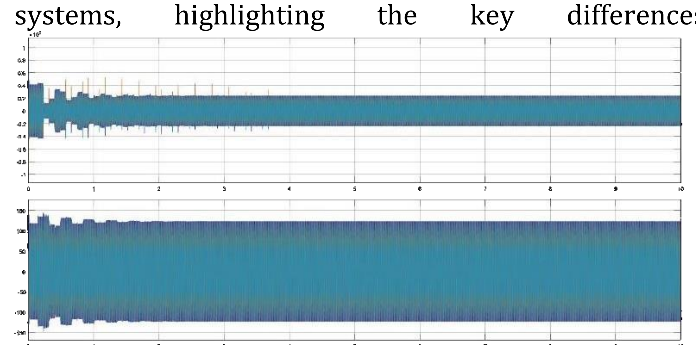

Fig. 11 Source Voltage and Current Waveforms for Double Line Network

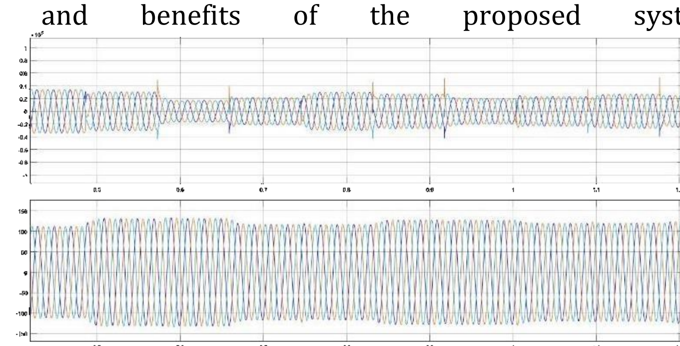

Fig. 12 Source Voltage and Current during Fault Condition

Table 2. Comparator Results of Simulations

S.No	Device	During Fault Condition				After Fault Condition			
		Single line DS		Double line DS		Single line DS		Double line DS	
		Voltage (kV)	Curren t (A)	Voltage (kV)	Current (A)	Voltage (kV)	Curren t (A)	Voltage (kV)	Curren t (A)
1	Generating Side	800V	120	33	120	140	50	11	80
2	HT Load	0	0	1	1.8	40	2.8	2.8	1.9
3	Domestic Load 1	0	0	550	25	415	25	415	28
4	Domestic Load 2	0	0	410	28	415	25	415	28

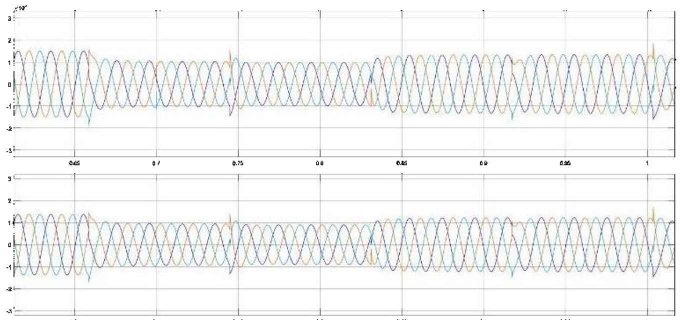

Fig. 13 HT Load Voltage and Current during Fault Condition

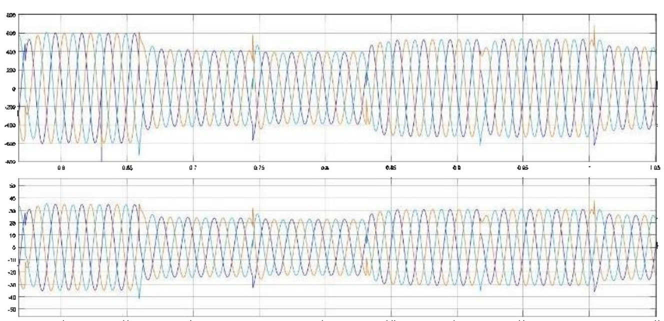

Fig. 14 Domestic Loads Voltage and Current during Fault Condition

5. CONCLUSION

The distribution power system faces a recurring issue involving frequent failures, primarily attributed to nonlinear fault characteristics that can occur at any load, subsequently affecting the entire connected load network. These faults often result in voltage spikes and current dips, leading to reduced power factor, which can,in turn, cause equipment failures within domestic loads.

To address this challenge, a single-line power distribution system was successfully modeled and simulated. This system featured three distinct loads at varying voltage levels. The simulation incorporated programmed three-phase faults at specificloads, allowing for a comprehensive study of their voltage and current profiles. The insights gained from this analysis led to the proposal of a new double-line model.

The proposed double-line distribution system was also successfully modeled and simulated within the framework of the existing single-line distribution system. This model integrated auxiliary circuit breakers dedicated to specific loads, each with its individual transformer source. The results demonstrated the system's robust fault tolerance capabilities, with faulted load circuits being bypassed by auxiliary circuit breakers to ensure a continuous power supply to the loads, even in the presence of faults. Importantly, this new system showed a significant reduction in the propagation of fault effects from one load to another and to the generating station.

The success of this proposed system opens up new avenues for further improvements, particularly in addressing voltage spikes on the load side and enhancing the voltage and current profiles of the generating station. This can be achieved through the thoughtful design and implementation of series and shunt active filters using solid-state devices, promising a more stable and reliable power distribution system.

7- ACKNOWLEDGMENT

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