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ENHANCING ACCURACY OF FAULT DETECTION SYSTEM AND REDUCING OUTAGE TIME WITH GIS: A CASE STUDY OF ARBA MINCH ELECTRICAL DISTRIBUTION SYSTEM

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Abstract

Fault detection and location in electrical distribution systems are critical for maintaining a reliable electric power supply and minimizing outage time. The Arba Minch District distribution department of Ethiopian Electric Utility (EEU) currently employs a manual trial-and-error approach for fault detection and location of the faults, is not only inefficient, time-consuming, and ineffective in the current state of the arts but crucial for resolving faults. This study evaluates the current approach and proposes an enhanced system utilizing Geographic Information System (GIS) technology to improve fault detection and location in the Arba Minch distribution system, specifically at the Shecha feeder. The implementation of GIS-based fault detection and location aims to address the limitations of the manual method and mitigate economic losses associated with feeder faults. By synchronization of the ETAP circuit and ETAP GIS network, the location of the fault visualized in the ETAP-GIS system. The GIS system achieved a 99.11% reduction in fault detection and location time relative to the conventional method. In this research by optimizing fault detection and locating time, the System's Average Interruption Duration Index (SAIDI) for the feeder significantly reduced from 216.36 to 1.93 hours/customer per fault. Consequently, the GIS system also eliminated economic losses associated with energy unsupplied (24,784.58 kWh and 13,625.41 kVArh) and non-collected revenue (42,000 ETB for 1 hour, 78,288 ETB for 1.864 hours, and 231,000 ETB for 5.5 hours). The results demonstrate the potential of GIS technology in enhancing fault detection and location, ultimately improving the reliability and efficiency of the distribution system.

Keywords: ***ETAP, GIS, Fault detection, Fault location, Distribution systems, SAIDI***

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I. INTRODUCTION

Electric power is vital for economic progress in a country. It encompassing generation, transmission, and distribution systems to deliver electricity to users. In the developing countries such as Ethiopia the disruptions in the distribution network are commonplace and present significant obstacles. The electricity distribution system consists of primary distribution feeders, distribution transformers, distributors, and service lines. Electricity produced at plants converted to lower voltage at substations, carried via primary distribution feeders to distribution transformers, and further decreased in voltage. In the current system the low-voltage power links to distributors or directly to consumer loads. Service lines transporting low-voltage electricity link to distributors and furnish power to users. Distributors classified as distributors and sub-distributors, are establishing an effective framework for delivering electricity to consumers [1].

In 2013, Ethiopia restructured its electric power sector, leading to the formation of two distinct entities: Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). EEP primarily handles electricity generation and transmission at voltages above 66 kV, while EEU oversees sub-transmission systems up to 66 kV and the distribution of electricity to end-users. Power transformers of varying capacities supply distribution transformers, typically deployed at standard medium voltage levels of 33 kV and 15 kV. The distribution grid follows a radial layout, with distribution transformers of various ratings stepping down the voltages of 33 kV and 15 kV to deliver 400 volts for three-phase systems and 230 volts for single-phase consumers [2].

In the current scenario the power demand on the distribution system continually changes [3]. To handle this, change the structure of distribution networks is undergoing profound changes. These networks are becoming increasingly intricate with the integration of new technologies, while the electricity demand continues to rise steadily [4]. Electrical circuit failures and disruptions to normal circuit functioning stem from physical faults, often triggered by over- currents, over-voltages, short circuits, open circuits, and damaged devices. Short circuits or overloads, the primary culprits, create abnormal connections or disturbances and divert current from its intended path. Short circuit faults exhibit either low or significant impedance.

Activation of a protective device in response to a short circuit fault may lead to service interruptions for utility customers. Conversely, high impedance faults with ample impedance to thwart protective devices may not cause outages, but they can still induce power quality issues and

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potential harm to utility equipment [5].

Effective fault detection and location are fundamental to the operation of electrical distribution systems. Traditional methods, such as impedance-based and traveling wave techniques, have been widely employed but often fall short in terms of accuracy and response time, especially in complex network environments [6], [7]. These limitations necessitate the development of more advanced solutions.

Modern smart grids and smart cities rely on efficient fault management for optimal functionality. This involves swiftly identifying and isolating faults, strategically deploying backup resources to restore power to affected customers, and minimizing the impact of outages. By automating fault location and service restoration, smart grids can significantly improve reliability and decrease revenue losses caused by interruptions. These interruptions, often due to weather events, equipment malfunctions, road work, and other factors, make up about 80% of all customer disruptions in electric power distribution networks [5].

The reliability of electrical distribution systems is heavily dependent on effective fault detection and location techniques. Historically, identifying faults in distribution networks has been a challenge for utility companies. Extensive research has focused on developing fault location methods to expedite service restoration, reduce outage time, and ultimately lower associated costs [8]. Traditional methods for detecting faults, like impedance-based and traveling wave techniques, have widely used. However, these methods can struggle with accuracy and speed, especially in large and intricate networks [9]. These traditional methods are gradually supplemented by more advanced technologies to address their limitations.

ETAP GIS offers a significant advantage in fault detection by seamlessly integrating electrical one-line diagrams with geographical maps, providing a comprehensive and dynamic tool for accessing, analyzing, and managing geospatial information. GIS provides a robust framework for integrating spatial data with real-time monitoring, facilitating precise fault localization and rapid response. By leveraging GIS, utilities can visualize the network topology, analyze spatial relationships, and efficiently deploy resources to fault locations [10],[11]. Compared to AI-based systems, which require extensive data and specialized knowledge, and IoT-enabled fault passage indicators, which depend on reliable communication networks and robust security measures,

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ETAP GIS stands out for combining geospatial and electrical data effectively [12]. This makes it particularly valuable for utilities looking to improve their fault detection capabilities while maintaining a clear and intuitive overview of their electrical network.

Incorporating GIS into fault detection systems has shown significant promise. For instance, GIS-based systems can process and visualize large volumes of data, offering insights into the spatial distribution of faults and their impacts on the network [5]. ETAP GIS can handle various network configurations and complexities making it suitable for different types of electrical distribution systems, whether urban or rural.

The Arba Minch distribution system, located in southern Ethiopia presents unique challenges due to its diverse topography and rapidly expanding infrastructure. The region's increasing demand for reliable electricity necessitates innovative solutions for fault management. In Arba Minch, traditional methods are employed to pinpoint outage areas in the 11kV and 15kV distribution network using earth fault indicators installed at distribution substations. Technical staff patrol the suspected faulty feeder and inspect the fault indicator's status to identify the faulty section of the feeder. Subsequently, they perform necessary isolation operations before restoring supply to consumers. Occasionally, switching operations are necessary to pinpoint the faulty section. Moreover, faults typically detected only when customers report outages, after which onsite fault location techniques utilized for LV feeders. This fault location process is time-consuming and may subject feeder cables to stress from frequent switching actions or high voltage surges from surge wave generators.

This paper explores the application of GIS technology in enhancing fault detection and the location of the faults within the Arba Minch distribution system. By utilizing GIS, the research seeks to demonstrate improvements in fault detection accuracy, localization detection speed, and overall system efficiency.

II. MATERIALS AND METHODS

A. Data Collection

The information gathered includes the ratings and loads of each transformer, the GPS coordinates of all transformers, some suspension poles, and all poles with angles along the Arba Minch Shecha

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feeder as shown in Fig.1. This data was collected through primary methods like surveys, observations, and measurements. Transformer loads were measured using Clamp meters and Energy analyzers. The GPS coordinates of transformers, poles, and line lengths were obtained through surveys and GPS GARMIN measurements at EEU Arba Minch District. Secondary data, such as outage times of faults and information needed to identify these faults, were acquired through interviews with the Arba Minch substation and the Arba Minch district distribution operation department.

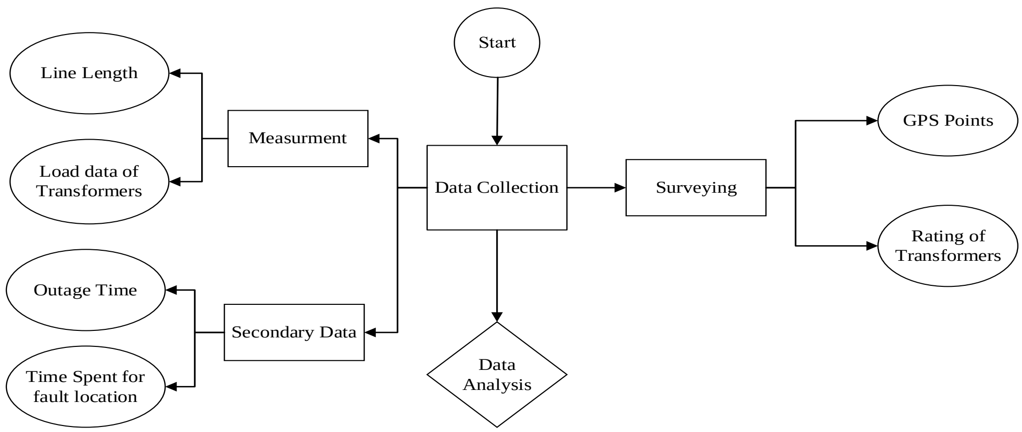

Fig.1. Data collection methods

The types of overhead line conductors are all alloyed aluminum conductors (AAAC) with the cross-sectional are sizes of 50 mm^2 and 95 mm^2. There are 31 public and 31 private transformers with ratings 25, 50, 100, 200, 315, 500, 630, 800 and 1250 KVA. The three-year data of fault duration greater than an hour is taken from the Arba Minch substation and the time required to find the corresponding fault is collected from the Arba Minch District distribution operation department. The Arba Minch substation is depicted in the single-line diagram shown in Fig.2.

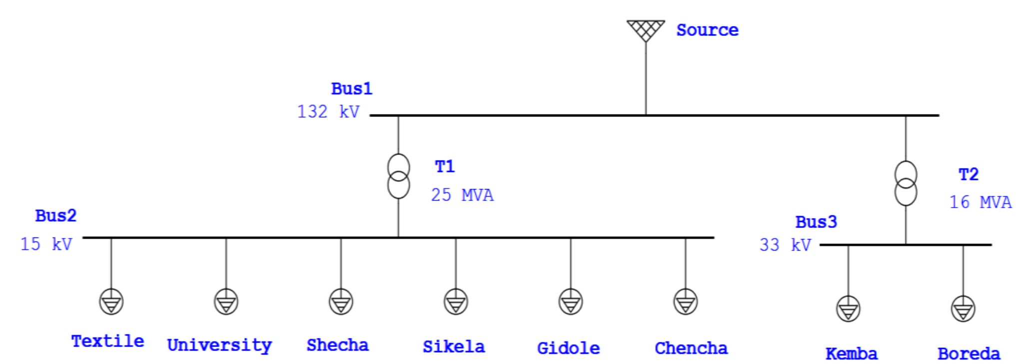

Fig. 2. Single line diagram of Arba Minch substation

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Fig. 3., which was created using real data, depicts the single-line diagram of the Shecha feeder,. The feeder comprises 62 distribution transformers (T1-T62), four section switches (SS1, SS2, SS3, and SS4), and 177 buses, including 115 main buses and 62 load buses. The network also includes 114 lines.

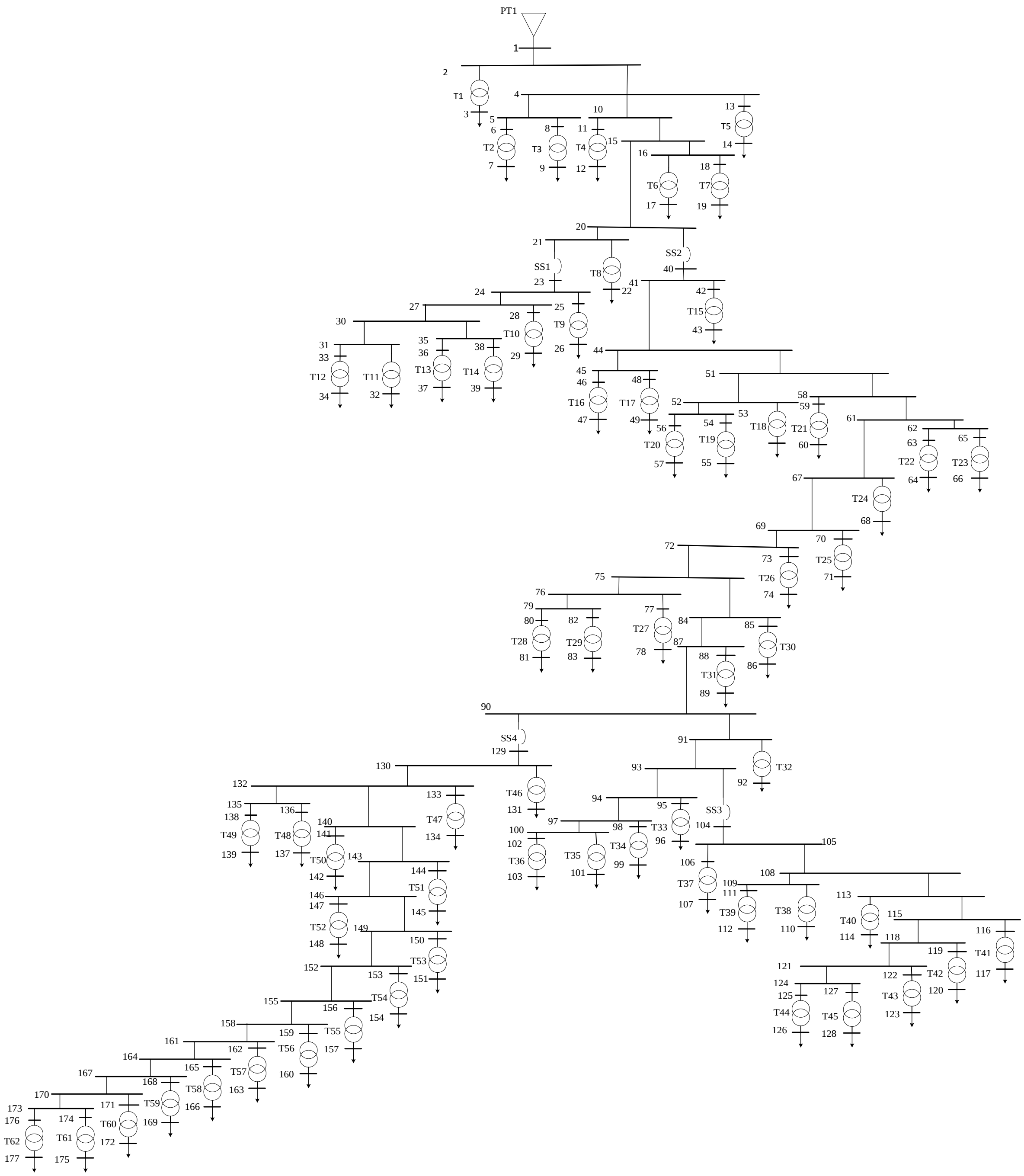

Fig. 3. The single -line- diagram of Shecha feeder

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B. Work Flow of the System

The overall block diagram that shows the complete work of the study is shown in Fig. 4 .

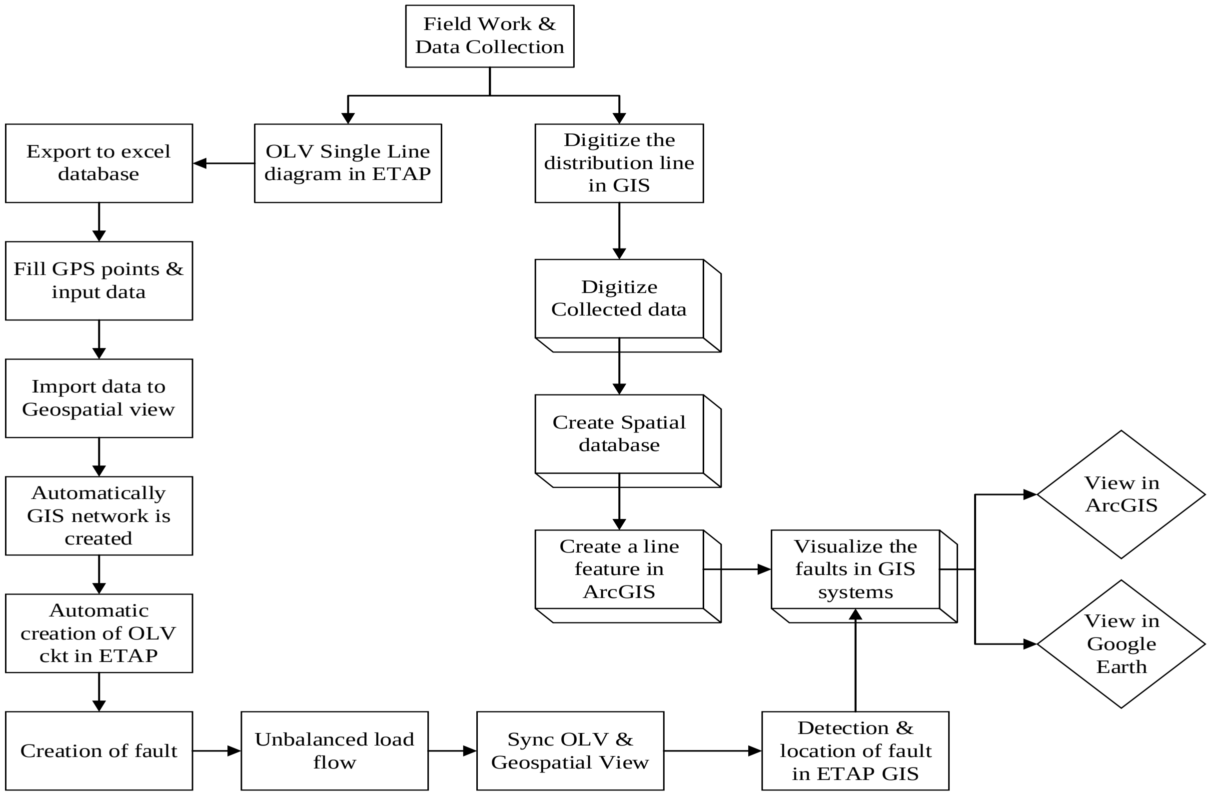

Fig. 4. Overall block diagram of the system

C. ETAP GIS Map

When an electrical system's GIS (Geographic Information System) map is available, data can be seamlessly transferred to ETAP (Electrical Transient Analyzer Program), eliminating the need for manual input and significantly reducing the potential for errors. This seamless data transfer facilitates the creation of one-line diagrams and ensures the accuracy of data used in system studies.

By integrating electrical one-line diagrams with corresponding geographical maps of power generation, transmission, and distribution systems, the ETAP GIS Map provides a dynamic tool for accessing, analyzing, and managing geospatial information. ETAP's one-line diagrams offer a logical representation of the electrical connections within a complex GIS map. These maps

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typically utilize one or more geometric networks, which represent one-dimensional linear networks such as utility or electrical power distribution networks through geometric shapes.

The components of the geometric network are associated with corresponding ETAP elements, resulting in a detailed and accurate illustration of the electrical system. During the initial data transfer process, ETAP generates electrical one-line diagrams using topology data from the geometric network and its features. These diagrams incorporate both default values and library data from ETAP. This combined information is then employed for conducting power system studies, including Power Flow Studies and Fault Analysis. The data flow process between ETAP and ETAP GIS is depicted in Fig.5.

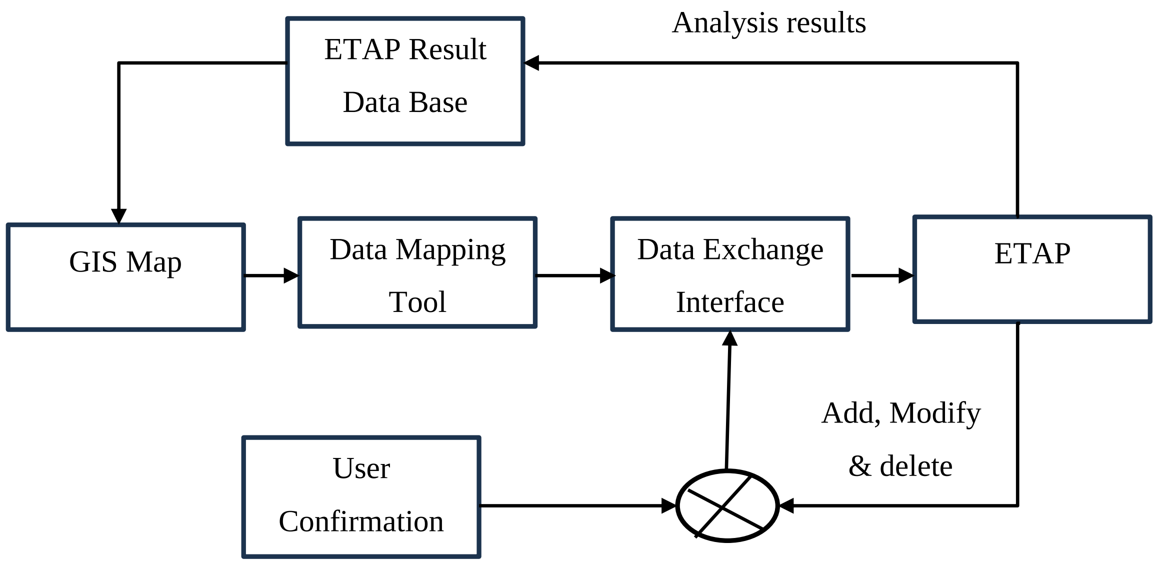

Fig 5. *ETAP and GIS map data flow*

D. GIS-based Fault Detection and Location Identification Methods

GIS platforms integrate various data sources, including network diagrams, equipment specifications, and sensor data. This integration provides a comprehensive view of the power distribution network. To effectively implement methods for improving the detection and location of faults, a range of devices are utilized to gather information about the fault's nature and its location. These devices are connected to network components like switch-disconnectors or circuit breakers, which can be found in both overhead and underground networks, on conductors or electrical towers. These devices, known as protection relays, are also referred to as Intelligent

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Electronic Devices (IEDs) when connected to circuit breakers, or Fault Passage Indicators (FPIs) when connected to switch-disconnectors. The key distinction between these devices is that while IEDs can identify a fault and promptly send a signal to open the circuit breaker and isolate the fault, FPIs can only detect the fault and report the information. As a result, IEDs offer additional features that allow for rapid response to a fault and provide other functions to improve fault protection. These devices possess the ability to detect the type, size, and direction of a fault, as well as continuously monitor these variables as shown in Fig. 6 thereby improving the overall reliability of the electrical distribution system [13]-[15].

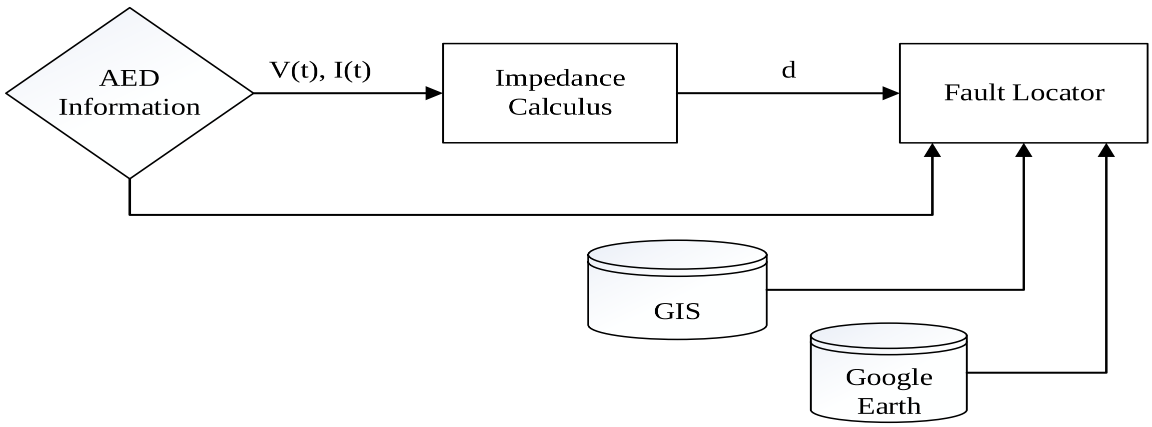

Fig. 6. Data flow of fault location

When using a fault indicator to collect circuit fault information, the primary method is to determine the type of fault by analyzing the current information in the fault indicator. The fault indicator employs a sensing device to monitor changes in the circuit's current, mainly detecting the conditions when a wire is grounded or short-circuited.

During a ground fault, the voltage of the affected wire relative to the ground will suddenly drop significantly. This rapid decrease in voltage, once it surpasses a predefined threshold, indicates a grounding fault. Similarly, in a short-circuit condition, the fault indicator detects abnormal current flows, which help in identifying the fault type and location [15].

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III. RESULTS AND DISCUSSIONS

A. Fault detection and its Location Identification in Shecha Feeder

The Logical Single Line Diagram is generated automatically by the ETAP GIS system to simulate balanced load flow, unbalanced load flow, and unbalanced short-circuit analysis. Unbalanced short-circuit analysis is used to introduce faults and compute fault currents in the system, with the fault being applied at any bus. The resulting fault current values can be viewed in ETAP GIS. To locate the fault in the Logical Single Line Diagram within the ETAP GIS system, the presentations must be synced in the window. The fault location's performance is 100%, detecting the fault through the execution of unbalanced short-circuit analysis.

Case 1: Assuming all types of faults occur at bus 28, the simulation for unbalanced short-circuit is displayed in Fig.7.

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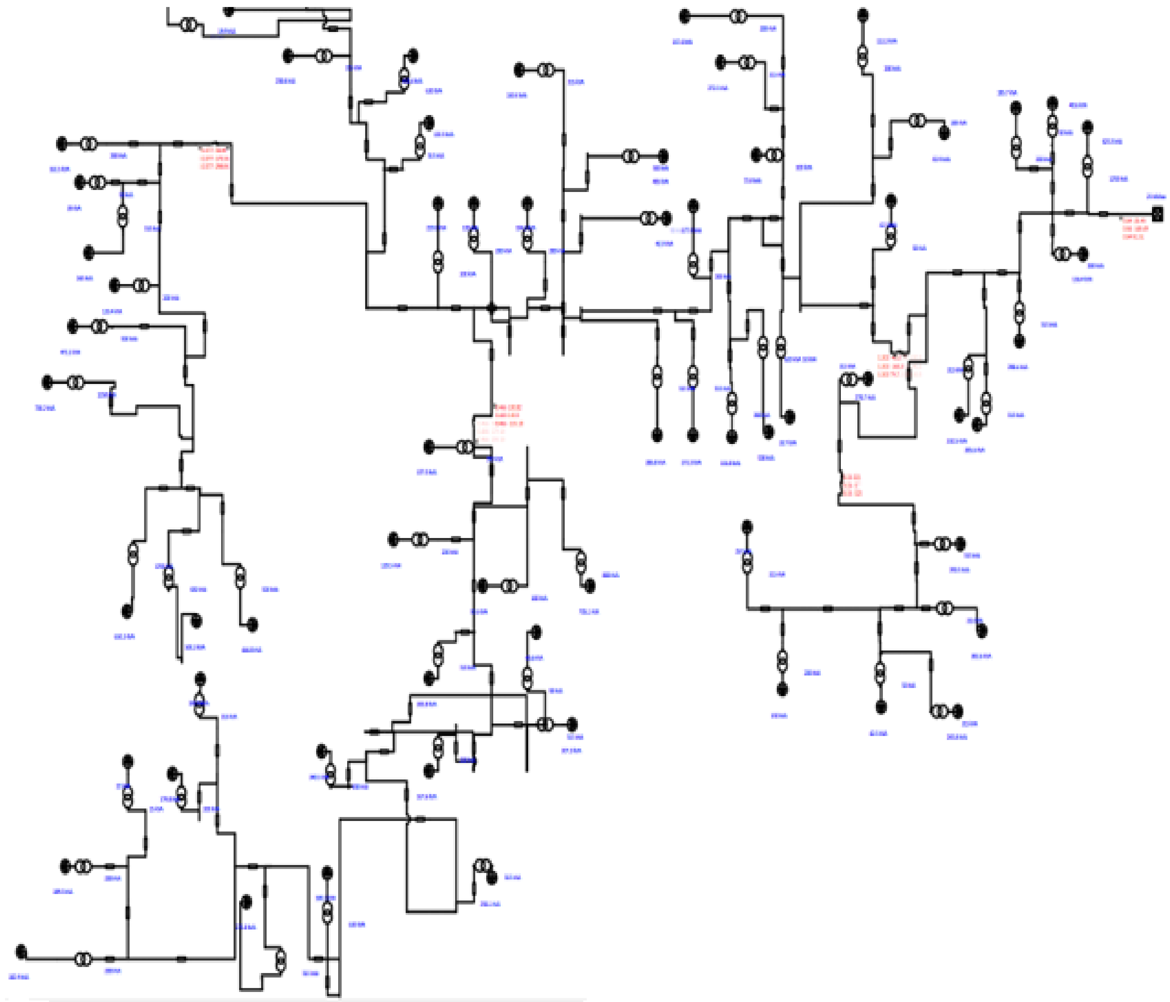

Fig. 7. Unbalanced short-circuit analysis of Shecha feeder

Fig.8 illustrates an ETAP GIS network of the Shecha feeder from a geospatial perspective. It identifies the fault and marks its location with a bold red point. The fault location, depicted below, corresponds to Bus number 28, with its GPS point named 336. In terms of geographical location, this fault is situated in front of the Arba Minch Tele office or the Grand Medical Clinic. This fault is also located at Longitude 37°33'4"E and Latitude 06°01'20"N, as shown in Fig. 8.

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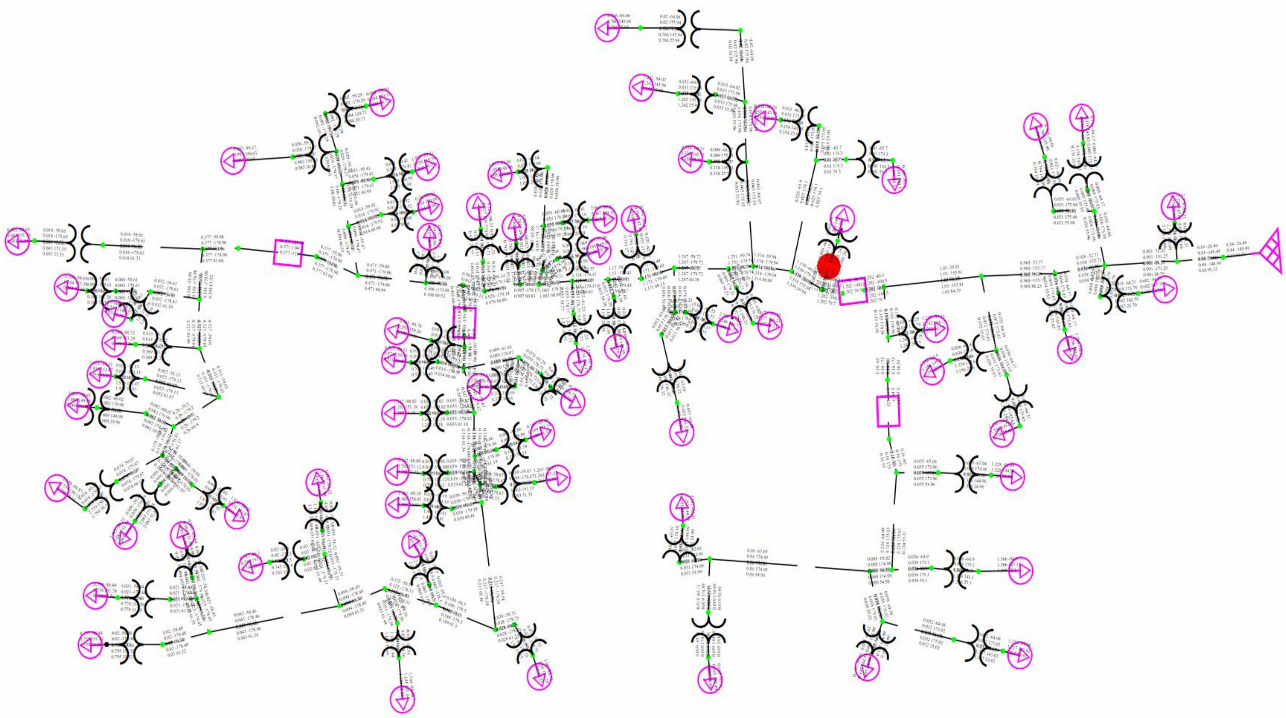

Fig.8. Fault location by ETAP GIS system for Case 1

Once the fault is detected and located by using the ETAP GIS system, there are many options to see the location of the fault. It is also possible to find the distance of the fault by adding the distances of the lines.

Fault distance from substation = length of (Line1 + Line2 + Line6 + Line9 + Line10 + Line25 + Line26 + Line27) = 552m + 380m + 206m + 372m + 650m + 136m + 399m + 2m

= 2,697m

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Fig. 9. Fault location in Google Earth for Case 1

As illustrated in Fig. 9., the faulted area in the electric distribution line has been accurately identified using the ETAP GIS software. This precise location is then showcased in Google Earth, providing a clear visual representation of the fault on the map.

B. Load Flow Analysis of Shecha Feeder

The total length of this feeder is 18.154 kilometers, with the longest branch measuring 7.155 kilometers and the shortest branch measuring 0.552 kilometers. ETAP software, utilizing precise data, was used to conduct a load flow analysis. The analysis revealed the following:

The shortest branch exhibits a 3.69% voltage drop, resulting in a terminal medium side voltage of 14.4375 kV. The longest branch experiences a more significant 18.34% voltage drop, leading to a terminal medium side voltage of 12.2625 kV. The low side voltage for the shortest branch is 385 V, while the longest branch measures 327 V. The feeder's total active power is 14.776 MW, with a reactive power of 8.082 MVAr. This equates to an apparent power of 16.842 MVA, representing 67.37% of the power transformer's 25 MVA capacity. The load flow analysis identified an overload condition in transformer DT32, operating at 107.2% of its capacity. The feeder experiences significant branching losses, with 2,197.20 kW of active power loss and 1,154.3 kVAr of reactive power loss. Minimizing these losses is crucial. Detailed reports on load flow, branch loading, and branch losses are included in appendices 3, 4, and 5, respectively.

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C. The Time Analysis for Fault Finding

To analyze the time aspect, a three-year dataset of faults lasting an hour, or more was collected from the Arba Minch Substation. The time taken to locate the respective faults was obtained from the EEU Arba Minch District Distribution Operation office. The data analysis reveals that the time spent finding faults constitutes 63.23% of the total fault-clearing time, while the remaining 36.77% is dedicated to technical maintenance for service restoration. This indicates that energy losses (Energy Not Supplied and Energy Not Sold) are a result of the traditional fault-finding method.

In the context of the Shecha feeder, the average estimated time to find faults using the conventional method is 63.23% of the total outage time. However, by employing the GIS method, the required time to locate or find faults is reduced to less than or equal to one minute. This translates to less than 0.56% of the total fault duration, resulting in a 99.11% reduction in required time compared to the conventional method.

- The percentage time to find the fault by conventional method = $\frac{1.864}{2.948}$ x 100 = 63.23 %
- Technical Maintenance time = 100 – 63.23 = 36.77 %
- The percentage time to find the fault by GIS method = $\frac{1}{60\ x\ 2.948}$ x 100 = 0.56%
- The time reduced by GIS referred to Conventional method = $\frac{63.23-0.56}{63.23}$ x 100 = 99.11 %
- SAIDI due to fault detection and location by try-and-error approach ≅ $\frac{63.23}{100}$ x 271.3 = 171.54
- SAIDI value with improved GIS technique ≅ $\frac{100-99.11}{100}$ x 171.54 = 1.53

D. Economic Loss Analysis

1) Energy not Supplied or Energy Not Sold: In Table I, the average energy loss in terms of real power and reactive power is depicted under the assumption of various load conditions (25%, 50%, 75%, and 100% of the total load) in a conventional method during a single fault. Assuming a 100% load during a single fault, the maximum energy not supplied amounts to 24,784.58 kWh and 13,625.41 kVArh, while the minimum energy not supplied is 6,196.15 kWh and 3,406.35 kVArh, considering the fault load as 25% of the full load.

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Table I: Economic Loss Analysis

No.	Full Load		% of Full Load	Load Assumption		Average Time taken to Single Fault (Hr.)	Energy Not Sold	
	KW	KVAr		KW	KVAr		KWH	KVArh
1	13,296.45	7,309.77	25	3,324.11	1,827.44	1.86	6,196.15	3,406.35
2	13,296.45	7,309.77	50	6,648.23	3,654.89	1.86	12,392.29	6,812.71
3	13,296.45	7,309.77	75	9,972.34	5,482.33	1.86	18,588.44	10,219.06
4	13,296.45	7,309.77	100	13,296.45	7,309.77	1.86	24,784.58	13,625.41

2) Analysis of Loss in Revenue: The Revenue loss can be analyzed in two ways. These are unsold Electricity (Unplanned Outage) of 15/33 KV and according to EEU Tariff.

According to EEU, the unsold electricity (unplanned outage) charge of the 15/33 KV line for two hours is 84,000 ETB. Taking the minimum, average, and maximum duration of finding a fault by a conventional method, the revenue not collected is illustrated in Table II below. The minimum revenue not collected per fault is 42,000 ETB, the average revenue not collected per fault is 78,288 ETB and the maximum revenue not collected per fault is 231,000 ETB.

Table II: Revenue Loss Analysis

No.	Duration of finding a fault	Unplanned Outage for 2 hours	Revenue not collected
1	1	84,000 ETB	42,000 ETB
2	1.864	84,000 ETB	78,288 ETB
3	5.5	84,000 ETB	231,000 ETB

Economic loss analysis shows significant energy not supplied during faults, with revenue losses due to unsold electricity. The GIS method, which only incurs the cost of software and utilizes existing measuring and relay protection devices, significantly reduces the time and economic losses associated with fault detection and location. This makes it a highly scalable and efficient solution for the Shecha feeder and the entire Arba Minch electric distribution system.

IV. CONCLUSSION

In this study, the existing fault detection and location identification method for the Arba Minch district's 15 KV Shecha feeder was evaluated. The feeder is 18.154 km long, with branches ranging

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from 0.552 km to 7.155 km. Currently, fault detection and location identification in the Arba Minch distribution system usesa conventional, manual approach, which is laborious and time-consuming. This method requires more personnel and prolongs outage times. About 63.23% of the total fault duration is spent on detection and location identification, with the remaining 36.77% on technical maintenance. Consequently, energy not supplied per fault is 24,784.58 KWh and 13,625.41 KVArh. Revenue losses range from 42,000 ETB to 231,000 ETB, depending on the fault location time, which can be up to 5.5 hours. The SAIDI value of this feeder is 271.3, with 171.54 due to fault finding, representing significant economic losses.

To address these issues, the GIS technique was implemented for fault detection and location identification. The ETAP GIS system successfully detected and identified the location of the faults with 100% accuracy, reducing outage time by 99.11%. This eliminated economic losses such as unsupplied energy (24,784.58 KWh and 13,625.41 KVArh) and uncollected revenue (42,000 ETB to 231,000 ETB). The SAIDI value due to fault location decreased from 171.54 to 1.53.

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