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Original Article

Development of Maintenance Management System to Improve Reliability of Power Supply in Medium Voltage Distribution Network: A Case of TANESCO, Kinondoni North Region

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Reliability of Power Supply, Medium Voltage Distribution Network, Distribution Automation, Maintenance and Operation Management, Reliability Indices, Development of Maintenance Management System.

ABSTRACT

The reliability of the power supply in medium voltage distribution networks is crucial in the Kinondoni North region due to the growing demand for reliable electricity, increasing by approximately 20 MW per year. However, power supply reliability is compromised by several factors such as aging infrastructure, equipment failures, vandalism, natural disasters like storms and floods etc. These issues contribute to faults in the distribution feeders, causing power interruptions. Key challenges include identifying the location of faults, restoring power efficiently, and managing network maintenance. This research aims to develop a Maintenance Management System (MMS) to manage both maintenance and operational activities in medium voltage distribution networks, enhancing the efficiency of operations and improving power supply reliability in medium voltage distribution networks in the region. To achieve this, factors affecting maintenance management were identified through a literature review, assessment, and site surveys. Data were collected and analyzed using SPSS and a regression model was developed to improve reliability. The analysis revealed six most significant factors out of ten factors that influence power supply reliability are Budget Constraints, Network Design, Fault Detection & Isolation Equipment, Maintenance Practices, Data and Information Management, and Skilled Labor. The model developed had high predictive accuracy, with R=0.915, indicating that these factors significantly predict the reliability of the power supply. To improve reliability, the study recommends adopting the reliability performance model and MMS in the Kinondoni north region. Key recommendations include investing in workforce development, training employees on advanced fault detection technologies, implementing smart grid technologies for real-time data monitoring, optimizing grid design with redundancy, and adopting predictive maintenance based on condition monitoring. These strategies will reduce downtime and improve the overall reliability of the power supply in the medium voltage distribution network.

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INTRODUCTION

Kinondoni's north region located in the East zone is among 29 TANESCO regions located in Tanzania's mainland. The region provides services to the 190,814 customers in Kinondoni municipal which covers approximately 269 square kilometres of area (Profile, 2018). The region is bordered to the north by the Bagamoyo district of the Pwani region separated by the Mpiji river at Bunju B, to the east by the Indian Ocean, to the west by Magomeni, Kimara, Mbezi and Kibamba of Ubungo district in TANESCO Kinondoni South region, and to the south by the Ilala region and the boundary is at Salender Bridge.

Kinondoni municipal has 20 wards, among those 20 wards Kinondoni North region provides services to the customers in 15 wards, and the remaining 5 wards of Kinondoni municipal it served by Kinondoni South region. Figure 1 shows the geographical area of the Kinondoni district wards served by TANESCO Kinondoni North region.

TANESCO has a mission to "Deliver electricity in a most effective, competitive and sustainable manner". To achieve the company's mission, the Kinondoni North region receives power from Ubungo grid substation through 132kV overhead transmission lines from Ubungo to Makumbusho and Kunduchi grid substations and also receives power from city centre grid substation through 132kV underground cable from the city centre grid substation to Makumbusho grid substation as the alternative power supply for Makumbusho grid substation in Kinondoni north region.

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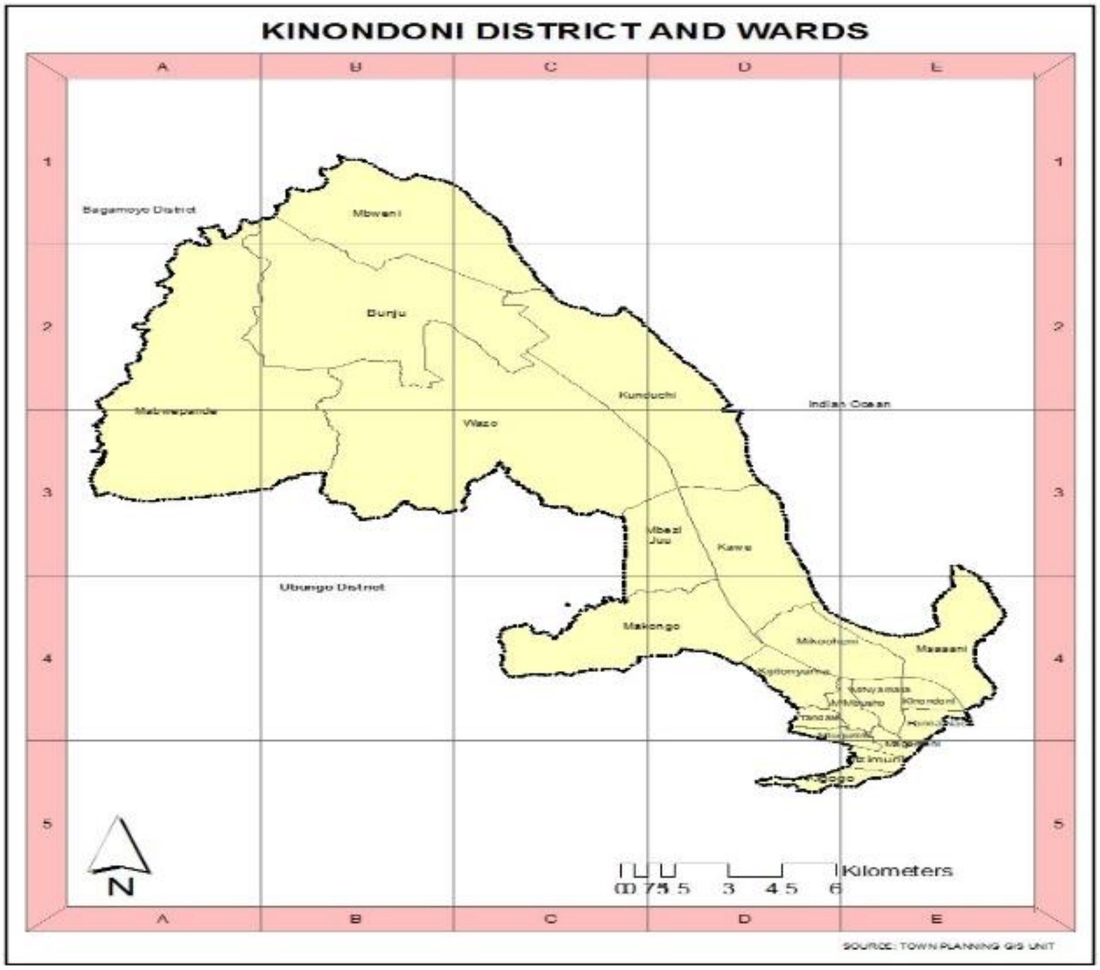
Figure 1*:* Kinondoni District Wards Served by Tanesco Kinondoni North Region



As stated above the region has two grid substations Makumbusho grid substation and the Kunduchi grid substation with the following installed capacity.

- Makumbusho 3 × 45MVA
- Kunduchi 3 ×50/65MVA

The distribution department stands at the customer end of the electricity supply chain and is, therefore, TANESCO's major interface with customers responsible for delivering power. It deals with the distribution of electricity, promotion of services and all customer service matters. To ensure reliable power supply, the Kinondoni north region has seven 33kV to 11kV Primary substations to the seven subwards as follows.

- Mikocheni 2×15MVA
- Mwananyamala 1×15MVA
- Msasani 2× 15MVA
- Oyster bay 2× 15MVA
- Mbezi Beach 2× 15MVA
- Jangwani Beach 1× 15MVA
- Bahari Beach 2× 15MVA

From two grid substations in Kinondoni north region electricity is delivered to the customers through thirteen 33kV medium voltage distribution feeders with a total coverage route length of approximately 355.4km, and thirty-five 11kV

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medium voltage distribution feeders with a total coverage route length of approximately 402.6km from the primary substation to the customers in a different area in Kinondoni north region within Kinondoni municipal.

The reliability of the power supply is crucial for economic growth and social stability. Medium voltage distribution networks play a critical role in the transmission of electricity from substations to end-users. A well-developed maintenance management system can significantly improve power supply reliability by reducing outages, preventing failures, optimizing maintenance activities and enhancing operation activities. The operation of the distribution network includes the following operations.

- Monitoring electricity parameters (voltage, current, frequency and power) in fault condition
- Opening and closing of the breakers
- Isolation of faulted parts of the distribution network
- Clearance of faults
- Restoration of power safely

This research on the development of a maintenance management system for medium voltage distribution networks to improve the reliability of power supply in Kinondoni north region to manage maintenance activities and manual operation activities such as line patrol and switching activities to reduce the time taken for that operation.

The Statement of the Research Problem

Due to the increase of demand of almost 20MW per year and reliable power supply in Kinondoni north region, and the nature of the wide extension of medium voltage distribution feeder to cover the all area in the region, there is a problem of unreliable power supply above the required standard measured values which is contributed by many factors such as aged infrastructure, equipment failure, vandalism, natural disasters such as storm, heavy rainfall, flood etc. All of those factors may cause a technical problem in medium voltage distribution feeders called faults (ENERGY, 2020).

Once the fault occurs the problem is how do we know where the fault occurs in our distribution network, How do we operate to restore power after faults occur? How long does it take to restore the power after a fault occurs? How do we inspect our network to isolate the source of faults, maintain the network and restore power? The four questions above are the main reasons for power reliability thus why we need to develop a maintenance management system to automate medium voltage distribution feeders' operations so as to locate where the fault occurs, quickly isolate the faulted parts remotely, and restore power safely within a short time period.

Currently when a fault occurs in medium voltage distribution feeders, finding the faulty point, isolating it and restoration of power to the customers by the technical team takes more than 30 minutes, and sometimes a few hours because currently most of the switches in medium voltage distribution networks are operated manually which affect the reliability of power supply.

The Objective of the Research

The aim of this research dissertation is to develop a maintenance management system which will manage maintenance activities and operations activities conducted in medium voltage distribution feeders as a smart way of approach to improve operation efficiency and enhance the reliability of power supply in the Kinondoni north region.

Specific Objectives

To achieve the general objective following are the specific objectives of this research.

- To identify technical factors affecting maintenance management to improve the reliability of power supply in medium voltage distribution networks.

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- To develop a maintenance model to improve the reliability of power supply in medium voltage distribution networks.
- To develop a maintenance management system to improve the reliability of power supply in medium voltage distribution networks.

RELIABILITY ANALYSIS IN MEDIUM VOLTAGE DISTRIBUTION NETWORK

Reliability of power supply can be defined as the probability of a network or piece of equipment effectively performing its intended function within a specified duration and under specified operating conditions. The reliability of a distribution system depends on several factors including the location (urban or rural), environment, the type of system and the type of equipment installed. According to the statistics and various studies, about 90% of customer outages are related to the distribution systems (Ali, 2017).

Evaluation of Reliability Indices

Analyzing reliability indices on medium voltage distribution lines involves evaluating various parameters to assess the performance and effectiveness of the distribution system in delivering uninterrupted power supply to consumers.

SAIFI (System Average Interruption Frequency Index): SAIFI measures the average number of interruptions experienced by consumers served by the distribution system over a specific period, typically per year. It quantifies the frequency of interruptions and reflects the reliability of the distribution network in terms of the number of outages per customer. Tanzania Standard requires that the annual SAIFI should be less than 3 interruptions per customer per year (EWURA, 2020).

$$SAIFI = \frac{\sum N_i}{N_T} \quad (3.1)$$

Where by

N_i =Total Number of customers interrupted

N_T =Total number of customers served

SAIDI (System Average Interruption Duration Index): SAIDI represents the average duration of interruptions experienced by consumers served by the distribution system over a specific period, usually per year. It measures the reliability of the distribution network in terms of the average outage duration per customer, providing insights into the system's ability to restore power promptly after interruptions.

Tanzania Standard requires that SAIDI should be less than 650 minutes (10.8 Hours) per customer per year (EWURA, 2020).

$$SAIDI = \frac{\sum (R_i \times N_i)}{N_T} \quad (3.2)$$

Whereby N_i =Total Number of customers interrupted

N_T =Total number of customers served

R_i= Restoration time

CAIFI **(Customer Average Interruption Frequency Index)** CAIFI can be defined as the average number of interruptions for customers who experience interruptions in a year. On the other hand, it can be referred to as an annual number of interruptions divided by the number of customers affected in a year.

$$CAIFI = \frac{\sum N_O}{Ni} \quad (3.3)$$

Whereby N_i =Total Number of customers interrupted

No =Total number of interruptions

CAIDI (Customer Average Interruption Duration Index): CAIDI calculates the average time taken to restore power to customers following

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an interruption. It is derived by dividing SAIDI by SAIFI and indicates the efficiency of the distribution system's restoration processes. Tanzania Standard requires that CAIDI should be less than 4 minutes (0.1 hours) per interruption event per year (EWURA, 2020).

CAIDI = SAIDI ÷ SAIFI………………………………………… (3.4)

Independent Variable for Reliability Analysis

To conduct a power reliability analysis of a medium voltage distribution line, we need to have historical performance parameter data of the feeders. These parameters play a crucial role in determining the reliability of the distribution network and are used to derive key reliability indices.

- **Number of Outages (N)**: The total number of interruptions or outages experienced by consumers served by the distribution system over a specific period, such as a year. This parameter is used to calculate SAIFI.
- **Duration of Outages (T)**: The total duration of interruptions or outages experienced by consumers served by the distribution system over a specific period, typically expressed in hours or minutes. This parameter is used to calculate SAIDI.
- **Number of Customers Affected (C)**: The total number of customers affected by interruptions or outages during a specific period. This parameter is used to calculate CAIDI.
- **Fault Location and Repair Time (T)**: The time taken to locate faults in the distribution system and restore power to affected customers following an interruption. Efficient fault location and repair processes contribute to minimizing outage durations and improving system reliability.
- Switch time (ST): When it is time to change the circuit connections, switches open and close the feeder, a faulty element from the network is isolated and the remaining parts of the network are kept energized. Switching time is usually expressed in terms of hours (h).
- **Equipment Failure Rates (λ)**: Average number of errors for an element, at any given time during which the average rate of failure occurrence is considered. The frequency of equipment failures, including transformers, switches, and circuit breakers, within the distribution system. Monitoring equipment failure rates help identify components with high failure rates and prioritize maintenance and replacement activities.
- **Customer Outage Statistics**: Detailed information on the number of customers affected, the duration of outages, and the causes of interruptions. Customer outage statistics provide insights into outage patterns, causes of interruptions, and areas for improvement in system reliability (Okorie et al., 2015).

Technical Factors Affecting Maintenance Management to Improve Reliability of Power Supply in Medium Voltage Distribution Network

Technology Adoption

Maintenance planning, data recording, evaluation and operations of medium voltage distribution network under both normal and fault conditions is still manually. We need to employ technology to change to automatic operations which will be conducted remotely. To achieve that, we need to integrate software, sensors and communication networks in medium voltage distribution networks.

Automation of medium voltage distribution lines involves the integration of advanced technologies and control systems to monitor, manage, and optimize the operation of electrical distribution systems. It encompasses the use of software, sensors, communication networks, and automated devices to enhance the efficiency, reliability, and flexibility of delivering electrical power to consumers (James, 2006).

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Requirements Components of Automation in MV Line

- **Remote Terminal Units (RTUs)**: RTUs are electronic devices installed at various points along the distribution network to monitor and control equipment remotely. RTUs collect data from sensors and meters, communicate with the central control system, and execute commands to operate switches, reclosers, and other devices.

- **Intelligent Electronic Devices (IEDs)**: IEDs are advanced devices used for monitoring, protection, and control of electrical equipment in distribution systems. They include devices such as protective relays, voltage regulators, and capacitor controllers, which perform functions such as fault detection, voltage regulation, and power factor correction.

- **Switchgear and Circuit Breakers**: Switchgear and circuit breakers are essential components of medium voltage distribution lines that enable the isolation and switching of electrical circuits. Automated switchgear and circuit breakers equipped with remote control capabilities allow for remote operation and rapid response to faults and abnormalities (James, 2006).

- **SCADA (Supervisory Control and Data Acquisition) Systems**: SCADA systems are centralized control systems that collect, monitor, and analyze real-time data from various components of the distribution network. SCADA systems provide operators with comprehensive situational awareness and remote control capabilities, allowing for efficient management and optimization of the distribution system.

- **Communication networks**: Communication networks are critical for transmitting data between distributed devices and the central control system. Communication technologies such as fibre optics, radio frequency (RF), cellular, and satellite communication enable reliable and secure data exchange in automation systems for medium voltage lines.

- **Smart sensors and measurement devices**: Smart sensors and measurement devices are deployed throughout the distribution network to collect real-time data on voltage levels, current flows, power quality, and equipment status. These sensors provide valuable insights into the operational conditions of the network and enable proactive maintenance and troubleshooting.

Distribution management **systems (DMS)**: DMS is a software platform that integrates various automation functionalities to optimize the operation of distribution networks. DMS includes features such as outage management, load forecasting, fault localization, and network optimization, enabling utilities to improve system reliability and efficiency (James, 2006).

Challenges of Automation of Medium Voltage Distribution Line

While automation of medium voltage distribution lines offers numerous benefits, it also presents several challenges that utilities must address to ensure successful implementation and operation. Some of the key challenges include:

- **Initial Investment Costs**: The upfront investment required for implementing automation systems in medium voltage distribution lines can be substantial. This includes costs associated with equipment procurement, installation, integration, and training.

- **Legacy Infrastructure**: Many medium voltage distribution systems consist of ageing infrastructure with limited or outdated automation capabilities. Retrofitting existing infrastructure with modern automation technologies can be challenging and may require significant modifications or upgrades to

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accommodate new equipment and communication protocols (James, 2006).

- **Interoperability Issues**: Automation systems often involve the integration of multiple devices and technologies from different manufacturers. Ensuring interoperability and seamless communication between disparate components can be complex, particularly when dealing with legacy equipment or proprietary protocols (Palak Parikh, 2011).

- **Cybersecurity Concerns**: Automation systems are vulnerable to cybersecurity threats, including unauthorized access, data breaches, and malicious attacks. Protecting critical infrastructure from cyber threats requires robust security measures, including network segmentation, encryption, access controls, and regular security assessments. Utilities must prioritize cybersecurity to safeguard automation systems and prevent potential disruptions or compromises.

- **Data Management and Analytics**: Automation systems generate vast amounts of data from sensors, meters, and control devices. Developing data management strategies and implementing advanced analytics tools are essential for maximizing the value of automation systems.

- **Workforce Skills and Training**: Automation introduces new technologies and processes that may require specialized skills and training for utility personnel. Ensuring that operators, technicians, and engineers have the necessary expertise to operate and maintain automation systems is critical for successful implementation (Palak Parikh, 2011).

- **Regulatory and Compliance Requirements**: Compliance with regulatory standards and industry guidelines is essential for ensuring the safety, reliability, and interoperability of automation systems. Utilities must navigate complex regulatory landscapes and adhere to stringent requirements related to cybersecurity, data privacy, reliability standards, and operational practices.

- **Resilience and Redundancy**: While automation systems can enhance the resilience of distribution networks, they also introduce dependencies on technology and communication networks. Redundant communication paths, backup power supplies, and contingency plans are essential for maintaining system resilience.

- **Public and** Stakeholder **Engagement**: Introducing automation technologies into medium voltage distribution lines may raise concerns among stakeholders, including customers, regulators, and local communities. Utilities must proactively engage with stakeholders to address concerns, communicate benefits, and build trust in automation initiatives.

Addressing these challenges requires careful planning, collaboration, and investment from utilities, regulators, technology vendors, and other stakeholders. By overcoming these challenges, utilities can realize the full potential of automation to improve the reliability, efficiency, and sustainability of medium-voltage distribution lines (James, 2006).

Budget Constraints

Budget limitations can impact the scope and frequency of maintenance activities. Effective budgeting and financial planning are necessary to balance maintenance needs with available resources. Budget constraints may force utilities to reduce the frequency of preventive maintenance activities, such as routine inspections and component testing. This can lead to an increased risk of equipment failures and reduced reliability also limited funds may restrict the use of advanced diagnostic tools like sensors and techniques for predictive maintenance, potentially resulting in

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unforeseen breakdowns. Limited budgets may also restrict the purchase of advanced tools and diagnostic equipment, which can hinder effective maintenance and repair efforts. Budget constraints may mean that emergency repairs are prioritized, while planned maintenance and improvements are postponed. This can reduce the overall efficiency of maintenance activities and increase the workload on existing staff, potentially impacting their effectiveness and job satisfaction (Aıroboman, 2022).

Maintenance Practices

The approach to maintenance can significantly impact the network's reliability, safety, and overall performance. Maintenance practices play a crucial role in the effective management of a medium-voltage distribution network.

i. Preventive Maintenance

It involves Regular inspections and routine maintenance tasks that can help to identify and address potential issues before they lead to distribution equipment failure. This helps in preventing unexpected outages and extending the lifespan of components. Preventive maintenance improves reliability and reduces the likelihood of emergency repairs. However, it requires careful scheduling and can be resource-intensive.

ii. Predictive Maintenance

It involves condition monitoring and data analysis. In-condition monitoring techniques such as vibration analysis, thermal imaging, and insulation testing can provide insights into the health of distribution equipment. This allows maintenance to be performed based on actual condition data rather than time intervals. Analyzing data from condition monitoring tools helps in predicting when maintenance should be performed, thus avoiding unnecessary maintenance and focusing resources where they are most needed.

iii. Corrective Maintenance

This practice involves performing maintenance only after equipment has failed. It is typically a response to unplanned outages or faults. Involves fixing or replacing faulty components as they break down. This maintenance strategy can lead to higher operational disruptions and costs, as repairs are often more urgent and expensive.

iv. Condition-Based Maintenance

This type of maintenance strategy involves real-time monitoring and decision-making. Maintenance decisions are made based on real-time data about equipment conditions. This approach allows for timely interventions. This maintenance strategy is a more targeted and efficient use of resources reduces unnecessary maintenance and helps prevent failures that could lead to outages.

Reliability Centered Maintenance

Reliability Centered Maintenance involves analyzing the criticality of different components and systems to determine appropriate maintenance strategies based on their impact on overall system reliability. It focuses on ensuring that maintenance practices align with the risk of failure and the consequences of such failures. This maintenance strategy enhances overall system reliability and efficiency by prioritizing maintenance efforts on the most critical components and systems.

Maintenance practices can significantly influence the performance, reliability, and cost-effectiveness of medium voltage distribution networks. By adopting appropriate maintenance strategies and practices, utilities can manage their assets more effectively, reduce operational disruptions, and enhance overall system reliability.

Network Design

The design of a medium voltage distribution network is fundamental to its maintenance and reliability. Different Medium voltage network configurations have an impact on the maintenance and reliability of the power supply as explained below.

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- **Radial Networks**: In a radial configuration, power flows from a single source to multiple loads. While simple and cost-effective, a fault in one part of the network can disrupt the power supply to all downstream users.
- **Ring Networks**: A ring configuration allows power to flow in two directions, offering redundancy. If a fault occurs, the network can reroute power through the other path, improving reliability but potentially complicating maintenance.
- **Mesh Networks**: Mesh networks provide multiple pathways for power flow, enhancing reliability by offering several redundant routes. However, they are complex to design and maintain due to their intricate interconnections (Lakervi, & Holmes, 1995).

A well-designed network configuration enhances reliability by reducing the likelihood of widespread outages and facilitates quicker restoration of service. However, complex designs may increase maintenance complexity and costs.

Load Growth Demand

Load growth demand significantly impacts both the maintenance and reliability of a medium voltage distribution network. As demand for electricity increases, several factors come into play that can influence network performance. As demand grows, existing infrastructure such as transformers, conductors, and switchgear may become overloaded. This can lead to equipment overheating, accelerated wear and tear, and a higher risk of failure. Overloaded components are more likely to fail, leading to more frequent maintenance and potentially unscheduled outages. As the network experiences higher loads, the frequency and complexity of maintenance tasks can increase. Load growth demand can significantly impact the maintenance and reliability of an MV distribution network. Managing these effects requires careful planning, investment in infrastructure, and the implementation of effective load management strategies.

Ageing of Infrastructure

The ageing of infrastructure in a medium-voltage distribution network has significant implications for both maintenance and reliability. As components and systems age, they become more susceptible to failures and inefficiencies. Over time, equipment such as transformers, circuit breakers, and cables undergo wear and tear. Insulation materials can degrade, mechanical parts can wear out, and connections can corrode. The likelihood of equipment failures increases as components age, leading to more frequent breakdowns.

Data and Information Management

Data and information management play a crucial role in the maintenance and reliability of a medium-voltage distribution network. Effective management of data and information can significantly enhance operational efficiency, improve decision-making, and optimize network performance (James, 2006).

Environmental Factors

Environmental factors can significantly impact the maintenance and reliability of a medium-voltage distribution network. These factors can affect both the physical infrastructure and operational aspects of the network. Extreme weather conditions such as heavy storms, heavy rain, high winds and flooding can cause physical damage to overhead lines, poles, and other infrastructure. Broken lines or fallen trees can lead to outages and require immediate repair, increasing the frequency of outages and damage, leading to higher maintenance needs and potentially longer restoration times.

DATA COLLECTION AND ANALYSIS

Study Area

The research was conducted at TANESCO Kinondoni north region in the East zone at Dar es Salaam city, data were collected and analyzed and transformed into credible evidence about the

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development of a maintenance management system in order to improve the reliability of power supply in medium voltage distribution network.

Sample Size

This provides a simplified formula to calculate sample sizes. This formula is used to calculate the sample sizes as shown below. A 95% confidence level and P=.5 (Israel, 1992).

Sample size (n) = $\frac{N}{1+\mathrm{Ne}^2}$ ………………………………………………(4.1)

Where, N=Population size

n = sample size

e = level of precision,

The population selected was 50 technical staff to be questioned in this research.

The sample size will be $\mathrm{n} = \frac{50}{1+50x0.05^2}$

Sample size n= 44 staff

The sampling has been selected to reduce the cost of collecting data and prevent systematic biasing and sampling error (Kothari, 2004).

Data Collected

Two types of data were collected qualitative and quantitative data. Qualitative data aimed to show cause and effect relationships while quantitative data was to provide data with measurable scale. They were categorized into two sections; section one was concerned with general information of respondents; section two focused on identifying the impact of factors affecting current maintenance and operation management to improve reliability of power supply in medium voltage distribution network. Then the questionnaire was distributed to TANESCO technical staff and the management.

Factors Affecting Maintenance Management to Improve Reliability of Power Supply

The assessment of the factors affecting maintenance management to improve the reliability of power supply in medium voltage distribution networks was carried out and the results of each questionnaire were analyzed in SPSS. Likert scale was used to analyse the variables of some perceived impact. Table 1 shows the ranking scale of the responses to the questionnaire from respondents. The questionnaire's response is going to be ranked according to Table 1.

Table 1: Ranking Scale

Very High	Its effect on the practice is very high
High	Its effect on the practice is high.
Low	Its effect on the practice is low.
Very Low	Its effect on the practice is very low.

In this section factors affecting maintenance management to improve the reliability of medium voltage distribution networks are analyzed in a tabular form based on the answered questionnaire.

Table 2 presents survey data on various factors affecting maintenance management practices aimed at improving the reliability of a power supply. Each factor is evaluated based on respondents' ratings of its perceived impact, from "Very Low" to "Very High".

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Table 2: Factors Affecting Maintenance Management and Reliability

	Factors Affecting Maintenance Management to improve Reliability of power supply	Characteristics	Frequency	Percentage %
F01	Availability of Fault Detection and Isolation Equipment	1-Very Low	0	0
		2- Low	5	11.3
		3-High	18	41
		4-Very High	21	47.7
F02	Data and Information Management	1-Very Low	2	4.5
		2- Low	10	22.7
		3-High	12	27.3
		4-Very High	20	45.5
F03	Proper Maintenance Practices	1-Very Low	0	0
		2- Low	8	18.2
		3-High	14	31.8
		4-Very High	22	50.0
F04	Network design Configuration	1-Very Low	0	0
		2- Low	5	11.4
		3-High	15	34.1
		4-Very High	24	54.5
F05	Good Communication Network system	1-Very Low	5	11.4
		2- Low	10	22.7
		3-High	14	31.8
		4-Very High	15	34.1
F06	Load Growth Demand	1-Very Low	6	13.6
		2- Low	8	18.2
		3-High	12	27.3
		4-Very High	18	41
F07	Availability of Spare parts	1-Very Low	4	9.1
		2- Low	8	18.2
		3-High	20	45.5
		4-Very High	12	27.3

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F08	Budget Constraints	1-Very Low	0	0
		2- Low	4	9.1
		3-High	12	27.3
		4-Very High	28	63.6
F09	Availability of Tools and Equipment	1-Very Low	6	13.6
		2- Low	24	54.5
		3-High	12	27.3
		4-Very High	2	4.5
F10	Availability of Skilled Labour	1-Very Low	2	4.5
		2- Low	10	22.7
		3-High	14	31.8
		4-Very High	18	41
RLM	Reliability of Power Supply in Medium Voltage Distribution Network	1-Very Bad	0	0
		2-Bad	28	63.6
		3-Satisfactory	12	27.3
		4-Good	4	9.1

ANALYSIS OF DATA COLLECTED

This is very important in the reduction of many data to manageable data. After the collection of data from the questionnaire then factors are coded and the calculation of the relative index of each factor is done. Consider the following factors for maintenance management as coded below,

TEQ- Availability of Tools and Equipment

CNS- Good Communication Network System

FDIE- Availability of Fault Detection and Isolation Equipment

BC-Budget Constraints

MSP- Proper Maintenance Practices

NDC- Network Design Configuration

SP- Availability of Spare parts

DIM-Data and Information management

LGD- Load Growth Demand

SKLD- Availability of Skilled Labour

Table 3 shows the result based on the Relative Important index calculated compared to each other. RII of each item within a group was used to rank its importance and degree of significance.

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Table 3: Calculation of Relative Important Index

		RATINGS					TOTAL	∑W	RII	RANK
SN	**FACTORS**	0	1	2	3	4				
F01	FDIE	0	0	5	18	21	44	148	0.84	3
F02	DIM	0	2	10	12	20	44	138	0.78	5
F03	MSP	0	0	8	14	22	44	146	0.83	4
F04	NDC	0	0	5	15	24	44	151	0.86	2
F05	CNS	0	5	10	14	15	44	127	0.72	9
F06	LGD	0	6	8	12	18	44	130	0.74	8
F07	SP	0	4	8	20	12	44	128	0.73	7
F08	BC	0	0	4	12	28	44	156	0.89	1
F09	TEQ	0	6	24	12	2	44	98	0.56	10
F10	SKLD	0	2	10	14	18	44	136	0.77	6

Degree of Significance

Table 4 provides a guideline for interpretation of the strength of the findings. By categorizing significance ratings into different levels, it helps determine which results are crucial and deserve further attention or which ones may not be meaningful enough to consider. This aids in making informed decisions about the implications of research outcomes (Vanduhe, 2012).

Table 4: Guideline for Degree of Significance (Vanduhe, 2012)

SN	SIGNIFICANCE	RATING
1	Most significant	0.76 and above
2	Significant	0.67-0.75
3	Less Significant	0.45-0.67
4	Not Significant	0.44 and below

Table 5 shows the degree of Significance based on RII, the table provides information on the significance of various factors affecting a system, ranked based on the **Relative Importance Index (RII)**. The RII values, which range from 0 to 1, indicate the degree of significance of each factor, with higher values showing greater significance. To signify factors the guideline Table 4 is used.

Table 5: Degree of Significance Based on RII

SN	FACTORS	RII	Rank	SIGNIFICANT
F01	Budget Constraints	0.89	1	Most Significant
F02	Network Design Configuration	0.86	2	Most Significant
F03	Availability of Fault Detection and Isolation Equipment	0.84	3	Most Significant
F04	Proper Maintenance Practices	0.83	4	Most Significant
F05	Data and Information management	0.78	5	Most Significant
F06	Availability of Skilled Labour	0.77	6	Most Significant
F07	Load Growth Demand	0.74	7	Significant
F08	Availability of Spare Parts	0.73	8	Significant
F09	Good Communication Network System	0.72	9	Significant
F10	Availability of Tools & Equipment	0.56	10	Less Significant

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Model Development

Reliability Performance Model

The reliability of the distribution network depends on various factors as discussed in Chapters 2 and 3 above. In this chapter the relationship between reliability as the dependent variable and factors that affect maintenance management to improve the reliability of power supply as independent variables is developed.

Model Generation

The data used to develop a maintenance management model for the improvement of the reliability of the medium voltage distribution network were primarily collected through questionnaires and site surveys. After data was collected and organized the data was input into SPSS software to be tested and analyzed for various characteristics. After various tests and analyses of the data and variables (dependent and independent variables), a mathematical model for improved reliability of the medium voltage distribution network was developed.

Testing Variable for Model

The regression data obtained from the analysis of the dependent and independent variables were checked to see if the data were well presented by the model. The output was checked on Multicollinearity, auto-correlation, analysis of Variance and model summary.

Testing Variables for Multicollinearity

Multicollinearity is correlation or multiple correlations of sufficient magnitude to have on the explanatory variables to have the potential to adversely affect regression estimates. To test for multicollinearity a regression model was used the two approaches to measure collinearity are tolerance and variance inflation factor (VIF) in regression analysis, tolerance is the percentage of variance in the independent variable that is not accounted for by the other independent variables. This is where an independent variable is regressed on other independent variables in a multiple regression analysis and produces an R Square value which is then subtracted from one (1-R2) the difference is tolerance. Most commonly, a tolerance value of 0.10 or less is deemed problematic (although 0.20 has also been suggested). Variance Inflation Factor is a reciprocal of Tolerance 1/ (1-R2) and indicates the degree to which the standard errors are inflated due to the levels of collinearity. A VIF value of 5 and greater is often problematic (O'brien, 2007).

Table 6 shows the correlation of the dependent variable and independent variables, also it is used to confirm if the independent variable has adversity impact in regression analysis.

Table 6: Collinearity Test

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1(Constant)	.253	.703		1.413	.166		
Budget Constraints	-.253	.118	-.150	-2.140	.039	.894	1.119
Availability of Fault Detection & Isolation Equipment	.271	.204	.132	1.331	.019	.450	2.223
Proper Maintenance Practice	.167	.164	.085	1.022	.034	.643	1.555
Data and Information Management	.637	.130	.267	2.393	.022	.355	2.820
Network Design Configuration	.597	.105	.324	2.565	.014	.278	3.598
Availability of Skilled Labour	.322	.090	.327	3.578	.001	.529	1.890

a. Dependent Variable: Reliability of MV network

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Table 6 shows the collinearity of independent variables to the dependent variable (Reliability of MV network). For this study, the tolerance is all above 0.20 and the VIF is all below five (5) suggesting there is no multicollinearity.

Table 7 indicates that 91.5 % of the variation in the reliability of the MV network is explained by the independent variables.

Table 7: Model Summary

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.915[a]	.836	.810	.365	2.021

a. Predictors: (Constant), Availability of Skilled Labour, Budget Constraints, Proper Maintenance Practice, Data and Information Management, Availability of Fault Detection & Isolation Equipment, Network Design Configuration
b. Dependent Variable: Reliability of MV network

Table 8 shows the analysis of variance. At 91% level of confidence, results show that the independent variables statistically significantly predict the dependent variable, the p-value is less than 0.05 which means the regression model is a good fit for the data.

Table 8: Analysis of Variance

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	25.245	6	4.207	31.530	.000[b]
	Residual	4.937	37	.133		
	Total	30.182	43			

a. Dependent Variable: Reliability of MV network
b. Predictors: (Constant), Availability of Skilled Labour, Budget Constraints, Proper Maintenance Practice, Data and Information Management, Availability of Fault Detection & Isolation Equipment, Network Design Configuration

Table 9 shows the results of a **multiple regression analysis** that explores how different independent variables (such as "Budget Constraints" and "Availability of Skilled Labour") influence the **dependent variable**, which in this case is the r**eliability of the medium voltage distribution network**.

According to Table 9, availability of skilled labour (p-value 0.001), network design configuration (p-value 0.014), proper maintenance practices (p-value 0.034), availability of fault detection and isolation equipment (p-value 0.019), data and information management (p-value 0.022) and budget constraints (p-value 0.039) have p-values less than 0.05.

Therefore, they are contributors to explaining the reliability of the medium voltage distribution network (dependent variable). Their Beta coefficients are Availability of Skilled Labour is +0.327, Network Design Configuration is +0.324, Proper Maintenance Practice 0.085, Data and information management is 0.267, Availability of Fault Detection and Isolation Equipment is 0.132 and Budget Constraints is -0.150, suggesting that availability of skilled labour is the highest contributor in explaining maintenance management to improve reliability of power supply in medium voltage distribution network followed by network design configuration, data and information management, availability of detection and isolation equipment and the least is proper maintenance practice.

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Table 9: Coefficients of the Model

Coefficients[a]							
	Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
Model	B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1(Constant)	.253	.703		1.413	.166		
Budget Constraints	-.253	.118	-.150	-2.140	.039	.894	1.119
Availability of Fault Detection & Isolation Equipment	.271	.204	.132	1.331	.019	.450	2.223
Proper Maintenance Practice	.167	.164	.085	1.022	.034	.643	1.555
Data and Information Management	.637	.130	.267	2.393	.022	.355	2.820
Network Design Configuration	.597	.105	.324	2.565	.014	.278	3.598
Availability of Skilled Labour	.322	.090	.327	3.578	.001	.529	1.890

a. Dependent Variable: Reliability of MV network

In linear regression, the value of the coefficient for each independent variable gives the size of the effect that variable is having on the dependent variable and the sign of the coefficient (positive or negative) gives a direction of the effect. From the data analysis above the key factors for Maintenance management to improve the reliability of power supply in medium voltage distribution networks were ranked and mostly significant factors for all respondents are:

- Budget Constraints
- Availability of fault detection & isolation equipment
- Proper maintenance practices
- Network design configuration
- Availability of skilled labour
- Data and Information management

The top six ranked factors selected by respondents are selected to be independent variables since have a high impact on maintenance management and improvement of reliability of power supply in medium voltage distribution networks. The dependent variable is the output of the model that predicts improvement of power supply reliability in a medium voltage distribution network. From there the relationship is developed between dependent and independent variables.

The regression relation equation

$$R=\beta+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6\ldots\ldots+\beta_nX_n \quad (5.1)$$

From the Table of Coefficients

$\beta=0.253$, $\beta_1=-0.253$, $\beta_2=0.271$, $\beta_3=0.167$, $\beta_4=0.637$, $B_5=0.597$, $B_6=0.322$

R= Reliability of power supply in medium voltage Network

X_1= Budget Constraints

X_2= Availability of Fault Detection and Isolation Equipment

X_3= Proper Maintenance Practice

X_4= Data and Information Management

X_5= Network Design Configuration

X_6=Availability of Skilled Labour

$$R=0.253-0.253X_1+0.271X_2+0.167X_3+0.637X_4+0.597X_5+0.322X_6 \quad (5.2)$$

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Model Validation

From the model summary Table 7, the R^2 value of 0.836 and the Adjusted R^2 value of 0.810 indicate a strong model fit. The model explains a significant proportion of the variability in the Reliability of Medium Voltage distribution network, and the fit remains robust even when accounting for the number of predictors. The standard error value represents the average distance that the observed values fall from the regression line. A lower value indicates a better fit of the model to the data. In this context, a value of 0.365 suggests that, on average, the predictions are fairly close to the actual values.

The Durbin-Watson statistic tests for autocorrelation in the residuals. Values close to 2 suggest no autocorrelation, which is ideal. A value of 2.021 indicates that there is no significant autocorrelation in the residuals, implying that the residuals are independent. Since the high R^2 and Adjusted R^2 values demonstrate that the model explains a substantial amount of the variance in the dependent variable, and the Durbin-Watson statistic confirms that residuals do not exhibit autocorrelation, therefore, the model appears to be valid and robust.

Best Scenario Test

Budget Constraints = 0, Availability of Fault Detection and Isolation Equipment =1, Proper Maintenance Practice = 1, Data and Information Management = 1, Network Design Configuration= 1, Availability of Skilled Labour = 1

R_{best}=0.253+0+0.271+0.167+0.637+0.597+0.322 =2.247…………………………………………...(5.3)

If the value is normalized

Vnorm =V/Sum of all values…………………………(5.4)

R_{best} =(0.253÷2.247)+(0÷2.247)+(0.271÷2.247)+(0.167÷2.247)+(0.637÷2.247)+(0.597÷2.247)+(0.322÷2.247)……………………………………………(5.5)

R_{best}= 0.112+0+0.120+0.074+0.284+0.266+0.143

R_{best}=1

5.5.2 Worst Scenario Test

Budget Constraints = 1, Availability of Fault Detection and Isolation Equipment = 0, Proper Maintenance Practice = 0, Data and Information Management = 0,Network Design Configuration = 0,Availability of Skilled Labour = 0

R_{worst}=0.253−0.253+0+0+0+0+0…………………………………………………………….(5.6)

$\mathbf{R_{worst}}$= 0

CONCLUSION AND RECOMMENDATION

This chapter presents the conclusion of the study drawn from the data collection and analyses in the preceding chapters focusing on each of the three objectives developed in chapter one, together with the recommendations made regarding the maintenance management system to improve the reliability of power supply in medium voltage distribution network and elsewhere this developed model would be applicable.

Conclusion

The main objective of this research was to develop a maintenance management system (MMS) to enhance the reliability of power supply in the medium voltage distribution network. The MMS will be built based on a maintenance model developed that incorporates key factors affecting maintenance and operations. The six most significant factors influencing reliability were identified: **Budget Constraints, Network Design, Fault Detection Equipment, Maintenance Practices, Data Management**, and **Skilled Labour**.

The developed reliability model explains **91.5%** of the variation in power supply reliability, showing a positive impact of factors like skilled labour and network design, while budget constraints had a

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negative effect. To improve reliability, reducing budget constraints is essential.

Recommendations

General Recommendation

The study identified **Data and Information Management** as the most impactful factors for improving power supply reliability (+0.637). Investing in integrated information systems and smart grid technologies for real-time data collection is recommended to enhance monitoring and reduce downtime. **Network Design** (+0.597) should be optimized with grid redundancy and smart technologies for greater reliability.

Skilled Labour (+0.322) is also crucial, so workforce development and training in advanced technologies are advised, along with offering competitive salaries to attract and retain skilled personnel. **Fault Detection Equipment** is essential for minimizing downtime by quickly isolating faults; thus, deploying automated monitoring systems like sensors and relays is recommended.

Maintenance Practices (+0.167) positively impact reliability through predictive maintenance and asset monitoring. **Budget Constraints** (-0.253) negatively affect reliability, so strategic budget allocation should prioritize investments in key areas such as skilled labour, data management, and fault detection equipment. Focusing on these areas will significantly enhance the reliability of the power supply in Kinondoni North's medium voltage distribution network.

Specific Recommendations

To improve the reliability of power supply in medium voltage distribution networks, a maintenance management system is recommended to manage maintenance activities such as inspection, planning and scheduling, reporting, and data and information management. Also, operation activities conducted manually such as line patrol for fault location, and line Isolation should be changed to automatic. Hence, as reduces manual operation activities which affect the reliability of power supply in medium voltage distribution networks. Further study on technical operation management shall be conducted to manage manual operation activities into an automatic remote by using a computerized management system.

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