Failure Analysis of Distribution Transformer and Proposing Proper Solution to Mitigate the Faults -A Case Study of Kombolcha City Dessie District Ethiopian Electric Utility, Ethiopia

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Abstract: - The distribution transformer plays an important role in the distribution of electric energy to the customers. The reliability of DT does not only affect availability of the electric power to the customers of utility, but also economical operation of a utility. They can operate up to 30 years; but they fail within a year, due to many reasons resulting big economic and service lose on the power supplying utilities as well as the power customers. This paper has exposed the root causes of failure of the distribution transformer in EEU Dessie district Kombolcha NO. 1 and No. 2-customer service centers by using data collected from the substation, EEU, and inspecting the status of some transformers at peak hours. From the analysis conducted it was observed that the most frequently occurring causes of failure of distribution transformers in the centers were overloading, uneven power overloading, external short circuit, and lightning. In addition to identifying the causes, the researchers have proposed some remedial solutions to reduce the problems.

Key-Words: - Distribution Transformers, Causes of Failure, Overload, Vandalism, lightning, frequency of Interruption and Unbalanced load.

Received: October 26, 2022. Revised: October 16, 2023. Accepted: November 17, 2023. Published: December 27, 2023.

1 Introduction

Ethiopian Electric Utility (EEU) is one of the integral elements of Ethiopian Ministry of Water, Irrigation and Energy ministry. EEU established with a central aim of becoming a utility center of the country that can foster the socio-economic transformation through delivering a cost effective, safe, reliable and high-quality power. Currently EEU has 11 Regional Offices, 28 Districts and 554 service centers, [1]. Out of the 28 districts, Dessie District is the one that is providing a utility service to most of the East Amhara cities. Kombolcha electric utility Branch, which founds under the umbrella of EEU Dessie District, will share the ultimate objective of the head office of providing a reliable and stable power to its customers. In order to achieve their own (EEU head office, regional district, branch offices and service centers) ultimate goal, the respective offices should have to strive aggressively on purchasing and sales of bulk power, construction and operation of off grid power generation, sub-transmission and distribution networks and their respective infrastructure that can meet international standards, [1].

Currently EEU, Dessie district Kombolcha branch administers distribution networks of Kombolcha branch service center. Due to the existence of dense high-power demanding industries in Kombolcha city, providing a balanced and sustainable power to the customers is the main burden of the respective branch utility office. Its efficiency is most of the time affected by the failures on the distribution network components, limitation on infrastructure, limited use of modern technological products, limitations on data recording mechanisms, unavailability of periodic maintenance, use of unplanned operation and distribution systems, natural and artificial factors and so on. During the rainy seasons and existence of high-level wind, it is usual to see power outage and damage on the components of the distribution network of the service center too. Not only these ones, with the presence of overloading, lightning, short circuit, un-periodic maintenance of the distribution network elements, failures on the network components, especially on the distribution transformers will be observed. The frequent power outage due to these cumulative factors is highly exposing users to loss grid power and think of unnecessary investment of using alternative temporary energy sources. To alleviate the challenges and difficulties, investigations focused on identifying the repeatedly occurred basic crosscutting factors of distribution system failures should be conducted; and suggestions on remedial actions were made accordingly.

2 Literature Review

The transformers are the static electrical devices used to transfer energy from one circuit to another circuit by using electromagnetic induction principle. There are mainly two types of transformers in use they are power transformers and distribution transformers. A transformer is basically two sets of wires (the windings) wrapped around a steel or iron core as given in the schematic in Figure 1. The windings and the core are insulated. The essential core of the transformer has no moving parts, [2].

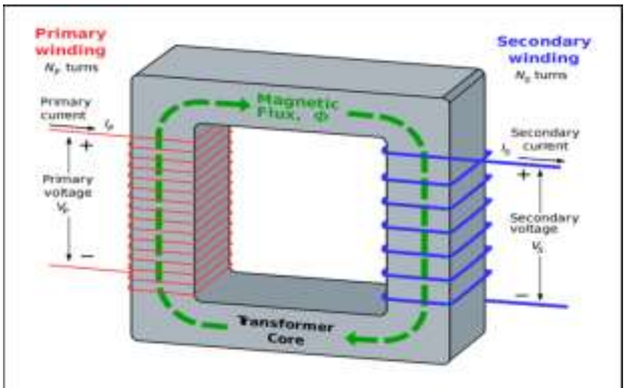

Fig. 1: Schematic Diagram of Transformer, [2]

The transformer plays an important role in power generating stations. Here the power needs to step up to high voltages for losses reduction in transmission lines. Then it will step down to low voltages for distribution purpose. Here the distribution transformer will act main role.

Faults also happen in the transformers like all other electrical devices which cause the failures. Some of the common failures occurs in distribution transformers are winding failure like dielectric faults, copper resistance thermal losses, mechanical faults in winding distortion, bushing failure, tap changer failure, core failure, tank failures, protection systems failure, cooling system failure etc., [3]. Comparatively faults occurrence in distribution transformers are more compared to power transformers. The transformer failures will result in loss, repair or replacement of transformer and also, power loss due to power not supplied to consumers. Some of the electrical, mechanical and thermal factors which are causing the transformers to fail are Lightning and switching surges; Transient or overvoltage conditions; Conductor tripping; Failure of cooling systems; operation of transformer on non-linear loads; High ambient temperature, [3].

The distribution transformers are the very important power equipment's that allows the high degree of electricity flow in distribution network. Distribution transformers are also called as service transformers. It will step down the distribution level voltage to the voltage level used by the consumer. The main components of distribution transformers are windings, core, and main tank, on load tap changer. The main faults of transformers occur in windings and in on load tap changer. In the distribution transformer the main failures occur in On Load Tap Changer (OLTC) and winding. Breakdown of a distribution transformer leads to costly repairs, [4].

In the past, distribution transformers served for more than sixty years. In recent years, many distribution transformers fail even a few years after commissioning, [4]. It is pertinent to address the cause of the premature failure of transformers because they are contributing to both loss of capital and revenue to the power utility and slowing down the economic growth of a country. It has been noted that due to relative low cost of distribution transformers (as compared with power transformers), very little effort is made by utility to find out the root cause of transformer failure. Lack of investigating the root cause, could be attributed to one of the reasons why more failures happen immediately or within a very short period after replacing a damaged transformer, [5].

Transformer fail due to insulation breakdown could be contributed to electrical, mechanical and thermal factors, [6]. Electrically induced factors include operation of transformer under transients or sustainable over voltage condition, exposure to lightning surges and switching surges, or partial discharge (corona) due to poor insulation system design. On the other hand, mechanically induced factors are such as looping of the inner most windings, conductor tipping, conductor telescoping and failure of coil clamping system. Thermal induced factors include degradation of cellulose insulation of oil and insulation material of the windings. Thermal induced factors are mainly due to overload beyond transformer design capacity as result of cold load pickup (loads transformer supplies after restoration of power after prolonged power outage), failure of transformer cooling system, operating transformer in an over excited condition (under frequency) and operating under excessive ambient temperature conditions, [6].

MIL-STD -1629A standards clarifies transformer faults in three categories; severity, frequency and detection factors. This give rise to priority number (PN) which is defined as:

PN=Severity*Frequency (occurrence)*Detection. (1)

The minimum PN of any faults on transformer is 1 and maximum is 120.
The PN for various elements of a transformer are as depicted in Table 1, [7].

Table 1. PN for Various Elements of a Transformer

S/no.	Failure type	PN
1	windings	6-30
2	Bushing	24-48
3	Tap-changer	28-52
4	Core	6
5	Tank	18
6	Protection System	22-64
7	Cooling System	26-48

Source: Data from MIL-STD-1629A

From Table 1, it is evident that protection system has the highest PN (22-64). This therefore implies lack of proper protection system contribute to high failure rate of transformer. Protection system includes poor fuse grading (over-rated fuses), lack of lightning arrestors and an ineffective earthing system. Core failure is the least cause of premature failure of distribution transformer. It is worth pointing out that bushing failure is associated with poor workmanship and O&M as is mainly caused by;

i. Loosening of conductor due to vibration
ii. Sudden over-voltage which causes partial discharge
iii. Ingress of water at seal of the transformer
iv. Not replacing old oil which may result in internal flashover

Research has shown that there are various measures which may increase the expectant life and efficiency of distribution transformers (The expected life span of transformer above 100KVA is 35 years while below 100KVA is approximately 25years). These measures include adequate and good design, [7]. Transformers manufacturer in recent time have compromised both on quality and reliability. This is achieved by lack of adequate clearance for free air circulation, economical size of winding wire which cannot withstand higher current densities due to short circuit conditions, and improper use of inter-layer papers. Enhanced O&M to ensure oil level of the transformer is sufficient, clearing trees which are main source of high impedance fault, proper fuse grading and remove of condensed water in the transformer. Use of correct diversity factor to avert overloading of the transformer and avoiding two phasing in rural areas which causes unbalance current that raise potential of neutral with respect to the earth are some of the measure's utility need to undertake to avert early failure of distribution transformers.

It has been observed that most of transformer supplying industrial and institution are premature failing. Increase of non-linear loads both at industries and at institutions has resulted to high harmonic content which increases the current leading to overload of transformers, [8]. It is worth noting winding copper losses (I^2R), the core losses and stray losses which increase significantly operating temperature of a transformer has direct proportionality with level of harmonic frequencies present. It is important to note that, average life expectancy of the transformers is directly proportional to the average life of insulating materials. On steady state power supply, harmonics and variations in frequency are the main factors that accelerated aging of insulation materials and hence premature failure of distribution transformers, [8].

There can be variety of reasons for failure of Distribution Transformers. Some of the important ones are listed in Table 2:

Table 2. Causes of Failures, [9]

Description	Failure Rate
Electrical disturbances, overloading	29.43%
Lightning strike	17.32%
Loose Electrical connections, high Resistance	7.3%
Maintenance Issues, Oil contamination	5.91%
Moisture Ingress	4.03%
Line Surge, Other Issues	3.25%

3 Methodology

Both quantitative and qualitative methods followed to obtain the root causes of distribution transformer failures in a Kombolcha city. The researchers carefully designed questionnaire and distributed to the operation and maintenance staff of EEU Dessie district, Kombolcha city number one and two-customer service office. The questionnaires include the main consequences of transformer failures like overloading, unbalanced load per phases, oil level, lightning, poor earthing or absence of earthing, improper or poor cable terminal, external short circuit, overrated fuses, vandalism and luck of primitive maintenance. Under each main cause, there are various sub causes which have its own weights as {(1) – strongly disagree, (2) – disagree, (3)-Moderately agree, (4) – Agree, and (5) – Strongly agree}.

The researchers measured phase and neutral current of the selected transformers at peak load time, and observed fuse connection and rating, proper lighting arrester connection, and oil level.

In addition, technical head and team leaders had participated in interviewing issues, who had directly linked with distribution transformers installation, handling, maintenance and operations. The researchers' triangulated questioner, interview and measured data to get better result.

In order to investigate the disturbance of the distribution network or feeder of the Kombolcha city, monthly power interruption readings for twenty-one consecutive months from july-2021 to march 2023 G.C. were obtained from Ethiopian Electric Power, EEP north east region Dessie and distilled into a spread sheet database using the Microsoft excel package from which further statistical analyses were performed.

The collected data were analyzed by using Microsoft Excel to determining the frequency of interruption, total duration, average un-served power and unsold energy in each feeder. The analyzed data covers 21 consecutive months as shown from Figure 2, Figure 3, Figure 4, Figure 5 and it used for the selection of a single feeder for further study.

The station recorded total frequency of interruption were 2,911 (21 from incoming side and remain 2,890 on load side) within 21 months. The data shows that, line two and three shares 30.5 and 32.6 percentages frequency of interruption accordingly as shown in Figure 2. These two feeders recorded 1836 interruption or 63.1% from the total interruption that happened on the station in the respective period.

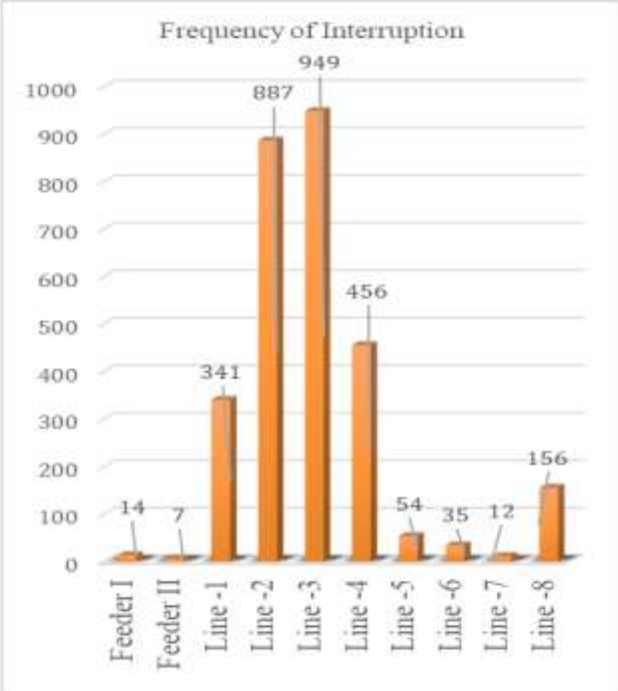

Fig. 2: Kombolcha Substation I Frequency of Interruption within 21 Months

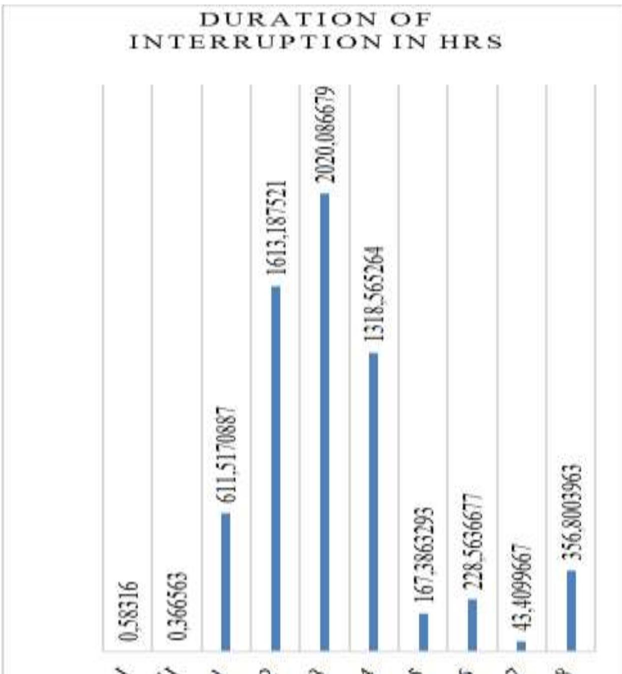

Fig. 3: Kombolcha substation I duration of interruption in hours within 21 months

As shown in Figure 3, the total duration of interruption was 6,360.5 hours within 21 months. Among this, line three had 2020.1 hours interruption duration, which means it sustained more than 406 hours than the other.

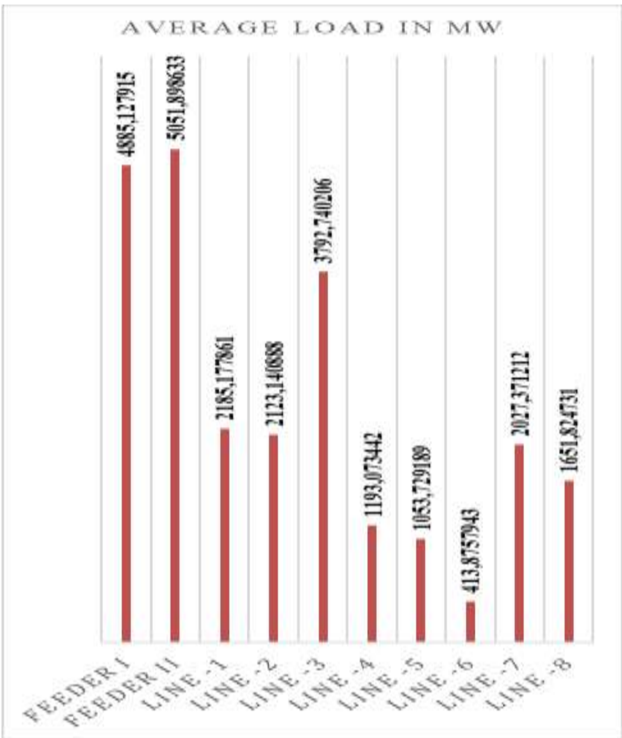

Fig. 4: Kombolcha substation I un-served average power in MW within 21 months

The sum of un-served power was 24,377.96 MW within 21 months because of uncontrolled interruption occurred on Kombolcha I substation. From this 3,792.7 MW power were un-served due to the interruption occurred in line three.

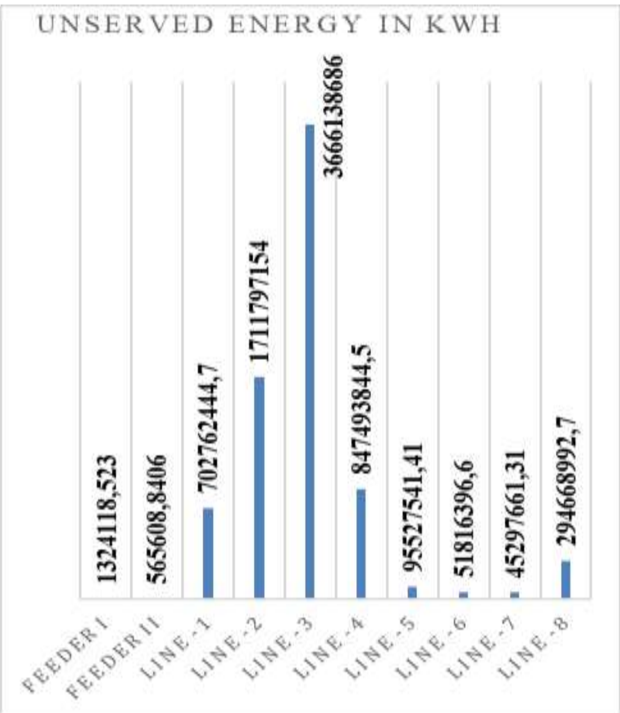

Fig. 5: Kombolcha substation I unsold energy in KWH within 21 months

Because of continuous interruption occurred on the substation 7,417,392,448 KWH energy lost starting from july-2021 to march-2023 G.C. As shown in Figure 5, huge amount of energy was unsold, because of the more interruption occurred on line three.

From the available feeders, the line-three had been selected for further study, due to the fact that this feeder is highly characterized by a frequency and long duration interruption, un-served power and unsold energy as shown in Figure 2, Figure 3, Figure 4 and Figure 5.

3.1 Distribution Transformer Data in Kombolcha City

Distribution Transformers play vital role in deciding the power flow in large power systems and they are the most expensive equipment's in the distribution network. There are more than 200 distribution transformers all over the city, which are connected to the 15KV distribution network to provide the current demand of the customer. These DTs have different ratings in units of kVA. The most common ratings of DT in Kombolcha city are 25kVA, 50kVA, 100kVA, 200kVA, 315kVA, 630kVA, 800 kVA, and 1250 kVA. In addition to these, there are some other DTs with uncommon ratings like 250kVA, 300 kVA, 400 kVA, 1500 kVA, 1600 kVA, and 5200 kVA. Figure 6 below shows the number of DTs and their ratings in kVA unit in the city.

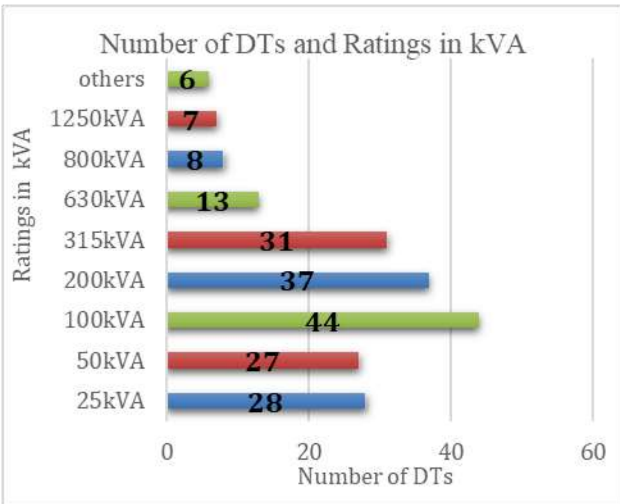

Fig. 6: The number of DTs and ratings in kVA available in Kombolcha city

As mentioned above there are eight medium voltage (MV) feeders with 15kV supplying electric power to the city. More than 200 DTs are connected to these feeders to step down the incoming voltage (15kV) into low voltage (380/220V) level. Figure 7 shows the number of DTs with their ratings loaded to the distribution network or feeder in the city.

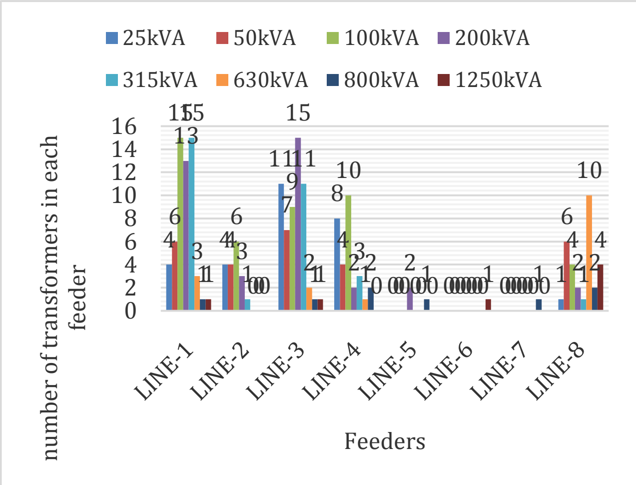

Fig. 7: The Number of DTs Connected to the Feeders in Kombolcha city

There are 57 distribution transformers under feeder three with a total installed load capacity of 11,300 kVA. Among these, 15-distribution transformers have 200KVA rating and 11-distribution transformers have 315 KVA rating. The remaining DTs have 25KVA (#11), 50KVA (#7), 100 KVA (#9), 630 KVA (#1), 800KVA (#1) and 1250KVA (#1) installed capacity. The researchers strongly believe that, transformer failure is one of the causes that lead the feeder interruption frequently. Furthermore, the researchers would investigate those 57 transformers by measuring phase and neutral current, observing lighting arrester connection, oil level, and earthing system of distribution transformers of the town, which were installed under selected feeder. Then, the researchers tried to triangulate questioner's data, interview information and measured data of selected transformers to get a much better result and to reach to a more soundful conclusion.

4 Data Analysis

Kombolcha City gets electric power from Kombolcha substation I, with power distribution network at a primary voltage of 15kV consisting entirely of 3-phases, 3-wire feeders and is stepped down to a utilization voltage of 380/220V (3-phase, 4 wire). There are eight feeders (lines) with 15kVA supplying electric power to the city. Three feeders provide electricity to the industries only while the rest five feeders supply electrical energy to some industries and other customers. Here are the lists of the feeders in the Kombolcha city.

- Feeder one (F1) -provides electric power to substation II area.
- Feeder two (F2) - provides electric power to Bati town and its surroundings.
- Feeder three (F3) - supplies center part of the Kombolcha city and its surrounds.
- Feeder four (F4) - supplies kombolcha technology institute, Harbu town and its area.
- Feeder five (F5) - supplies to BGI beer Factory.
- Feeder six (F6) and Feeder seven (F7) provide power to Kombolcha Textile Factory
- Feeder eight (F8) used to supply Dessie city, but now supplies the small factories in Kombolcha city too.

We have combined the interview and substation data for 21 months which should help us for assessing the frequently interrupting feeder in the city to determine the sample distribution transformers to take tests during peak hours. And also, we have combined well organized questionnaire and measured transformer reading data which should help us to know the causes for transformer failures. The combination of all data has justified that, the most common transformers failures in the Kombolcha city are overloading, unbalanced loading, lightning, improper use of protection, and external short circuit.

Twenty questionnaires were distributed to the maintenance, inspection and emergency maintenance staffs of EEU Dessie district Kombolcha customer service office No. 1 and No. 2. Out of twenty questionnaires sixteen were collected. Figure 8 represents a plot of the frequency of failure causes.

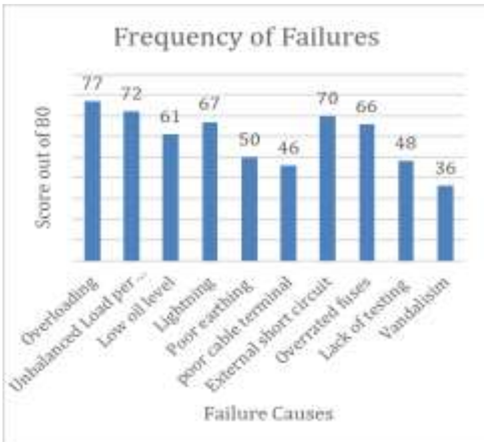

Fig. 8: Frequency of failure causes

From the graph in Figure 8, the major causes of transformer failure include overloading, unbalanced load, low oil level, lightning, short circuits, poor earthing, poor cable termination, over rated fuses, lack of testing, and vandalism were highlighted as a cause of failure. From the graph it was observed that overloading is the most frequently occurring cause with score 77 out of 80. Next to it, uneven loading, short circuit, lightning, over rated fuse, and oil level follow scoring 72, 70, 67, 66, and 61 out of 80 respectively. While vandalism had least effect on the transformer failure with least score of 36. For the question why these problems occurred on the transformers or what were the root causes for the problems, the answers were summarized in Table 3 in descending order of their occurrence as per the questionnaire responses.

Table 3. Questionnaire responses summary of root causes for different effects

No	Effect	Root causes
1	Overloading	✓ Absence of record on the loading of the transformer ✓ Unauthorized usage/ theft of power
2	Unbalanced load per phases	✓ Absence of loading records per phases (random connection of new customers) ✓ Long single phase/two phase line
3	External short circuit	✓ Poor safety clearance ✓ Contact of the conductor with trees / branches ✓ Long LT line span ✓ Sagging of conductors
4	Lightning	✓ Absence of lightening arresters/damaged arresters ✓ Disconnection earth wire and rusted earth wire ✓ High resistance of earthing electrode
5	Over rated fuse	✓ Non-availability of rated fuse ✓ Frequent blown off HRC fuse
6	Low oil level	✓ Leakage of oil ✓ Un-filling of oil ✓ Theft of oil
7	Poor Earthing	✓ Disconnected earth wire or rusted earth wire ✓ High soil resistivity of the earth pit
8	Lack of testing	✓ Absence of a routine for testing ✓ Non-availability of megger, filter machine, oil testing kit
9	Poor cable termination	✓ Non – availability of materials ✓ Loose connection
10	Vandalism	✓ Unsecured station ✓ Lack of awareness among the public

From the Table 3, it was observed that the main causes for overloading on the transformer is absence of record on the loading of the transformer. Next to it, unauthorized usage/ theft of power is another serious issue that results over loading. This case hurts the company in two ways. First using power without paying for energy bills and secondly it causes transformer failures. The Plot of the causes that have severe effect on DTs is given in Figure 9.

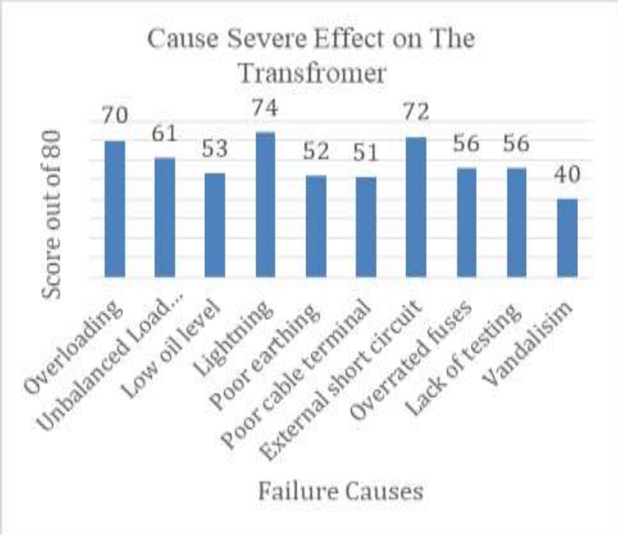

Fig. 9: Plot of the causes that severe effect on DTs

From Figure 9, Lightning with score 74 out of 80 had the most severe effect once it occurred. Next to lightning, external short circuit, overloading, and unbalanced load followed with score 72, 70, and 61 respectively. While vandalism had least severity on DTs. According to the data plotted in the Figure 9, serious care must be taken while giving protection against lightning, external short circuit, overloading and unbalanced power per phases.

Overload is when a transformer is subjected to sustained loading/or currents that exceed its design specifications or the name plate capacity. During overloading conditions, excess heat will cause the insulation system to break down, resulting failure of DTs due to overloading. In distribution network transformer load data, the distribution transformers with load ratio greater than 100% is defined as overload transformer, the definition between 80%-100% is heavy load, and less than 80% is considered normal, [9].

The rise of temperature of winding, leads, insulation and oil to unacceptable level are the consequence of overloading on the transformer. This consequence will cause a risk of premature failure associated with increased currents and temperature.

It is impossible to avoid overloading for a short duration. But overloading distribution transformer for long duration is not recommended. As DTs overloaded, it generates more and more heat, which damages the winding insulation resulting whole damage of the transformer.

Checking and recording on the loading of a transformer as well as recording the total number of connected loads (customer) from each transformer are main responsibility of the EEU inspection staff. Three failed transformers (Shewa Ber, Frutuna, and Yimer Ali (Berber Wenz) areas of the Kombolcha city) were extracted to analysis the overloading case.

According to the load reading measured at peak hours, the Shewa Ber, Furtuna (around Kebele 05) and Yimer Ali (Berber Wenz) stations transformers were 31.01%, 17.75% and 12.5% overloaded respectively. According to the result obtained from questionnaires data in the Table 3, this overloading is due to absence of record on the loading of the transformer so that new connections to customer above the capacity of the transformer were made. Most of the times a number of new connections are added to the existing transformer without calculating the load which it can supply. Additional cause of overloading is due to power theft. From these observations, the researchers may suggest that the transformers might have failed due to overloading.

Measuring the load current during peak load hours will give information about load condition of the transformer. If loading is greater than the rating of the transformer during peak hours and continuous for several days, it's recommended to upgrade the existing transformer with a larger rating transformer immediately.

In case of unbalanced loading, voltage is generated on the neutral and will remain floating between neutral and earth. Since the neutral is solidly grounded through external link, a circulating current will flow through the loop of delta winding. This additional circulating current will superimpose on the main branch current of the delta winding and will cause additional heat, which may lead to the failure of the HV winding insulation. Proper and timely maintenance could have saved this transformer. R phase of LV winding could have burnt due to line to ground fault. In this situation, heavy current would have been drawn that cause not only the LV winding to burn but also punctured the HV winding, [10].

Distribution transformer should be loaded evenly on all the three phases. However, in the case of load measure of distribution transformer taken at peak hour, there are many instances where even though transformer doesn't overload there was huge gap between the currents in the phases.

For analyzing unbalances, the following Cases were considered and unbalance data was generated.
Cases:
Shewa Ber and Haile (Berber Wenz) areas
Feeder: feeder 3
HV side voltage: 15KV
LV side voltage: 220V

It was observed that there were unbalanced currents per phases. In the Haile (Berber Wenz) transformer, phase S current is nearly 12 times phase T current and phase R current is nearly equal to 7 times phase T current. Similarly, in the Shewa Ber transformer, there were significant gap between each phase currents. Phase R current approximately two times phase T. Due to this the load on one phase goes excessively high, causing operational disturbances which leads to failure of transformers. This matches with the result obtained from the questionnaires data analysis that unbalanced loading is second prominent causes for failure of DTs.

The purpose of the fuse is short circuit protection and overload protection. The HV fuse provides protection by isolating the system upstream of the transformer from faults in or beyond the transformer, and protecting the transformer and conductors against rushed LV faults, such as wires twisted or firmly held together by fallen tree branches. The HV fuse rating was selected to handle approximately 150% of the transformer nameplate rating whereas LV fuses were selected to handle around 120% of the transformer nameplate rating on the transformer LV terminals according to IEC 60269 – 2 standards.

In many instances of our inspection, we had observed that using of higher rating of fuses or not using of fuses at all or use of unequal fuse rating size in one circuit were common circumstances with respect to fusing. The first reason was occurred, when transformer HRC fuses were blown off frequently, and the maintenance team replaces the fuse element of higher rating to avoid frequent interruption of supply and frequent replacement of fuses. The second reason occurred due to unavailability of proper size of fuse for replacement during maintenance activities. Figure 10 shows the picture of a typical DT operating without HRC fuse which we encountered during our field inspection of some distribution transformers.

Fig. 10: DT Operating without HRC Fuse

Four different Cases (Shewa Ber, Furtuna, Haile, Donat 1 site) of transformers were selected from the samples to analyze the improper uses of fuses.

4.1 Shewa Ber Site Transformer

In this site 200kVA transformer with two out going circuits was failed due to prolonged overloading and replaced by 315kVA higher than the previous transformer. Still now this site transformer is suffering from the phase unbalance (as explained in the previous part) and improper size of fuse. In the first circuit the installed HRC fuse sizes are unequal. As per IEC 60269 – 2 standards, it is not recommended to use HRC with different size in a single circuit. In the second circuit two phases, phase R and T are unprotected. Using transformer without installing HRC in the LV side cause damage in the transformer, because there is no protection against external faults like external short circuit and sustained overloading. Therefore, installing correct size of HRC fuses on LV side will avoid the probability of failure of transformer due to overload and external short circuit.

The same issue was happened for the transformers in Furtuna, Haile, and Donat 1 stations. These are bad practices and they must be avoided to ensure the protection of distribution transformer from external faults on the secondary side.

Lightning is another major reason for distribution transformer failure during the summer season. It occurred when lightening arrester is not installed at all or the lightning arrestors failed to divert direct lightning strikes or surges due to discontinuity in the earthing system that causes the primary winding to fail due to surge voltage or the lightning arrestor itself may burst.

During our site inspection, all of the sampled site transformers were protected against lightening by the lightening arrestor. But, some transformers (out of the sampled sites) as shown below in Figure 11 were not protected against lightening.

Fig. 11: Some of Unprotected DTs against Lightening

In Figure 11, the first transformer (left) is 100kVA with two outgoing LV feeder and located around Kombolcha general high school supplying power to the customers around the school and Biraro auditorium. For this transformer, the two lightening arrestors are not connected to the MV lines whereas the other one is missing. The second (right) transformer located around Kombolcha general hospital on the way to Woyraw with capacity of 315kVA. This second transformer has two outgoing LV side feeder providing power to the customers around the hospital. For this case too all the three lightening arrestors were not connected to the MV lines. In general, in both cases the transformers are not protected against lightening. This may cause the transformers to fail due to lightning stroke during summer season.

MV side short circuit fault does not cause fault to the transformer. But in case of an external short circuit on primary (LV) side affect the transformer to fail. Very large amount of fault current (approximately 20 to 25 times the rated current) will pass through the windings. The winding is designed to resist such a fault current not greater than 3 seconds. If the fault stays more than 3 seconds the transformer winding will be burned causing the transformer to fail. Figure 12, shows possible cause for external short circuit problem.

Fig. 12: MV and LV lines are in Contact with Tree Branches

By selecting the correct rating of protection device in the LV side or HRC fuse it possible to protect the transformer from damage from LV short circuit. But on – site investigation showed us, many cases were observed the distribution transformer with improper size of fuse, absence of fuse, and unacceptable fusing type on LV side are major reason for failure of DTs and affecting the safety of DTs.

During our site inspection time, it had been observed, there were sparks from the bushing termination joints especially on L.V connections due to lose contacts. Sparks were happening because of loose terminations during the installation or else have been loosening due to poor service conditions. Once spark occurred at the cable termination, it causes melting of the busing sealing gaskets, effecting oil leakage from the bushing top, and later resulting in failure of the transformer in due course of time because of low oil level.

Also, during cable termination, we have to consider the effect of bimetallic action. If aluminum cable or conductors are to be connected with brass/copper terminal or vise-versa, a proper bi-metal remain in between. Due to bimetallic action, a milli-volt will generate causing a localized current and may deteriorate the current carrying thread, [11]. A typical picture of poor cable termination is shown in Figure 13.

Both the MV and LV terminals must be connected through suitable lugs and connectors. Direct Connection of cable/conductor to the bushing terminal must be avoided.

On the other hand, transformer oil is used to insulate high-voltage in transformers and is designed to operate effectively at very high temperatures for cooling, and insulating. Low oil level is due to timely un-filling of oil tank and oil leakage. Oil leak from bushing gaskets is mainly due to high heat or stress developed in the bushings. This will make the level of oil in the tank low causing in deterioration of HV and LV insulation and ends up with failure of transformer. In overloaded transformer oil leak through LV bushing is very common.

Fig. 13: Damaged DTs part due to poor cable termination

5 Conclusions

This investigation had been conducted to analyze and identify the root causes of DTs failure and propose possible remedies to the identified problems in EEU, Dessie District, Kombolcha city. It had been observed, that the failure of DTs has persistently devastating problems in EEU Kombolcha customers No. 1 and No. 2. The result of this work generally illustrated that the existing problems in EEU Kombolcha customer No. 1 and No. 2 related to failure of distribution transformers are caused by inappropriate operation and maintenance practices. Next to lack of protective devices had significant contribution to the failure of the distribution transformers.

It has been recognized that the leading and most frequently occurring cause of distribution transformer failure is related to overloading due to lack of power loading record (this leads to connecting new customers without upgrading the existing transformer capacity) and unauthorized use of power. On the other hand, the cause that had a severe effect on the DTs was lightning. Most of the time lightning affects those transformers having poor lightning protection mechanism.

The benefits of this analysis of distribution transformer failure types and the proposal of different mitigation techniques for the identified failure types is that it helps the utility provider to take all safety measures concerning the different operational distribution transformers as well as to conduct a variety of preventive maintenance to distribution transformers.

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Contribution of Individual Authors to the Creation of a Scientific Article

The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.