IMPACT OF MODIFICATIONS IN ASSET MANAGEMENT PRACTICES ON QUALITY OF SUPPLY FOR INDUSTRIAL CUSTOMERS

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ABSTRACT

Umeme Limited's industrial customers constitute 9% of the customer base but consume 74% of the power produced. Hence when the quality of supply improves for the minority group of customers, then this will ensure sustainable economic growth. The research involved soliciting responses from customers using questionnaires, observation of network assets in the field and analysis of existing data on the performance of the power supply. An electrical model was developed to simulate the impact of changes in asset management practices on power quality. Reliability of power supply was analysed using Monte Carlo Simulation in MATLAB programme. The research was conducted on Umeme Limited network of Natete District. The findings reveal signs of poor asset management practices which negatively affects the quality of supply to industrial customers. It was demonstrated that poor asset management practices negatively impact on power quality for industrial customers due to increase in contact resistance as a result of poor fusing, poorly made jumpers and joints. The change in resistance significantly affect medium industrial & commercial customers compared to heavy industrial customers. Poor asset management practices reduce the mean time to failure of electrical components which reduces the overall reliability of the supply. Good asset management practices therefore improves power quality by minimizing contact resistance and reliability by good maintenance practices for industrial customers.

Keyword: *— Asset Management, Industrial Customers, Quality of Supply*

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1. INTRODUCTION

The desire of every utility all over the world is to supply quality and reliable power to its customers at all times. The main task is to provide uninterrupted energy with the desired voltage and frequency [1]. This research was conducted on Umeme Limited network in Natete District being one of 25 operational districts for serving its customers.

2. ASSET MANAGEMENT

Electricity utilities are preoccupied with providing reliable & quality power supply to their customer at all times. This is possible through proper network assets management so as to reduce electrical faults on their systems.

Asset management is a philosophy and discipline which enable utilities to acquire, use and dispose assets in a cost effective manner so as to provide high levels of customer service over the entire lifecycle of an asset [2,3]. It is an organized procedure of operating, maintaining and improving of electrical assets [4]. The main purpose of asset maintenance is to prevent its deterioration and to obtain maximum financial value of the asset [5].

Although there is limited competition in the provision of grid electricity, effective monitoring of customer satisfaction is necessary for gaining acceptance and good public relations [6].

The following are the major network assets that were considered in this study.

2.1 Distribution Transformers

A transformer is at the heart of power transmission and distribution which requires particular attention in order to enable the grid operate optimally. Distribution transformers step down the voltage to supply customer equipment.

2.2 Underground Cables and Overhead Lines

Underground cables are used on the MV network to cross roads and transmission towers. They are also used at the customer premises.

2.3 Line Supports and Switches

Wooden poles are the most common form of line supports on which the conductors are supported while transferring electricity to the final consumers. The main switches that are used in sectionalizing the lines include load break switches and air break switches.

To minimize power quality problems, adequate planning and maintenance is required [7]. The main purpose of asset management is to use assets efficiently to realize the organization's objectives [8]. Network asset management is a complex task involving safety and reliability of assets, planning, operating & maintaining, monitoring and asset life cycle management [9].

3. QUALITY OF SUPPLY

Good power quality is a power supply which is always available, is within voltage & frequency tolerances and has a pure sinusoidal waveshape [10]. The quality of supply at the point of connection is of high importance for proper operation of industrial systems [11].

Umeme has 82,837 industrial customers which represent only 8.71% of the total customer base of 950,814 [12] but consume 74% of the power [13].

Quality of supply comprises customer service, reliability (continuity of supply) and voltage (power) quality [11]. Quality of supply means a minimum number of interruptions with durations kept to a minimal period of time [14]. The power quality issues are different for both customers and the power distributor [7].

Symptoms of power quality problems include: malfunctioning of equipment at the same time of day, tripping of circuit breakers without overload, equipment failure during thunderstorm, failure of automated systems for no reason, frequent failure of electronic systems and electronic systems which only work in specific locations [15,16].

3.1 Power Quality

The common power quality issues are summarized in Figure 1 below.

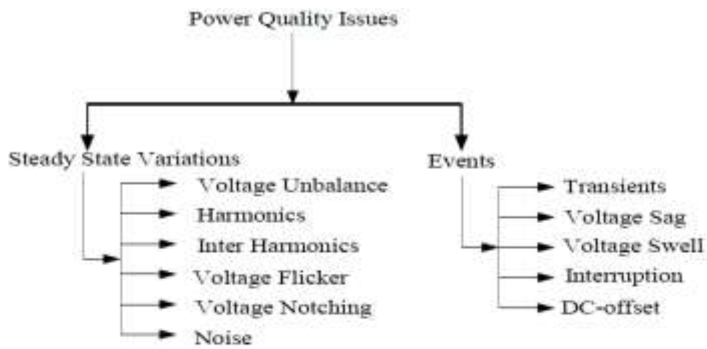


Figure 1: Steady state and events power quality issues

Source: [17]

3.2 Reliability

These performance parameters indicate the degree of reliability and are referred to as the indices of reliability and are calculated as follows [18].

Failure rate (λ) = $\frac{\text{Cumulative fault frequency for each year}}{\text{Period of occurrence for each year}}$

Mean time between failure (MTBF) = $\frac{\text{Total system operating hours}}{\text{Number of failure}}$

Mean time to repair (MTTR) = $\frac{\text{Total system downtime}}{\text{Number of failure}}$

Availability (A) = $\frac{\text{MTBF} - \text{MTTR}}{\text{MTBF}}$

Reliability (R) = $e^{-\lambda t}$

where λ = Failure rate
t = time (1 day)

4. RESEARCH METHODS

The research methods that were used include:

4.1 Document Review Method

Secondary data and reports already available from the various systems of Umeme Limited were reviewed e.g. incidences from IMS, SCADA reports, GIS database and planned shutdowns. A similar study was done in Ekiti State, Nigera where data on the operational and failure features of the network in terms of availaibility, quality of power, types and frequency of faults were obtained and analysed to determine root cause of the power problem. [19]

(a) IMS Data Analyses

The table below shows the average between 2012 – 2016 for incidences related to quality of supply.

Table 1: Filtered incidences related to asset management

Feeder/Year	Average
Katwe 2 11kV Feeder	295
Nakawuka 11kV Feeder	1,269

Kabusu 11kV Feeder	679
Buddo 11kV Feeder	2,593
Masaka 33kV Feeder	2,990
Mityana 33kV Feeder	3,797
Total	**11,623**

Table 2 illustrates the main 20 causes of incidences reported. In order to improve on quality of supply, the four main causes (fault drivers) that need attention are transformer LV fuse, loose connection, transformer MCB and transformer HV fuse. They account for 7,554 incidences (67%) of the average annual incidences reported (11,270) which are related to asset management. This means that if these issues are properly addressed, then the number of incidences will greatly reduce.

Table 2: Main causes of incidences reported in Natete District

No	Causes of Incidences	Total Number Reported
1	Transformer LV Fuse Blown	2,188
2	Loose Connection	1,944
3	Transformer MCB Trip	1,735
4	Transformer HV Fuse Blown	1,687
5	Transient Fault	673
6	Conductor Broken	509
7	Transformer Faulty	339
8	LV Jumper Broken	286
9	Conductors Clashing	249
10	Pole(s)-LV Broken	239
11	HV Jumper Broken	226
12	Conductor Badly Sagging	222
13	Pole(s) Rotten	209
14	Transformer Wiring	208
15	Pole(s) Leaning	138
16	HV-TX Link Blown	118
17	Overload	104
18	Transformer Vandalised	75
19	Trees on Line	63
20	Circuit Breaker Trip	58

(b) SCADA Data Analysis

The top 15 causes for feeder interruptions is as shown in Table 3 below.

Table 3: Top feeder interruptions fault drivers

Cause	Frequency	Duration (Hours)
Transient Fault	357	16
Broken Conductor	85	148
Broken Jumper	76	111
Network Asset Installation or Repair	60	97
Faulty Transformer	55	134
Bad Weather	41	46

Broken Pole	29	49
Blown Links	24	9
Tree Branch	21	70
Entangled Conductors	18	71
Knocked by Vehicle	12	29
Burning Pole	10	9
Surge Arrestor	8	24
Conductor on Crossarm	7	21
Faulty Cable	6	21
Total	**809**	**854**

Table 3 indicates that the majority of faults are transient in nature with each lasting an average of 161s. The maximum period for such faults considered in this research lasted 10 minutes whereby there is interruption in supply for a short period of time and then a reclosure of the circuit breaker is successful.

The graph of Figure 2 shows the total annual interruptions for six feeders.

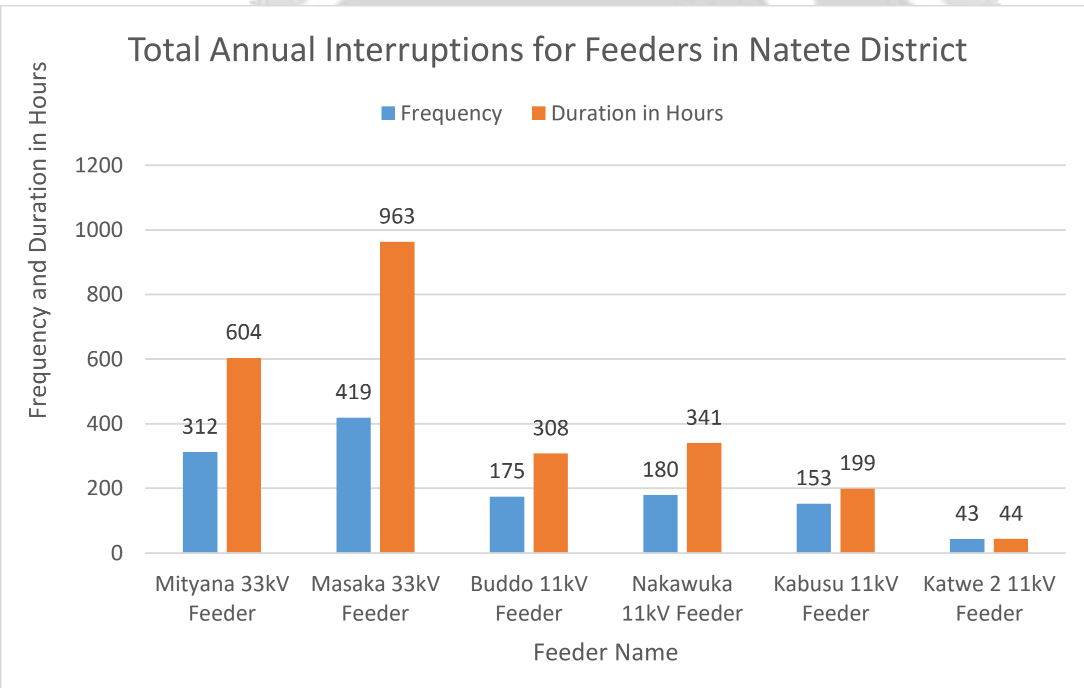


Figure 2: Bar Chart showing Average Annual Interruptions in Natete District

Masaka 33kV Feeder was the worst performing feeder while Katwe 2 11kV was the best performing feeder between 2012 and 2016. The average annual number of interruptions per feeder is 214 lasting 410 hours which means that each feeder is interrupted 18 times a month culminating into outage of 34 hours. On a daily basis, a feeder is interrupted 1.5 times lasting 1 hour 8 minutes which is equivalent to an unplanned interruption of atleast once a day lasting 59 minutes.

The reliability of the different feeders is shown in Table 4 below. The most reliable feeder is Katwe 2 11kV feeder while Masaka 33kV feeder is the most unreliable feeder. The data considered was for unplanned power interruptions only i.e. faults, unplanned shutdown and emergency shutdown.

Table 4: Reliability of power supply by considering unplanned interruptions

Feeder	Frequency	Duration (Hours)	Reliability (%)
Mityana 33kV Feeder	312	604	40%
Masaka 33kV Feeder	419	963	28%
Buddo 11kV Feeder	175	308	61%
Nakawuka 11kV Feeder	180	341	60%
Kabusu 11kV Feeder	153	199	65%
Katwe 2 11kV Feeder	43	44	89%

4.2 Questionnaire Method

This was used to collect information from customers. A written questionnaire with closed end questions were issued to the different categories of customers. This method has been used by different researchers to solicit views and opinions on power quality, reforms, interruptions, etc [20, 21, 22]. In order to support data obtained from field inspection and analysis of existing data, additional information was obtained from interviews with staff during research in Ekiti State, Nigeria [23].

Questionnaires were distributed to three phase customers at different locations for the six feeders under consideration. The customers had an average of 9 days to complete the questionnaires which were later collected. The response rate is indicated in Table 5.

Table 5: Response rate for customer surveys

Tariff Category	Sample Size	Actual Response	Response Rate
Industrial HV	11	10	**91%**
Industrial LV	51	47	**92%**
Commercial TOU	159	127	**80%**
Total	**221**	**184**	**83.3%**

A study on Libyan Electrical Distribution Networks revealed power quality disturbances experienced by customers and the underlying causes. In the study, a survey was conducted based on five factors namely, management commitment (MC), employees training and participation (EPT), customer satisfaction (CS) and power quality awareness (PQAW) and power quality disturbance measurements (PQDs). Questionnaires were given out to managers, engineers, technicians and other employees of the utility. The model obtained was as follows [24].

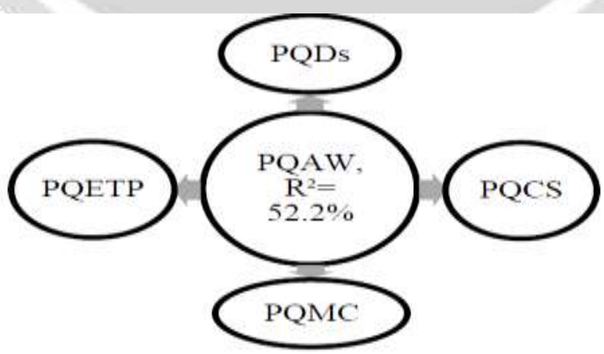


Figure 3: Power Quality Disturbances Model

In this study, the survey focused on three factors namely quality of supply as the dependent variable while the independent variables were asset management and electrical faults. The model obtained after analysis using SPSS was as follows:

Quality of Supply = 1.955 – 0.008 x Electrical Faults + 0.242 x Asset Management

4.3 Observations Method

There was observation of the state of the network assets within the district. This involved inspection of the assets by observing the condition by paying particular attention to distribution transformers, network switches, wooden poles, underground cables, overhead conductors, line accessories, terminations and joints. A similar study was conducted by a group of researchers who carried out research on reliability by first giving questionnaires to customers and then observing the condition of the network [17, 25].

(a) Transformer Inspections

Table 6: Number of transformers inspected in Natete District

No.	Feeder	No. Inspected
1	Mityana 33kV Feeder	41
2	Masaka 33kV Feeder	30
3	Kabusu 11kV Feeder	19
4	Buddo 11kV Feeder	25
5	Nakawuka 11kV Feeder	20
6	Katwe 2 11kV Feeder	15
Total		**150**

The average proper protection status for both MV and LV has been calculated as the average of protection on MV and LV sides. Based on this, the protection status was found as follows: Katwe 2 at 53%, Mityana at 29%, Masaka at 44%, Kabusu at 39%, Buddo at 64% and Nakawuka at 56%. It can therefore be concluded that the feeder with the best protection of its distribution transformers is Buddo 11kV feeder while Mityana 33kV feeder is the worst feeder in terms of protection of its transformers.

The correct information in the field is necessary for proper asset management. 24% of the transformers had no location numbers, 14% had wrong transformers but same rating, 13% had wrong transformer with different rating and 9% had no transformer rating indicated. This totals to 60% of the transformers with incomplete or wrong information. An up to date record of the transformers is necessary for historical information so as to determine its life cycle. The photos below are for some of the transformers which are poorly protected.

Photo 1: *Protection status of distribution transformers on the LV side*

(b) Line Anomalies

Table 5 is a summary of other anomalies that were identified on the network assets per feeder.

Table 5: Other anomalies on the structures

Feeder	Rotten Pole	Line Clearance
	% Total	**% Total**
Mityana 33kV Feeder	3%	12%
Masaka 33kV Feeder	3%	13%
Kabusu 11kV Feeder	2%	14%
Buddo 11kV Feeder	1%	14%
Nakawuka 11kV Feeder	2%	9%
Katwe 2 11kV Feeder	4%	4%
Total	2%	11%

Source: Primary Data (Observation of Network Assets)

Vegetation management was identified as a major issue in asset management practices. Buddo and Nakawuka feeders may not pose a very big threat to power supply interruptions since the LV network is composed of ABC (aerial bundled conductors) unlike the other feeders which have open wire for the LV networks. A similar concern was raised by UEDCL during their inspection of Quarter 2 of 2017 [26]. Some of the field findings are illustrated in the photos below.

Photo 2: *Signs of poor vegetation management on the network*

The status of underground cables is shown in Table 6 below.

Table 6: Status of underground cables in Natete

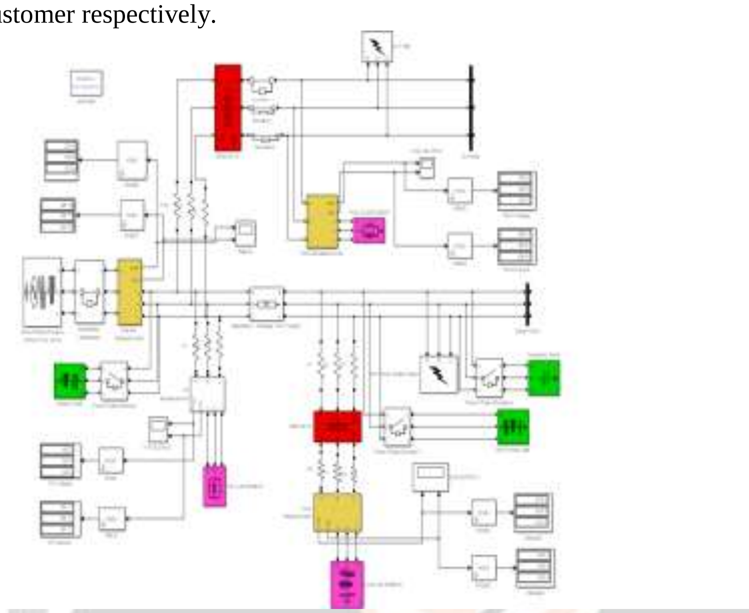
Feeder	OK	Anomalies
Mityana 33kV Feeder	0	2
Masaka 33kV Feeder	3	1
Buddo 11kV Feeder	0	6
Nakawuka 11kV Feeder	1	2
Katwe 2 11kV Feeder	2	1
Kabusu 11kV Feeder	1	0
Total	**7**	**12**

63% of the underground cable inspected had poor terminations which lead to power loss due to loose connections.

5. ELECTRICAL DISTRIBUTION MODEL

Mutundwe – Kabusu 11kV feeder was considered in the model as the developed model in MATLAB is shown in the figure below.

A 12.46 km 11kV distribution line having 2MVA heavy industrial load, 300kVA medium industrial load and 50kVA commercial load. Two transformers rated at 500kVA and 200kVA for the medium industrial and commercial customer respectively.



A heavy industrial customer is the one which has power demand exceeding 500kVA and is supplied at 33kV or 11kV. A medium industrial customer is supplied at three phase 415V with a power demand upto 500kVA. A commercial customer is supplied at three phase 415V and has a current rating not exceeding 100A [27].

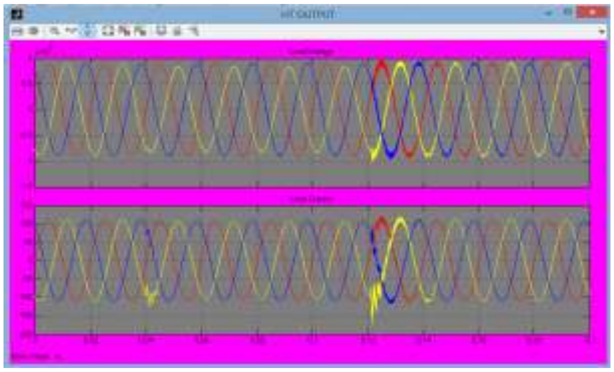
6. RESULTS OF SIMULATION AND GENERAL DISCUSSION

6.1 Impact of faults due to poor asset management practices

The most common fault is single line to ground fault which can present itself as broken conductors. Three phase symmetrical faults are less common but conductors entangle due to wind and when there is vandalism conductors are tied together so that the circuit trips and can't be reclosed.

A fault on the distribution network normally leads to power quality issues. Faults have many causes and lead to damage to part of the electrical network assets. Breakdown (corrective) maintenance needs to be carried out on the network assets to correct the anomaly whenever a fault occurs. This will ensure that the consequences of poor power quality issues will be minimized. Power quality disturbances may be due to insulation failure, tree contact, birds, etc and are impossible to avoid [28]. The most common fault is the single line to ground fault [29].

To generate faults on the network, a three phase fault circuit breaker was used whereby different fault types such as line to line fault, line to ground fault, etc can be simulated. A capacitor bank is used for simulating impact of capacitor switching for the different customer types. The simulation time was set at 0.2 seconds. The fault time was considered between 0.04 and 0.06 seconds. For capacitor switching, the initial status of the breaker was set as open before the simulation could start running. The results of the different simulations are displayed as waveforms having voltage and current against time on a single graph.



Similar studies done by [30,31].

6.2 Impact of AM Practices on Power Quality

There are different asset management activities that are normally carried out in order to improve the quality of supply to customers. As clearly revealed from the field inspections, majority of the transformers have poor protection on both HV and LV sides. The connection for the T-Offs also have poor jumper connections.

A fuse is designed to carry a predetermined current and then blow when the current is exceeded for a given period of time. In order to minimize power loss, fuses are designed to offer minimum resistance to the flow of current since

$P = I^2R$ where P = power in watts
I = current in watts
R = resistance in ohms

The resistance of the wires that are used as fuses in the transformers have higher resistance compared to the actual fuses. This will therefore be used to model effect of modification in asset management practice on quality of supply. The joints or jumpers on the conductors are required to be properly made. However due to the poor connections, the resistance increases and this also affect the power quality to industrial customers. Constriction resistance arises because of loose contact and applied contact pressure [32]. It is therefore good asset management practice to ensure that the joints are mechanically and electrically sound. Stable and minimum contact resistance of joints reduces frequency of maintenance & costs [32].

When resistance changes by say 0.01 ohms, voltage for medium industrial customer changes from 237.8V to 234.5V representing a 1% drop in voltage. However further increase in resistance along the line is likely to cause the voltage to drop below 6% which is the grid code threshold for Uganda.

6.3 Impact of AM Practices on Reliability

Modeling can either by done analytically or by using Monte Carlo Simulation. Monte Carlo simulation of power systems comprises power system modeling and reliability modeling. The approach used is either sequential simulation or random sampling. System reliability can be improved by minimising occurrence of faults and reducing the repair time [33].

Components that were considered in reliability evaluation are as illustrated in Figure 3.8 below.

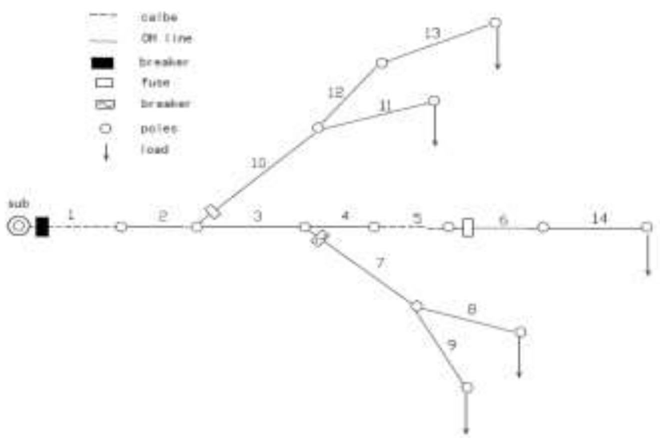


Figure 3.8: Typical distribution feeder with major components
Source: [33]

A radial distribution system consists of series components and a customer connected to any load point requires all components within its path to be operating [34]. The components that were considered during this study include distribution transformer, overhead conductor, underground cable, pole, fuse and jumper. A feeder normally consists of lines (conductors & cables), poles, breaker, switches, fuses and transformers [33]. Other components in a power distribution system include line supports, ring main units, cross arms, isolators, etc [35].

In this research, each component was considered to have two states (normal or faulty) according to their failure and repair rates. The sequential Monte Carlo Simulation simulates the system as an up and down state [36]. Exponential distribution was considered for generation of random numbers during MCS in the evaluation of reliability for the different components. The exponential distribution is the most common distribution function because it is characterized by a constant failure rate [33, 37]. By considering a component which takes 1 year (8760 hours) to operate without breaking down, it will have a reliability of 0.977. However due to poor asset management practices, the component may break down say after 6000 hours which then reduces its reliability to 0.964.

7 CONCLUSION

Any change in asset management practices results in change in power quality and reliability of supply. The resistance of the line components increase due to loose connections as a result of modifications of asset management practices e.g. improper protection of distribution transformers, poorly made jumpers & joints, etc. Increase in contact resistance will lead to a reduction in voltage and current at the customer's point of supply. Poor asset management practices reduce the mean time to failure of a component which will eventually reduce the reliability of the feeder concerned.

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