MAINS VOLTAGE PROFILE IN DAR ES SALAAM: A CASE STUDY

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ABSTRACT

Electrical and electronic systems and equipment need the mains supply voltage to be at normal level and to remain stable to ensure proper operation and long service. However, the stability of the mains supply and level has been observed to be a problem in Tanzania for sometime now, particularly in residential areas. This paper presents the results of a study made over a period of six months in various parts of Dar-es-Salaam. The result confirms that power quality in a number of places is unacceptable, particularly between 6 and 9 p.m. when the voltage drop is as low as 40% and surges as high 17.4% above the normal value. The paper further proposes methods to address the problems at the consumer end.

Keywords*:* *Voltage instability, under-voltage, over-voltage, shedding, brownouts, voltage dips, voltage sags, voltage regulation.*

I.0 INTRODUCTION

The mains voltage system can in principle be summarised as shown in Figure 1.

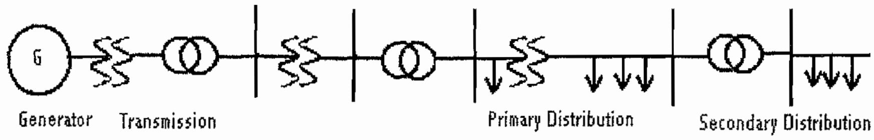

Fig. 1: Schematic diagram of Main Voltage Supply

Impedance associated voltage drop (***iZ***) between the power source and the consumer end is therefore inevitable. In addition to the voltage drop in the transmission and distribution network components, the system induces environmental and customer disturbances [1]. The problem therefore is the control of such disturbances and voltage drops or surges, so that voltage regulation at consumer end remains within specified standard limits.

The ***iZ*** voltage drop results in a voltage regulation as load conditions vary from no-load to full-load. For adequate mains supply system, the regulation should not exceed 10% of the nominal standard value in the case of Tanzania [2] (that is, 230 V ± 10%). An adequate system must ensure sufficient generation capacity to meet peak demands plus marginal standby capacity, and properly designed and implemented transmission, primary and secondary distribution networks with appropriate redundancy. Any deficiency in any part of the network shall influence stability and hence quality of the supply at the consumer end [3]. The load power factor and the current drawn from the source will also influence the voltage variation at the consumer end. Any voltage regulation from no-load to full-load conditions is undesirable to the consumer and needs to be controlled to ensure that it is kept as low as possible.

The Tanzania mains voltage supply system has deficiencies in all the three major sections of the network shown in Figure 1. There are frequent complaints by Tanzania Electric Supply Company (TANESCO) customers that the level of the supplied voltage is mostly below and occasionally above nominal value outside tolerance limits, and is also unstable. This leads to frequent malfunction and/or pre-mature failures of various electrical/electronic equipment, systems or components due to either over-voltage or under-voltage [4]. Moreover, frequent prolonged load shedding (i.e., for more than 50% of the time) was common during prolonged dry spell in the country for those customers connected to the national grid network to improve power quality for fewer connected loads [4,5]. The problem becomes strongly pronounced when the main power sources Kidatu, Mtera, Pangani, Kihansi, etc, experience operational problems. A fault in the network causing tripping in any of these sources leads to a collapse in the entire network. It is apparent that the national grid transmission network is not optimal, as observed in number of localities like Mwanza, Mbozi in Mbeya and Arusha. Therefore, the transmission network accounts for part of the main voltage fluctuation at the consumer end because of the differences observed at different loading points of the national grid network. However, at the consumer end, the effect of the primary /secondary distribution network is also included.

The paper presents a study of the mains voltage fluctuation at consumer end done in Dar-es-Salaam. This was chosen as a sampling point in the national grid network for the study. The objective is to quantify the magnitude and pattern of variation of the mains voltage level. The outcome can be a useful tool for electrical/electronic equipment users and for specifying equipment during procurement process. Moreover, the result of study provides a laboratory model for designers of mains voltage stabiliser for low power applications appropriate for Tanzanian environment.

1.1 Causes of Voltage Instability

The power stability problem can appear in form of voltage surge or dip, phase imbalance, harmonics, voltage profile, unstable frequency, loss of synchronisation, low power factor or voltage flicker [6]. This paper however addresses mains voltage fluctuation (i.e., voltage profile, voltage surge or dip and voltage flicker), and its conformity to standard nominal value.

1.1.1 Over-Voltage Sources

The mains supply voltage fluctuation can appear as low voltage (brownouts) or over-voltage. Over-voltage can be in a form of high frequency transient caused by lighting strikes (atmospheric disturbances), intermittent earth faults (such as arching grounds) for underground neutral, switching operations and induced harmonics due to operations of high power electronics devices and arcing devices such as welding machines [7].

Over-voltage can also appear as power frequencies, voltage surge or prolonged level shift.

In addition to effects of system impedance, over-voltage can be caused by a defective operation of the voltage regulator that is out of service and the regulation operated manually (i.e., equipment malfunction and maloperation). Under such conditions, a sudden appearance of load variation (load switching), particularly the reactive power component, results in a substantial rise in voltage inherent in typical generators [8,9]. Also, a sudden loss of load (e.g., due to the line tripping) can cause hydro-set to have high terminal voltage and later overspeed because of the relative slow operation of the governor and turbine gates. In addition, faulty connections in the secondary distribution network due to accidental connection of an isolated neutral to any of the opposite phases will result in over-voltage [10].

1.1.2 Under-Voltage Causes

Inadequate radial network with multiple sources, uncompensated long lines with many tear-offs (rural feeders) and overloaded feeders and/or distribution network are factors that cause brownouts (low voltages) [6]. The other factors include the loss of neutral, temporary bridging of lines, under-sized conductors and cables, high load imbalance between phases in the low voltage network (improper planning, undeclared loads or negligence), excessively long low voltage lines and overloaded distribution transformer. In addition, poor workmanship may result in poor or partial contact (faulty connections) in various connections in the network, and hence account for a large number of highly unstable low voltage conditions [7]. Faulty connection can be as a result of wrong termination of joints that may lead to arcing and overheating of joints. Malfunction and mal-operation of voltage regulators can also cause low voltage.

1.2 Effects of Brownouts, Voltage Dips and Sags

All motor driven loads (e.g., air-conditioners, lifts, etc.) experience performance problems since electric motors fail to develop the required amount of torque to overcome the load, hence stalling. Due to lack of back emf, large amounts of currents are drawn that can destroy motor insulation due to overheating. Electric appliances tend to malfunction during brownouts and create false data, interrupt program execution and memory loss for microprocessor-based equipment. Persistent brownouts can lead to power transformer failure and breakdown of generator winding, since the utility does not protect medium and low voltage levels of distribution against low voltage. Such defects may persist until rectified, or may result in a major fault of the trip feeder pillar fuse.

Other effects include loss of control, forced shutdown, speed variation, reduced equipment lifetime, tripping of protective devices, wasted energy and increased maintenance and operational costs. Power electronics variable speed drive needs adequate protection to survive voltage dips because the loss of mechanical synchronism can be catastrophic.

It is thus obvious that the consequences of poor supply to consumers are immense. This work tries to map the magnitude of problems existing in the mains supply as seen at the consumer side in Dar-es-Salaam.

2.0 SELECTION OF SAMPLING SITES

The objective of carrying out this study included the characterisation of the voltage regulation problem. Hence, choice of sampling sites was seen to be important. The consumer end was chosen since the consumer is the interested party in this work and at the consumer end, the entire network, up to generation is included. Therefore, by using different test locations in the network, it is possible to assess the major points of weakness in it. However, there were constraints in available locations in that the proprietor of a selected premise has to accept to guarantee both access and security of installed equipment. Furthermore, limited resources (finance and equipment) available to researchers made field tests be limited to Dar-es-Salaam localities. In Dar-es-Salaam, the choice of test (sampling) sites was guided by the need to cover different loading conditions that are reflected in locations such as heavy plants, planned residential areas, congested and unplanned residential areas, and mixed residential/small scale industrial areas. Nine Dar-es-Salaam test sites were chosen to reflect the set criteria. These were Faculty of Engineering (FoE), Kigogo, Sinza, Mtoni, Ukonga, Upanga, Wazo Hill, Mburahati and Darajani (UDSM residential area).

2.1 Data Recording and Results

The mains voltage level was recorded continuously using x/t recorder for a total of 175 days in all test sites. The recorded data is grouped according to trend revealed by the results. These areas had:

- High voltage throughout the night, early mornings, and late in the evenings, typical in office environment.
- A voltage dip of about four hours starting from around 6.00 p.m., as is typical of primarily congested and unplanned residential areas.
- No particular trend in relation to any particular time of the day. This trend represented areas near a heavy industry or plant where the main load operates for 24 hours.

3.0 SAMPLES OF RECORDED DATA

Figures 2 and 3 show extracts of samples of data recorded with the x/t recorder. The figures reveal some of the features observed in the mains voltage supply as experienced by TANESCO customers in some localities. It shows the degree of instability in the mains voltage level (voltage level fluctuations) occurring in a number of localities in Dar-es-Salaam. For the two samples, the recorder was set to 500 V range and the paper speed was 2 cm/hr. The samples show variations experienced daily by some customers Figure 2 depicts a typical voltage dip, while Figure 3 shows continuous perturbation of voltage level.

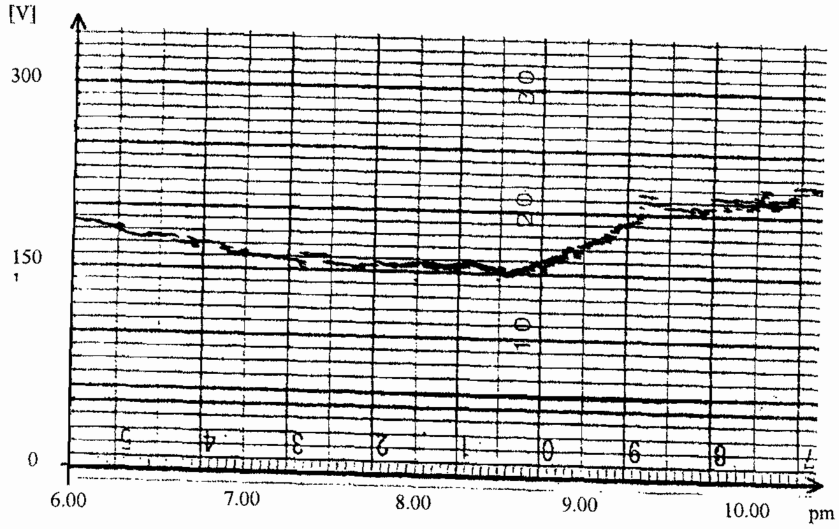

Figure 2: A section of the voltage as a function of time record for the Kigogo site showing a voltage dip

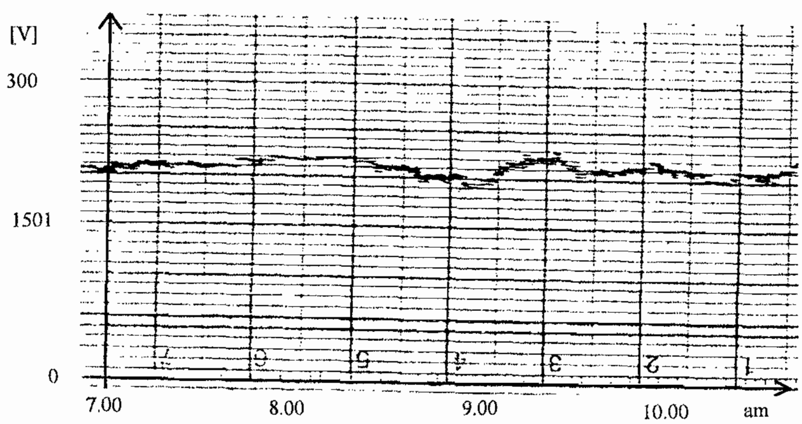

Figure 3: A section of the voltage as a function of time record for Kigogo site showing a typical voltage fluctuation

3.1 Sample Analysis

The study made on the collected data showed that a sample for ten consecutive days contained enough information on the voltage stability trend for all the data collection sites in that the data displayed cyclic variations that repeated, at the worst, after 10 days. The pattern observed is attributed to the random nature to which the consumers connect to and/or disconnect from the mains power supply. Therefore, a data sample of 10 days (same calendar days) from the various sites was taken from the collected data for further analysis and comparison. The ten days samples were from data collected in all nine sampling sites over period of six months.

One of the purposes of this work is to find corrective action for the mains voltage fluctuation at consumer end. For this purpose [1] (e.g., development of a main voltage regulator), it was considered that the average value and standard deviation of the measured sample, though powerful statistical analysis tool, might have very little value in this respect, if not misguiding. The collected data showed that the dominant window in the data where voltage was stable did not coincide with that of human life cycle of the day in terms of basic activities (i.e., late in the evening and early mornings). Statistical characteristics of the data evaluated are provided in Table 1 to illustrate the point.

Table 1: Voltage profile data for various test sites

Site	Minimum level		Maximum level		average		Std. Dev.	
	[V]	%	[V]	%	[V]	%	[V]	%
FoE	190	83	270	117	238	104	0.8	0.34
Darajani (UDSM)	185	80	242	105	234	102	0.5	0.21
Mburahati	170	74	265	115	218	95	0.8	0.34
Wazo	180	78	239	104	211	92	0.6	0.26
Upanga	187	81	239	104	211	92	0.3	0.13
Mtoni	160	70	234	102	205	89	0.6	0.26
Kigogo	140	61	220	96	195	85	1.2	0.52
Sinza	140	61	209	91	191	83	0.9	0.39
Ukonga	136	59	234	102	190	83	1.0	0.43

It was of interest to know the peak and the crest values under normal operation (these quantities are given below), how frequent the values occur and for how long they remain there before assuming other values. These were considered as the most significant factors that can help an individual to judge whether there is need to use a voltage stabiliser or a line inspector, depending on appliance/equipment connected to the mains supply.

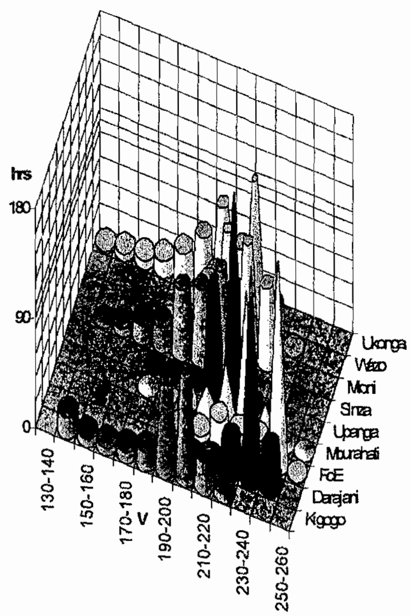

Figure 4: Duration in hours against voltage level for different sites for a total of ten days

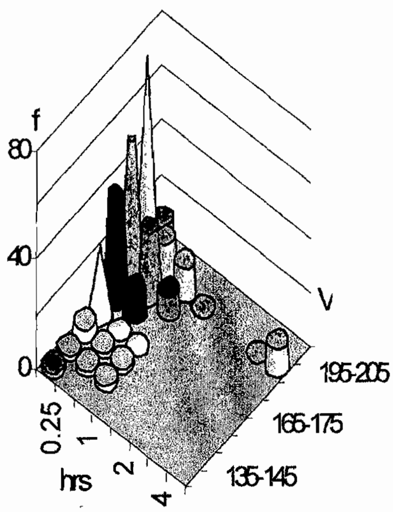

Figure 5: Duration (hours) against frequency for Kigogo for various voltage

The peak-crest voltage range was divided into ranges since it was not practical to consider all discrete values. For this purpose, a 10 V range was considered reasonable, since it is about 4.3% of the nominal standard value for Tanzania. From the recorded data (x-t plots), the summary showing the total number of hours that the magnitude of the voltage remained in any one range for all the different mains voltage-monitoring sites is shown in Figure 4.

The minimum and maximum values displayed in Figure 4 are important parameters in the design realisation of a voltage stabiliser that shall be necessary to compensate voltage variations. The optimal design and realisation of such a stabiliser must address the realistic conditions that exist in certain locality where it shall be used.

Additional information extracted from the recorded data was the duration that the mains voltage level remained in any one region (range) before changing to a lower or higher level, temporarily or permanently. The parameter is important since it is an indication of degree of stability and determines the possibility of the equipment in an area to withstand/tolerate such disturbance. The duration observed varied from less than a minute for transient conditions to 78 hours. The two extremes reflect cases from short-term to long-term mains voltage stability observed in various test sites. For the purpose of analysis, the interval chosen were as follows; 0- ¼ hr, ¼ - ½ hr, ½ -1hr, 1 - 1½ hr, 1½ - 2hr, 2 - 3hr, 3 - 4hr, 4 - 5hr, and above 5 hrs.

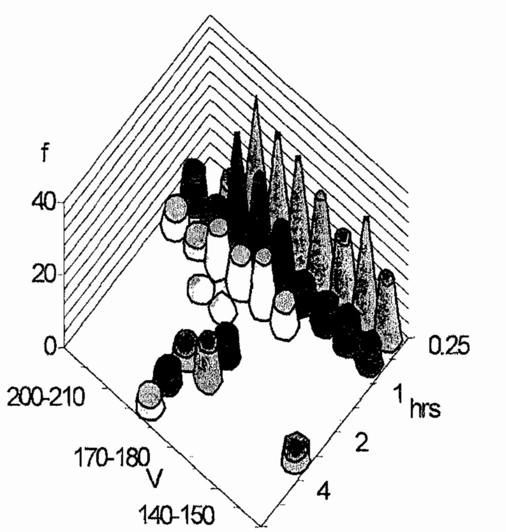

Figure 6: Duration (hours) against frequency for Ukonga for various voltage ranges

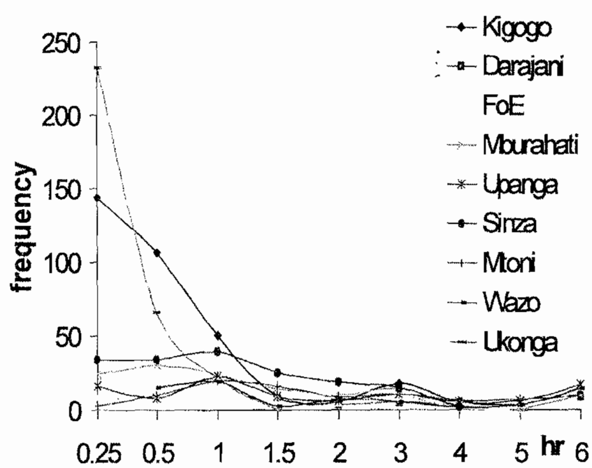

Figure 7: Duration from voltage entering a defined range to leaving it against frequency for all sites

The above time intervals were used to determine the number of times (number of occurrences) the mains voltage enters a given voltage range and remains there before moving to another range. This treatment of data is meant to compress the collected information to assess the stability of the mains voltage of the test sites. The result is shown in figures 5 and 6 for two of the sites and 7 for all sites. Figure 5 shows that voltage stays mostly at any level for less than 15 minutes when above 195 V, while for the site in Figure 6, the voltage level is mostly unstable at all voltage levels. It is significant to note that points close to the y-axis in the curves shown in Figure 7 reflect unstable (transient) conditions while the further away they are from the axis the better is the stability of the mains supply level for that test site.

3.2 Observations

Figure 4 shows the total number of hours that a voltage level remained in respective voltage ranges.

The histographs show the differences that exist in the mains low voltage outlets in various localities in Dar-es-Salaam. It is clear that no two consumer sites are identical. This therefore confirms a deficiency in the distribution network in Dar-es-Salaam. The secondary distribution network is largely responsible for the poor mains voltage regulation at the consumer end because all sites showing differing variation pattern are supplied from the same source via either Ubungo or Ilala main substations. Therefore, generation and transmission are not the main sources of the wide variations in the mains voltage observed by consumers in Dar-es-Salaam at their premises.

3.2.1 Faculty of Engineering Site

The mains voltage is observed to be in the range 190-250 V, as in Figure 4, with an average value of 237.8 V and standard deviation 12.7 V. It is apparent that for most of the time, the mains voltage remained in the range 240-250 V. This period, however, is either during the weekends or early mornings, evenings and late at night. During office hours, the mains voltage remains mostly in range 210-240 V. Figure 7 shows that the dominant voltage range was indeed a stable level and that the occurrence of low voltage was not frequent, i.e., the 190-200 V and 200-210 V ranges, but when they occurred, they were sustained for a significant length of time (i.e., 1 - 3 hours).

It is significant to note that the dominant voltage range is above the nominal voltage and its tolerance. In general, the mains voltage at FoE is on the higher side. FoE has a dedicated substation that is connected to a primary distribution network that operates well below its capacity. The site represents an office complex environment with appropriately designed substation.

3.2.2 Wazo Site

At Wazo, Figure 4, it was observed that the mains voltage level remained for a large part of the time within the tolerance range of the nominal value (i.e., 210-230 V). The voltage, which occurred beyond the tolerance range, was occasional and transient in form (i.e., for duration less than an hour in the 230-240 V range). The voltage level was below tolerance range for a significant fraction of the total sample duration, i.e., 30.4% of the time. The voltage level in the low voltage region (below tolerance) appeared as a level shift and in transient form. In a number of occasions, it remained stable (within a given range) for duration exceeding 5 hours. The site reflects areas close to heavy industrial plants, but within the plants' power network.

3.2.3 Darajani Site

The mains voltage of this particular site is quite stable, as can be seen in Figure 7. The voltage remained in one range continuously for up to 78 hours in one case. The lowest duration spent in a particular region is 2 hrs. The site depicts a well-planned residential area with matching electrical network.

3.2.4 Mtoni Site

The mains voltage in this monitoring site is generally low, the voltage level being below the nominal voltage outside tolerance values for a large part of the sample time (63.8% of the time), see Figure 4. The mains voltage variation magnitude is also large (80 V), with mixture of long period level shifting and short period transitions, as can be observed in Figure 7. The trend of the supply voltage level in this area is cyclic dependent on the time of the day. The mains voltage is at its lowest level at 7 p.m., or thereafter. The area experienced frequent blackouts around the time when main voltage level dip occurs, particularly when there is load shedding.

3.2.5 Kigogo Site

The mains voltage in Kigogo area is generally poor. It fluctuates heavily, as shown in Figure 7. The longest duration that the mains voltage remained in any one range continuously is 5 hours, which occurs primarily late at night. The occurrence of this duration was itself occasional. It is significant to note from Figures 4 and 5 that more time was spent at the lowest voltage range than the intermediate ranges. This is explained by the fact that the intermediate values are transitional values. Moreover, the main voltage is mostly below the lowest tolerance value of 207 V. It remains below the limit for 86.4% of the total sample time. The mains voltage level is cyclic and dependent on the time of the day. It was also very unstable for a wide range of voltages (155-205 V), as shown in Figure 5. The site reflects densely populated residential areas that are poorly planned (or rather, unplanned) and with equally poor electrical distribution network.

3.2.6 Sinza Site

In this area, the mains voltage was observed to be low, mostly 30 V below the nominal value of 230 V, as shown in Figure 4. The mains voltage level remained below the nominal tolerance value throughout the monitoring period. The voltage level was also cyclic in relation to the time of the day. It was poorest during the time when needed most for domestic functions. Figure 7 shows that the stability of the mains voltage level is also very poor. The only stable voltage level is in the range 200-210 V that occurs late at night.

3.2.7 Upanga Site

This site displayed the best mains voltage stability at the consumer end (with an average of 211.4 V and standard deviation of 6.6 V) when compared to all the sites used in this exercise. The voltage mostly remained in the range of 200-220 V (i.e., 96.8% of the sample duration). Figures 4 and 7 show that even when the mains voltage deviated from the above range, it was only for a limited period not exceeding one hour. However, it should be noted from Figure 4 that although for a large part of the sample duration the voltage is within the tolerance of the nominal value, it does go below the nominal tolerance value for a significant duration.

3.2.8 Mburahati Site

The mains voltage level in this area is quite unstable, specifically during the day, and dropping sharply during the evenings. The mains voltage variation is cyclic in relation to the time of the day. Usually, the mains voltage is high late at night and remains relatively stable. Figure 4 shows the wide range (170-260 V) that the voltage in this area does assume. This particular site displayed the largest voltage variation magnitude of all sites surveyed in this study.

3.2.9 Ukonga Site

The mains voltage level at Ukonga monitoring site was observed to be very poor. The voltage level is widely spread, as can be observed in Figure 4 (i.e., 136-234 V), and is highly unstable over the entire voltage range, as shown in Figure 6. The mains voltage level hardly remained in any one range for one hour. It remained in one range for long period (maximum seven hours) during the late at night, see Figures 6 and 7. The voltage level was observed to be generally low, i.e., 89.6% of the total sample time the voltage level remained 13% below the minimum tolerance value. Mostly, the voltage was fluctuating, hence the large number of occurrence is near the y-axis, as can be seen in Figure 6.

4.0 DISCUSSION AND CONCLUSION

4.1 Discussion

The measurements of mains voltage at different locations in Dar-es-Salaam showed clearly the need for a voltage stabilizer. Sinza has maximum voltage of 209 V and a minimum of 140 V. This site requires voltage stabilizer to raise the main voltage to acceptable value, otherwise the residents there shall suffer frequent breakdown in their equipment, especially those incorporating rotary components. The same applies to Mtoni, Mburahati and Kigogo sites. However, it should be noted that some of the locations used to monitor mains voltage variations displayed remarkably good mains voltage stability levels. For such areas, the use of a stabilizer can be a luxury and at times prove to be a liability. In all the sites where the voltage appeared stable, the level is either skewed to values below or above the nominal values. For such cases, it can be sufficient for the users of electronic equipments to select the appropriate input level for their appliances, where applicable. For example, selecting a 240 V input option can easily accommodate the Faculty of Engineering mains voltage level case, which is skewed to values above the nominal values. It is unfortunate, however, that not every one is technically minded to implement the above option, hence even in a situation like this, the use of voltage stabilizers is still recommended. An alternative would be to adjust the transformer tapping position at the local substation, which is a much better option to that of using stabilisers at various outlets.

At a first glance, the mains voltage level in various places in Dar-es-Salaam does not appear to be that bad (see Figure 4 and Table 1) because the voltage level is reasonably stable for a significantly larger part of the sample period. However, it should be remembered that a larger part of the duration when the voltage level is observed to be reasonable and stable may be regarded as "idle" time in relation to the productive periods in domestic, industrial and office activities requiring electric power. At the time when electrical power is needed most for domestic activities ranging from kitchen activities to leisure and extended office assignments, the mains voltage level is at its worst. When the period for active domestic function is compared the whole day, it may appear insignificant (i.e., 8 - 16% of day's time). Therefore, a voltage dip for this period can easily be misread as insignificant when looking at the overall picture, but in reality it is very frustrating to the consumer. For this reason, the duration for which the low voltage (or high voltage) persists was considered very significant in this study. The average value of voltage over the sampling period may be significant but misleading and is of small value to the users of electric power if it is too low when most needed, e.g., between 6 and 9pm in domestic areas. Moreover, prolonged low-voltage conditions for 3-4 hrs continuously per day for electric motors, and the like, running under load is undesirable, though the average value may seem satisfactory.

It is thus clear from these results that a mains voltage stabiliser would be a relief to a number of domestic users of electric power. It will tend to compensate for the deficiencies in distribution network as indicated by the voltage level fluctuations at the consumer end observed in this study.

The mains voltage appeared to vary widely the most frequent variation amplitude range being 140-260V. Higher voltage levels exist but appear as short-lived transients. Low voltage condition is dominant over that of high voltage, both in occurrence and in range. Therefore, particular effort is needed in the correction of the low voltage situations. However, high-voltage, although occasional, can be destructive for some electronic systems even when the over-voltage is only for a very short duration. Therefore, such condition has also to be addressed by protection means or compensation as shall be most appropriate.

4.2 Conclusion

The study on the mains voltage level conditions confirms the large degree of inadequacy in the mains voltage distribution network in Dar-es-Salaam. As a short-term solution, the TANESCO customers may have to employ mains voltage stabilisers at their premises for sensitive loads to improve life span of their equipment, or in the first place enable them operate. The need is particularly strong in domestic areas where the voltage fluctuation is very pronounced. The required stabiliser should cover the range 140 V to 260 V. This range should be able to accommodate the observed fluctuation range of 136 V to 270 V. The secondary distribution network, is to a large extent, responsible for the mains voltage level instability at the consumer end. The differences in the fluctuation of the mains voltage level both in magnitude and pattern between different test sites that are supplied from the same source and transmission network justifies this conclusion. The difference between the sites is in the distribution networks, hence the main source of the problem in Dar-es-Salaam. The problem can be eliminated by improvement of the distribution network.

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