CHARACTERIZATION AND MINIMIZATION OF VOLTAGE TRANSIENTS

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ABSTRACT:

Magnitude levels and frequency of voltage transients have been measured at two consumer centres. Out of 121 transients recorded 118 were of negative polarity. Magnitudes were as high as-100V. However 81% of transients at one station and 65% of transients at the second measurement point had magnitudes not exceeding-30v. The transients are evenly distributed throughout the day. It is known that the main cause of negative transients are motor switching actions. Therefore the necessity of installing star delta starters is apparent as well as is the need to curtail the effect of air conditioner switching on generation of negative voltage transients.

INTRODUCTION

Network voltage transients may be caused by lightening (Kuffel 1986), switching functions (Smith 1993), inrush magnetizing currents and intermittent earth faults (Beeman 1955). Depending on magnitude, waveform, and duration they may be destructive to equipment. Insulation failure can occur and equipment operation may be interfered with. Low level transients are particularly harmful to electronic equipment (Kadete 1990).

Voltage transients are known to cause computer maloperations. They cause damage to computer hardware, destruction of memory, and erasure of data.

Transients also are a very well known cause for protective relay maloperation. They may cause relays to overreach or underreach their zones of protection [Stevenson 1988].

Short circuits which may occur due to transient phenomena may cause strong destructive electromagnetic forces on windings, busbars, and other components.

There are several important methods which can be used to minimize the effects of transients. The most common one is the use of lightening arrestors or surge diverters, use of filters, applying the principle of point-on-wave switching, and proper load circuit design by application of the pole zero concept.

In this paper, preliminary data on voltage transients which has been collected for the Dar es Salaam power distribution network is presented. The quantitative characteristics of transients which appear in the distribution systems and industrial consumer centres are presented. The data was collected at main intakes of two industrial consumers. Gaining an insight on their characteristics may enable a knowledge on their origins and causes, and consequently pave a way to their minimization or total elimination. This would ensure longer lifetimes for equipments such as motors. it would also eliminate maloperation of computers and other devices such as relays and contactors.

THEORETICAL BACKGROUND

The lightening travelling voltage wave [Kuffel, 1986] is characterized by a double exponential function

$$V_m[e^{-\alpha t} - e^{-\beta t}]V \qquad (1)$$

$1/\alpha$ is a much longer time constant than $1/\beta$. So this unipolar waveform, has a very short period between 0 and peak and a rather long time to decay. The wavefront is characterised by the front time T_1. The wavetail is characterised by the time to half peak value on the wavetail T_2. Typically the ratio T_1/T_2 for a lightning impulse is 1.2μs/50μs. A switching function can generate a voltage wave similar in form with the values T_1/T_2 of the order 250 ± up to 20%/2500 ± up to 60%.

Changes in network configurations due to switching functions also may yield voltage transients. This is mainly due to transfer of energy stored in electric or magnetic fields.

For example for an R-C circuit consisting of a single energy storage element, C which is initially charged to voltage V_0, when short circuited will be governed by Kirchhoff's voltage law to yield an equation

$$V_0 - \frac{1}{c}\int_0^t i\,dt - Ri = 0 \qquad (2)$$

This is an integral differential equation which is satisfied by an equation

$$i = Ae^{st}$$

The exponent may be solved from the homogenized characteristic equation

$$C + sR = 0$$

yielding $s = -1/CR$

Initial conditions yield $A = V_0/R$

This leads to a solution

$$i = \frac{V_0}{R} e^{-\frac{t}{cR}} \qquad (3)$$

In case there are two energy storage elements then the exponent may be obtained from a similarly homogenized integrodifferential equation. The two values of s are solved from the equation

$$s_{1,2} = \frac{-R}{2L} \pm \sqrt{(\frac{R}{2L})^2 - \frac{1}{LC}} \qquad (4)$$

depending on the value of s therefore an exponentially decaying, oscillatory voltage, or initial damped voltage, may be generated as part of the natural response. Initial or boundary conditions help to determine the amplitude of the waveforms.

If a series inductive circuit carrying a current i is suddenly shortcircuited to a capacitor a voltage transient will occur. Here the energy in the magnetic field of the inductor has to be transferred to the electrical field of the capacitor and will decay in the resistive component of the circuit. Consequently the peak voltage generated across the capacitor is given by

$$\frac{1}{2}Li^2 = \frac{1}{2}Cv^2$$

or

$$v = i\sqrt{\frac{L}{C}} \qquad (5)$$

where L is the series inductance of the circuit and C is the phase capacitance to earth. The same and similar diagnosis applies to repetitive intermittent earth faults.

High voltage transients may be caused also by accumulating of static charge on insulating material and non current carrying metallic parts, if a part of a low voltage network touches a high voltage part of the network, due to autotransformer circuits, resonance, and poor grounding.

The commonly experienced low voltage disturbance can be in the form of noise with respect to ground superimposed on the power conductors. Amplitudes range from millivolts to several volts.

The other type of voltage disturbances are low level signals superimposed on the power sinewave with amplitudes of 0.5V to 25V.

The third type are the normal type impulses. Typically a narrow fast voltage rise voltage variation. It can be followed by a damped oscillation decaying to nominal in less than one cycle. Amplitudes range from 50V to 6kV with a duration of 0.5μs to 2000 μs.

Then there are sags and surges. Sags are a low voltage condition on one or more phases. RMS voltages below 80-25% of normal with duration of greater than 1 cycle.

Surges are a high voltage condition on one or more phases. Voltage above 110% of nominal with a duration greater than one cycle.

Outages are a zero-volt condition lasting longer than a half cycle.

Table 1: Significant voltage transient peak values recorded at Tanzania Diaries Ltd TDL main intake.

	1	2	3	4	5	6	7	8	9	10	11	12
23.12.93	0	0	0	-12	-2	15	-68	0	-52	-12	-12	-10
24.12.93	0	-16	0	-18	0	0	0	12	0	0	0	0
25.12.93	0	-20	0	0	0	0	-26	-18	0	-32	0	-18
26.12.93	0	0	0	-14	-20	0	-16	0	0	0	-18	0
27.12.93	-30	-15	-50	0	0	-12	-15	0	-42	-56	-16	-16
28.12.93	0	0	0	0	0	0	0	0	0	0	-18	0
29.12.93	0	0	0	0	-11	0	0	0	0	-18	0	-13
30.12.93	0	0	0	0	0	-22	0	0	0	0	0	-16
31.12.93	-16	0	-20	-13	0	0	-18	0	0	0	0	0
1.01.94	-16	-11	-11	-11	-11	-11	-11	-16	-13	0	0	0
2.01.94	0	0	-12	0	0	-20	0	0	0	0	0	-28
TOTAL	3	4	4	6	4	5	6	3	3	4	4	6

	13	14	15	16	17	18	19	20	21	22	23	0	Total
23.12.93	-15	0	-22	-20	0	0	0	10	0	0	-35	-10	14
24.12.93	-16	-16	0	0	-16	0	0	0	-18	0	-26	-24	9
25.12.93	-20	0	-18	-18	15	0	0	0	0	0	0	0	9
26.12.93	0	-16	-18	-56	0	0	-18	0	0	0	0	0	8
27.12.93	-22	-20	0	0	0	0	0	0	0	0	0	0	11
28.12.93	-18	-16	0	0	-16	-23	-25	0	-45	0	0	0	7
929.12.93	0	-16	-13	0	0	0	0	-16	0	-11	0	-20	8
30.12.93	0	-10	-10	-14	-10	-16	0	0	0	-20	0	-18	9
31.12.93	-16	-18	-20	-16	-18	-16	-20	0	0	0	0	0	11
1.01.94	0	0	0	0	0	0	0	0	0	0	0	0	9
2.01.94	0	0	0	0	0	0	0	0	0	0	0	0	3
	6	7	5	5	5	3	3	2	2	2	2	4	98

MEASUREMENT RESULTS

Voltage recorders were installed at two different industrial consumers selected at random. At the first one Tanzania Diaries Ltd voltage was recorded non stop from 22 Dec. 1993 to 2 Jan,1994. At the second measuring point, Institute for Production Innovation (IPI) of the University of Dar es Salaam measurements were for three days from 22-

24 Jan. 1994. The measurements are presented in Table 1 and Table 2 respectively.

The voltage electronic recorder used was type HIOK 8710 with possibilities for both analogue and digital measurements. The sampling rate of the recorder is 12.5/sec at 30 Div/min and the sampling rate is 10/sec at other speeds. Therefore the digital reading of the transients was practically not possible. Therefore the digital reading of the transients was practically not possible. Therefore we resolved only to take analogue measurements.

Table 2: Significant voltage transient peak values recorded at Institute for Production Innovation (IPI).

Hours												
Hours	1	2	3	4	5	6	7	8	9	10	11	12
22.2.94	0	0	0	0	0	0	0	0	0	0	0	0
23.2.94	-22	0	0	0	0	0	+16	0	-80	-100	0	-8
24.2.94	-8	-20	-12	-38	0	0	20	0	0	0	-48	0
	2	1	1	1			2		1	1	1	1

Hours													
Hours	13	14	15	16	17	18	19	20	21	22	23	0	
22.2.94	0	0	0	0	0	-20		0	-11	0	-10	0	3
23.2.94	+10	-20	-40	-60	0	-10	0	-10	-8	0	-8	-10	14
24.2.94	0	0	0	0	0	0	0	0	0	0	0	0	6
	1	1	1	1	0	1		1	2	0	1	1	23

DISCUSSION OF RESULTS

A significant number of negative voltage transients were recorded. The highest in one day recorded was 14 at TDL. The minimum number was 3 at IPI. Only in one day out of the 14 days of measurements we recorded we recorded two positive transients.

Since almost 100% of the transients have negative polarity, one is led to conclude that these are caused mainly by switching on of loads such as large motors, air conditioners, etc We noted that IPI has a heavy load of air conditioning load. It is therefore apparent to encourage the use of star-delta motor starters. However, depending on the origin and nature of the transients, several methods are known which can be used to minimize or eliminate transients. Among them is the use of the following equipment and/or principles:

Table 3: **Classification of voltage transient peak magnitudes by times they occurred per day at Tanzania Diaries Ltd (TDL)**

	0-10	11-20	21-30	31-40	41-50	51-6	61-70	71-80	81-90	91-100	TOTAL
23.12.93	3	7	1	1 1	0	1	1	0	0	0	14
24.12.93	0	7	2	0 0	0	0	0	0	0	0	9
25.12.93		7	1	1							9
26.12.93		7				1					8
27.12.93	6	2	0	2	1						11
28.12.93		4	2		1						7
29.12.93		8									8
30.12.93	3	5	1								9
31.12.93		11	0								11
1.01.94		9									9
2.01.93		2	1								3
Total	6	73	10	2	3	3	1	0	0	0	98

Table 4: **Classification of voltage transient peak magnitudes by the times they occurred per day at Institute of Production Innovation (IPI)**

	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	Total
22.2.94		1	2								3
23.2.94	7		1	1		1		1		1	14
24.2.94	1	3		1	1						6
TOTAL	8	4	3	2	1	1		1		1	23

1. Isolation transformers
2. Spike transformers
3. Voltage regulators
4. Capacitor banks
5. Tap charging transformers on load
6. Uninterruptible power supplies
7. Point on wave switching
8. Pole-zero based network design
9. Filters

From Table 2 and Table 3, it is clear that the transients are almost evenly distributed through out the day. This is apparently due to the fact that they are caused by the normal switching functions of motors in factories.

From Table 3, we not that the majority of transients in this case about

81% peak magnitudes lie in the range below 30V. In Table 4, it is about 65% of voltage transients at IPI that have a magnitude below 30V. However depending on the type of low voltage equipments such as computers and contactors, such magnitudes of over voltages could be harmful.

CONCLUSIONS

(i) Although our main objective we set out to achieve is to obtain enough data which can enable us to eliminate transients whenever necessary. Such data must include recordings of waveforms. However our measuring instrument was not fast enough. Nevertheless the data recorded so far is helpful to make an initial assessment of the problem.

(ii) The is ground enough to proceed with this research. One area of interest is to determine the characteristics of transients generated by air conditioner switching function and how these may affect personal computers' performance.

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