Power Quality Assessment for Large Commercial Center in Riyadh

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Abstract:

In the last decades, the percentage of nonlinear loads have increased sharply due to the wide spread of electronic equipment in different applications. The non-linear loads are mainly responsible for low Power Quality (PQ) in the consumer facility and in the utility grid. In many cases the consumer feels that the equipment are operating normally, but only the continuous monitoring of PQ may confirm the real operating conditions. In this study, it is found that the voltage and current waves have high harmonic content. For instance the Total Harmonic Distortion (THD) of the neutral current of one of the power transformer has reached over 900% and the neutral voltage is around 59 volts. The high values of THD decreases the capacity of transformers and cables, increases the power losses and reduces the life time of equipment.

This paper discusses the results of PQ monitoring in a large commercial and office building which includes main supply transformer, distribution boards and various loads.

1- Introduction

In many countries, the electric utilities have an increased concern for the Power Quality (PQ), due to the increased number of nonlinear loads. The PQ is defined as "the degree to which the utility voltages approaches the ideal case of a stable, uninterrupted, zero-distortion, and disturbance-free source"[1].

Although the non-linear loads have the advantages of been electronically controlled, yet the increase in their usage in the past few decades have increased the level of power pollution in the consumer premises and in the utility grid. The common origin of PQ problems is due to the excessive distortion of the current and/or the voltage of the power supplied to the consumer by the power distribution system. This distortion has several detrimental effects, including overheating of the components of the distribution system, mechanical oscillations in generators and motors, and insulation or capacitor failure due to electric resonance, not to mention the increased audio noise, impaired performance of power-line due to communication systems, and unpredictable behavior of installed protection systems. Also the rapid voltage fluctuations makes lights flicker, and induce radio frequency interference. The percentage of nonlinear loads in USA represent around 30% in 1995 and is expected to increase to 60% by the year 2000 according to Electric Power Research Institute (EPRI). To the best knowledge of the authors there is no study of PQ in Riyadh, therefore the percentage of nonlinear loads in Saudi Arabia is not known, but it may be comparable to that of USA, due to the wide use of electronically controlled equipment. The power quality of the utility grid is also affected by the switching of heavy loads. There are other reasons, which affect the power quality i.e. lightning, accident to power equipment, and their failures due to natural disaster. Due to all previous circumstances, the utility, the consumers and the manufacturers have all a high concern in continuous monitoring of PQ. Many utilities have installed a network for monitoring power quality to provide real time information to their control center, to consumers and to consulting engineering offices. In many cases the consumer feels that the equipment are operating normally, but the optimum operations can be ensured only through the continuous monitoring of PQ. EPRI states that around 80% of all PQ problems may result on the customers premises, therefore the utility is advising the medium and large size customers to install a PQ system. The automatic PQ system will identify various problems for the consumers leading to a high reliability, energy conservation, optimum management, efficient planing for normal and preventive maintenance and reduced operation cost. The cost of power pollution is difficult to estimate at present time. The poor PQ in USA causes about 13.3 billion dollars in damage per year [2]. A sizeable portion of PQ problems is related to harmonic distortion, so a few billion of dollars could be saved if the majority of the non-linear loads included low harmonic distortion line interference.

2- Power Quality Assessment

A large commercial and office building was selected , due to the great diversity of the type of loads, and their wide random operation time. The number of loads in the building is very big, such as air conditioning equipment, lighting fixtures, Personnel Computers (PC), and other equipment, therefore the simultaneous PQ monitoring of all loads is not possible because the PQ measuring equipment is quite expensive. The PQ, first, is monitored for the essential parts such as power transformers and big size loads, such as, air conditioning equipment, then for smaller loads, such as, photocopy and PC's. The large building has 6 floors with a total covered area of 60,000 m^2. The total number of offices, shops and other support services is about 500. The electrical power to the building is supplied through 5 transformers, 1MVA each. Figure 1 shows a single line diagram of one transformer and some typical loads. The building has various loads, mainly chillers, Air Handling Unit (AHU), elevator, escalator, different lighting fixtures, photocopying machines and Personnel Computers (PC). Table 1 shows a summary of main loads in the building. The selected PQ measuring equipment are programmed to measure, record and analyze the desired parameters. The measured parameters include average, Root Mean Squares (rms), unbalance, harmonic content of voltage, current and power. The time interval for PQ measurement is varied according to the location and the load type. The time duration is one week for main transformer and one day for small loads which are around 100A or less. A summary of daily average measured PQ variables of all supply transformers and some selected loads in the building are given in tables 2 and 3 respectively. It is clear from table 2 and 3 that the maximum daily average of harmonic content of the neutral current is very high, it reaches 958.7 5% and 35.7% for the transformers 5 and 2 respectively. The average of maximum unbalance between line voltage on the secondary side of the transformer is relatively small, it varies between 0.5% and 1.8% for the transformers 4 and 3 respectively, which implies that the electric grid has good reliability. But the average maximum unbalance of the line current is high, it varies between 36.1% and 3.9 % for transformer 2 and 5 respectively. As a result , the maximum average neutral to ground voltage varies between 57.2 and 56.8 V for transformer 1 and 5 respectively. The harmonic content of the load current can increase the losses in the distribution cable, in customer equipment and transformer. Also the high harmonic content of the load current decreases the cable nominal capacity, and reduces the life time. It is found from this study that the load types are the main sources of the low PQ in the transformers, which is clear from table 3. Measured variable of transformers and loads are plotted in figures 2 and 3.

Figure 4 shows a wave shape of a PC in the building. A summary of the analysis of the wave shape of the PC is given in table 4. It is clear from the table that the THD of the wave current is very high it has an average of 126%. From the analysis, the odd harmonics current of the PC wave shape are very high, rather than canceling each other, those harmonics add up in the neutral conductor leading to a net increase in the neutral current. The building has a big number of PC's , mostly single phase, they are distributed randomly among the three-phase 4 wires power system of the building, therefore the current harmonics in the neutral is very high, which causes an increase of the neutral to ground voltage, an increase in the power loss and a decrease in the cable ampere carrying capacity. More over, the presence of high harmonic current is linked with the phenomena of skin effect of the cable, therefore an oversize of the neutral conductor is needed to compensate for the effective area of the cable. Figure 5 shows the wave form of a load in the building ,from which, it is found that maximum and minimum average values of THD of neutral current reaches 275 and 18 % respectively.

It is noted that, a high average phase voltage (130 to 139.2 V) as compared with customer equipment voltage which is normally between 110V and 120 V, has an increase of 26.5% with respect to 110V, resulting in an increased power consumption of around 60% and a shorter life time. From the analysis, it is found that the PQ has hourly, daily and weekly fluctuations in most of the area of the building. The fluctuation of the PQ is very common and is due to the different equipment and to various operating time (random switch ON and OFF time).

Because the supply voltage is common to all loads in the building, therefore the voltage harmonics can have interference on the operation of nearby loads in the buildings. Also the harmonic current can excite resonance in the power system. From the PQ analysis in the building it is clear that PQ hardware is needed for the management of harmonic pollution.

3- Recommendations

Many industrial equipment are available and can be used to control the problem of harmonic and improve the

PQ. Active filtering of electric power has now become a mature technology for harmonic and reactive power compensation. A comprehensive review of active filter configurations, control strategies, and their selection for specific applications is given in many references, such as [3]. To control harmonics, it is possible to use Power Quality Manager (PQM) which is a hybrid device consisting of passive filter in series with a converter [4]. The power rating of the converter is lower than that of an equivalent Static VAR Compensator (SVC) or an active filter, and therefore it can be made relocatable. When necessary, it can be moved to a passive filter on another line. Only reactive power is needed by PQM, therefore no dc source is required for the converter.

From the PQ analysis for this large commercial and office building it is recommended to follow a number of methods to control the operating condition of power transformer and consumers loads. The methods may include: (a) select a suitable hardware for PQ management, (b) balance the load to the best optimum percentage, (c) selecting the specification of the customer equipment with low THD to limit harmonics generated from the customer equipment, (d) reduce supply voltage variation to decrease power losses. The application of standard reduce the problem of pollution to the power system, for instance the international standard IEC 555 which was published in 1982 include 3 parts, including definition, harmonics and voltage fluctuations. The standard about harmonics was amended several times and became in 1990 as part of the IEC 1000 family of Electro Magnetic Compatibility (EMC) standards. In the United States, the ANSI/IEEE Standard 519-1992, "IEEE recommended practices and requirements for harmonic control in electrical power systems" sets limits to both the voltage and current harmonic. The IEC standards limit the harmonic emission produced by the equipment, while the ANSI/IEEE standard 512-1992 limits the harmonics to the point of common coupling with the consumer. In other words, the responsibility for curtailing harmonics lies equally with the electric utility and the users of the electric equipment, rather than the vendor.

4- Conclusion

From the analysis of PQ for this large commercial and office buildings, it is found that the power transformer and the consumers loads need to be monitored permanently because the PQ varies with the operation time and with the locations. It was observed that some loads generates high harmonic content which can have an effect on other customer loads in power system. High harmonic content increases energy losses, unbalance between the 3-phases and neutral current. The PQ is a suitable tool to monitor the present condition and to estimate the future possible problems, so that a suitable preventive solutions can be studied and applied in advance. The estimated extended use of nonlinear load in the future is expected to increase, therefore it is recommended to take the necessary steps to decrease the effect of harmonic distortion by controlling the PQ and applying the standards issued in this regard.

5- References

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Table 1 - Building main loads

Item	Description	Main Equipment
1	AirConditioning	Chiller , HVAC , Pumps , Blower
2	Offices	PC , Printer , Fax , Photocopy , UPS , Lighting Fixtures
3	Support Services	Passenger Elevator , Freight Elevator , Escalator , Lighting Fixture , UPS , Standby Generator
4	Shops	Lighting Fixture , PC
5	Restaurants	Oven , Electric Cooker , Dish Washer , Lighting Fixture
6	PhotoLaboratory	Photo Machine , PC , Printer , Fax
7	Entertainment	Children Games, electrical , electronic

Table – 2 Building Power Transformers PQ measurement

S.No.	Parameters	TR-1	TR-2	TR-3	TR-4	TR-5
1	AVR(1) -V(2)(v)M (3)	138.5	130.2	135.5	139.2	137.1
2	AVR-V(v)m(4)	125	121.2	122.4	130.5	124.4
3	UNB(5) -V(%)M	1.5	1.6	1.8	0.5	0.8
4	UNB-V(%)m	0.1	0.0	0.4	0.0	0.0
5	AVR-THD(6)V (%)M	3.8	3.9	2.0	2.4	1.3
6	AVR-THDV (%)m	0.7	0.6	0.4	0.8	0.5
7	T–I(7) (A) M	1800	1600	1600	2000	1500
8	T-I (A) m	200	1000	200	300	100
9	UNB-I (%)M	16.4	3.9	14.8	22.6	36.1
10	UNB-I (%)m	0.4	0.8	6.1	2.3	0.1
11	AVR-THDI (%)M	4.9	1.5	1.9	5.5	13.4
12	AVR-THDI (%)m	0.9	0.9	0.7	2.1	2.4
13	AVR-HI(8)2 (%)M	1.1	0.5	1.0	1.3	3.0
14	AVR-HI2 (%)m	0.0	0.0	0.0	0.0	0.0
15	AVR-HI7 (%)M	0.5	0.6	0.6	0.7	1.8
16	AVR-HI7 (%)m	0.2	0.3	0.1	0.1	0.1
17	N-I(9) (A)M	95.9	60.7	70.8	65.5	64.5
18	N-I (A)m	13.2	21.6	6.2	12.7	9.1
19	THD-NI (%)M	161.1	35.7	117.5	526.7	958.7
20	THD-NI (%)m	8.2	2.7	3.7	59.3	40.7
21	V-NG(10) (V)M	57.2	56.9	57.4	57	56.8
22	V-NG (V)m	51.3	51.1	52.7	0.8	51.6

(1) AVR : Average , (2) V: Voltage , (3) M: Maximum , (4) m: minimum , (5) UNB: Unbalance , (6) THD: Total Harmonic Distortion , (7) T-I: Total Current , (8) HI: Harmonic Current , (9) N-I: Neutral Current , (10) V-NG: Voltage Neutral-Ground .

Table 3 Measured parameter of selected loads in the building

S No	Parameter	Load-1	Load-2	Load-4	Load-5
1	AVR-V(v)M	131.9667	130.5	120	130.125
2	AVR-V(v)m	130.7583	129.1	120	128.775
2	AVR-V(v)m	130.7583	129.1	120	128.775
3	UNB-V(%)M	0.991667	1.15	0	0.625
4	UNB-V(%)m	0.758333	0.775	0	0.3
5	AVR-THDV(%)M	1.5	1.325		1.15
6	AVR-THDV(%)m	1.391667	1.25		1.1
7	T-I(A)M	69.22733	60.912	268.9	198.325
8	T-I(A)m	68.57633	60	114.225	192.775
9	UNB-I(%)M	78.25	102.725	69.87917	13.35
10	UNB-I(%)m	75.95	4.05	49.13333	12.125
11	AVR-THDI(%)M	37.30833	59.775	34.30417	8.075
12	AVR-THDI(%)m	32.29167	2.175	4.066667	7.025
13	AVR-HI2(%)M	3.7	11.375	8.4	0.325
14	AVR-HI2(%)m	0.65	0.05	0.05	0.1
15	AVR-HI5(%)M	16.01667	11.3	7.258333	3.225
16	AVR-HI5(%)m	12.63333	1.35	0.758333	2.725
17	N-I(A)M	5.195667	4.3525	50.42083	12.325
18	N-I(A)m	4.968	4.1875	33.36667	11.675
19	THD-NI(%)M	49.90833	471.675	21.13333	73.325
20	THD-NI(%)m	27.95833	24.45	14.3875	67
21	V-NG(v)M	55.475	55.3	55.3375	54.925
22	V-NG(v)m	54.83333	54.45	54.6	54.225

(1) AVR : Average , (2) V: Voltage , (3) M: Maximum , (4) m: minimum , (5) UNB: Unbalance , (6) THD: Total Harmonic Distortion , (7) T-I: Total Current , (8) HI: Harmonic Current , (9) N-I: Neutral Current , (10) V-NG: Voltage Neutral-Ground .

Table 4 - PQ analysis of PC's in the building

Voltage (V)	Single phase , 125 (rms)
Current THD(%)	Average =126, Min=123, Max=133,
Voltage THD(%)	Average =0.7, Min=0.7, Max=0.7,
Current Harmonic (%)	3^{rd}=88, 5^{th}=69, 7^{th}=47, 9^{th}=25
Power Factor	Average =0.62, Min=0.59, Max=0.63,

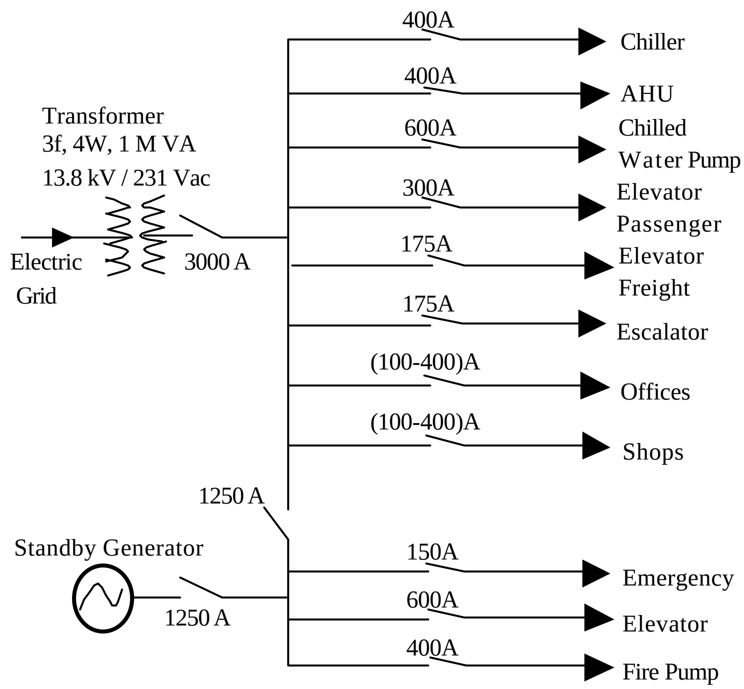


Figure 1 Single line diagram of power system and sample loads in the building.

Figure 2 - Power transformers measurements analysis (a) Current Unbalance (b) Current THD (c) Voltage THD (d) Total Neutral current (e) Neutral Current THD (f) Neutral to Ground voltage

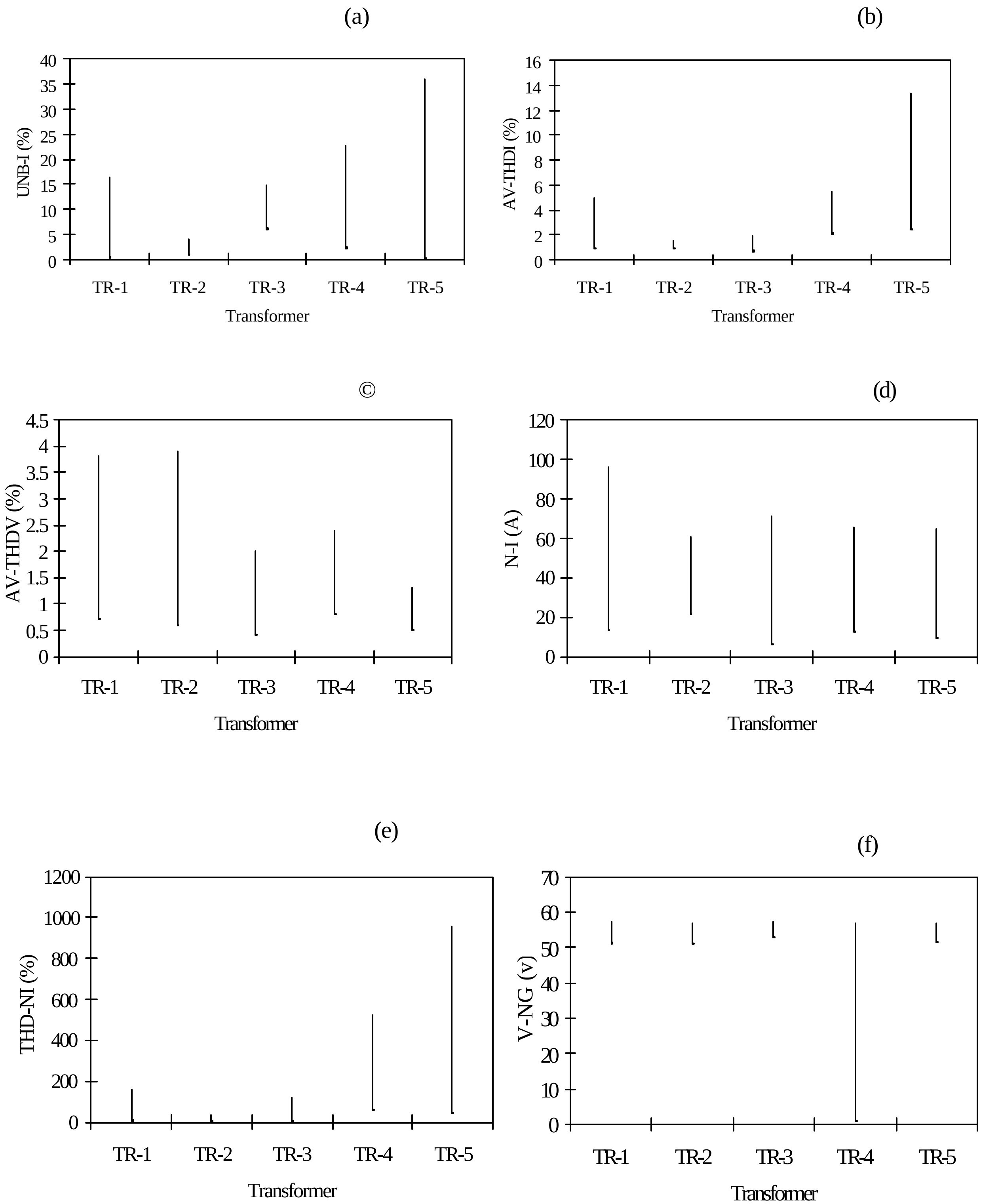
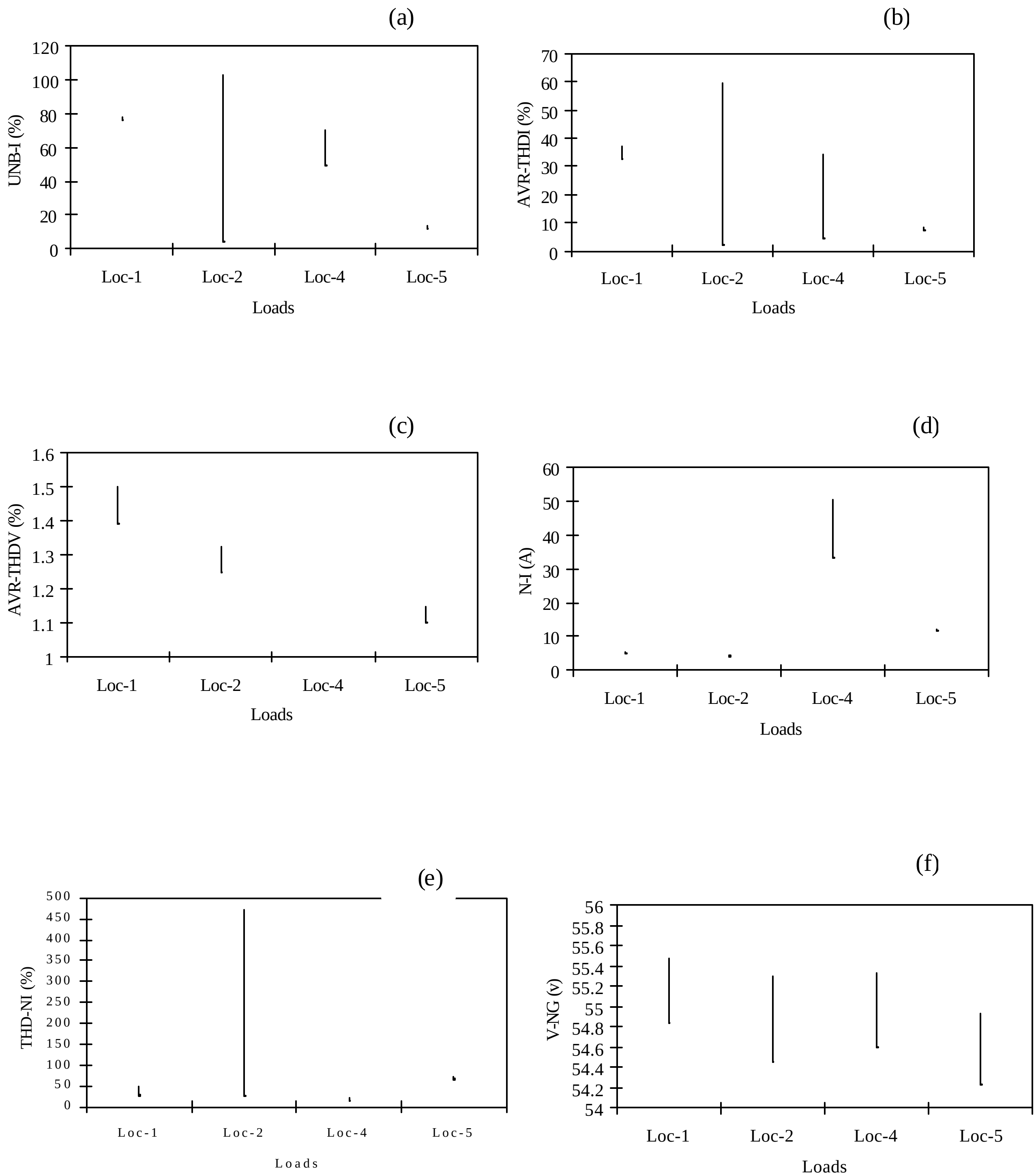


Figure 3 - Loads measurements analysis (a) Current Unbalance (b) Current THD (c) Voltage THD (d) Total Neutral current (e) Neutral Current THD (f) Neutral to Ground voltage



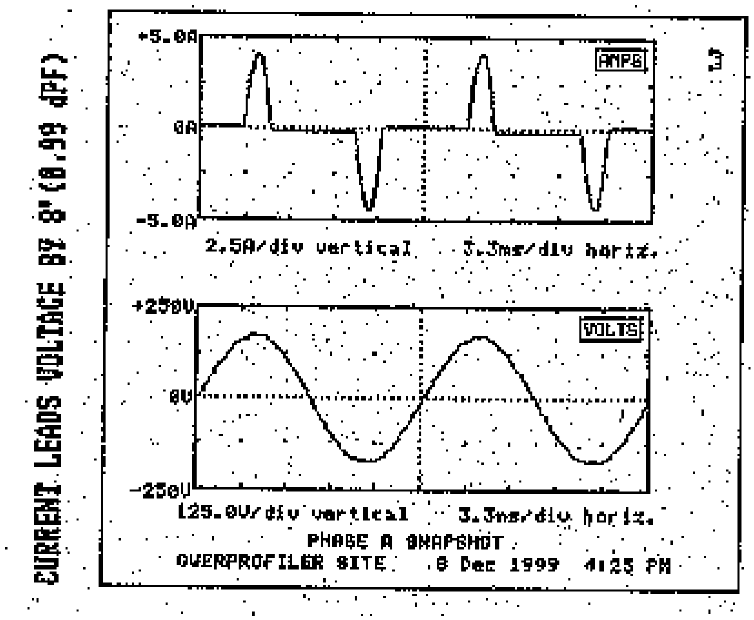


Figure 4- PC's wave shapes of current, voltage and power.

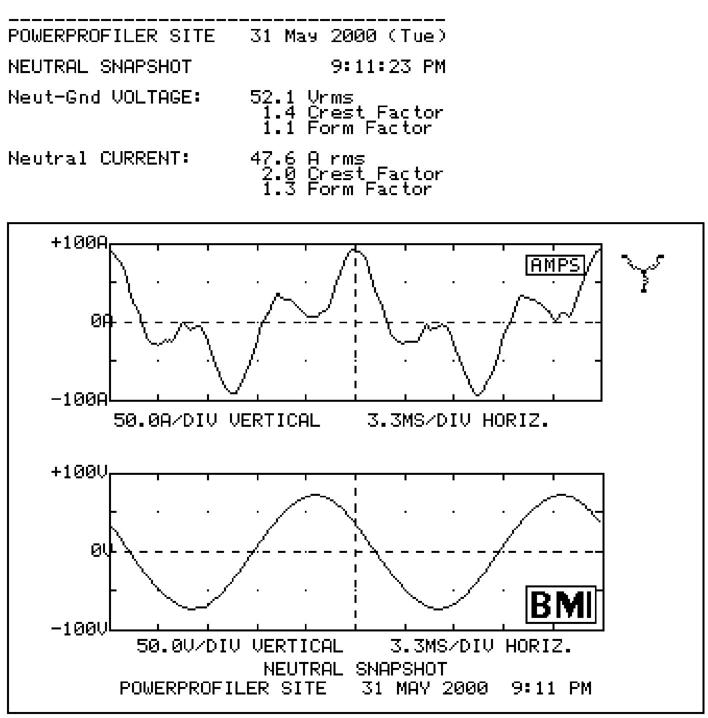


Figure 5 - A sample for a load neutral current , voltage and power wave shapes.