Analysis of System Failure in a CNG Site

M. Osouli Tabrizi, H. Kharradmehr, and K.R. Milani
Director, Project Engineer and Manager
West Azarbayjan Utility, Tabriz, Iran

H. Mokhtari
Associate Professor, Department of Electrical Engineering
Sharif University of Technology, Azadi Ave., Tehran, Iran
mokhtari@sharif.edu

***Abstract* — This paper presents the results of a thorough power quality analysis in order to determine the cause of failure in a Compressed Natural Gas (CNG) distribution transformer. The paper presents the field data and determines power quality indices of such loads based on IEEE/IEC standards. It provides steady state time-series parameters as well as transient waveforms. Different signatures of the voltage and current signals are extracted, and consequences of the distortions are described. The analysis is clarified by presenting both time domain captured waveforms and statistical power quality indices. Optimum solution for improving power quality and prevent component failure is also proposed.**

***Index Terms* — power quality, IEEE standard, harmonic content, flicker, CNG, power failure.**

I. INTRODUCTION

Use of power quality disturbing loads has raised concerns for both utilities and customers in recent years. Loads such as power-electronic based devices or arc furnaces with their nonlinear behavior and highly varying nature have resulted in poor power quality at low and medium voltage distribution systems. There have been many reports on the disturbing effects of low power quality on equipment and power system failure or malfunction [1-5]. On the other hand, cost of consequences of low power quality has made engineers to carry out further studies into this issue for two reasons; 1) to correctly determine the reason for such incidents, and 2) to take counter measures in order to mitigate the problem [4].

Increase of the number Compressed Natural Gas (CNG) operated and dual-fuel (CNG + gasoline) cars in the past few years has required many CNG stations to be built in some countries. People are encouraged to switch to the cars which can work with both gasoline and CNG due to the fact that these cars generate less pollution in environment. CNG stations employ many pumps and motors which are turned on and off very frequently. Some of these motors are equipped with thyristor-based soft starters and some of them are fed through IGBT based drives. Therefore, one expects to see several power quality issues at CNG stations.

There have been reports on overheating and failure of distribution power substations feeding CNG sites including transformers, cables, relay malfunction and ... The objective of this paper is to present the results of a thorough study into these incidents in a CNG site in Maraghe, a city located in north-west of Iran. To do so, the CNG site has been monitored for a one-week period with a power quality monitoring device with the specifications given in the appendix. Steady state power quality parameters as well as voltage/current transients have been captured to investigate the problem.

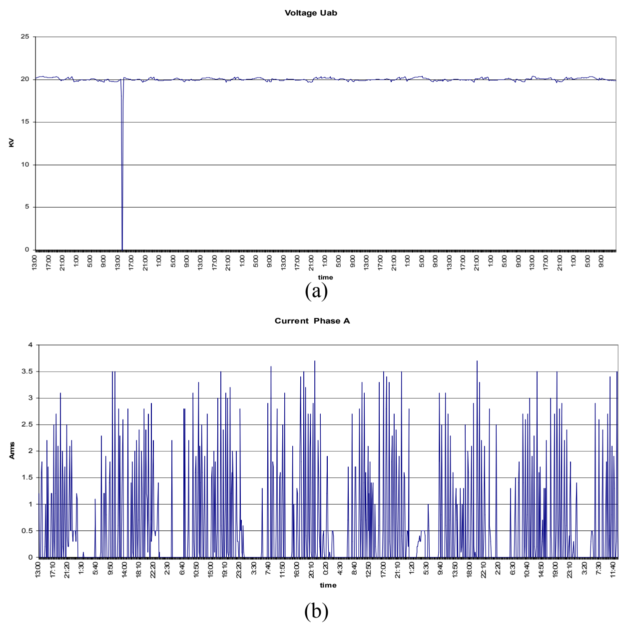
The structure of this paper is as follows. The next section presents some of the field data. Section III carries out steady state analysis in order to determine power quality indices at steady state and perform standard compliance. Section IV presents some of the transients captured during the monitoring period. Section V is a discussion on the study and the conclusions come in Section VI.

II. FIELD DATA

The medium voltage side of the distribution transformer feeding the CNG station has been monitored with a power quality analysis device. The transformer rating is 600kVA. The power quality analyzer is a three-phase device capable of sampling voltage and current waveforms at a rate of 256 samples per cycle. Each parameter, e.g. line voltage, is measured every cycle and the results is averaged over a 10-minute period and logged as one data. The analyzer specifications are given in the appendix. The logged data includes all the power quality indices such as voltage/current rms variation, imbalance, harmonic content, voltage flicker and transients. Suitable voltage/current thresholds are also defined to capture transients.

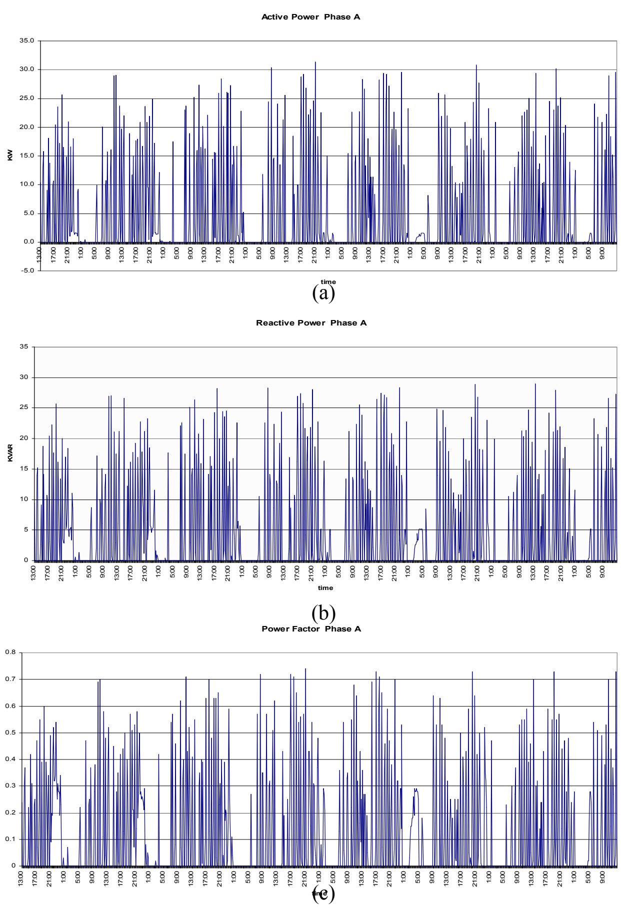
Fig. 1 depicts voltage and current rms variation at the 20 kV side of the 20kV/380V transformer. Looking at this figure reveals that the voltage profile is acceptable although the rate of load change is very high. A short interruption is also seen on the second day of monitoring period.

Active power, reactive power and power factor of one of the phases, i.e. phase a, are depicted in Fig. 2. It can be seen that the system power factor, i.e. load + transformer, is of highly varying nature with a minimum of zero and a maximum of 0.73. This shows the fact that the rate of load change is so high that the power factor compensating device cannot effectively improve the load low power factor. No need to mention that Fig. 2-c shows the power factor averaged every 10 minute. Typical voltage/current transients are provided in Fig. 3.



(a) (b)

Fig. 1: Filed data (a) line voltage b) line current



(a) (b) (c)

Fig. 2: Field data, phase-a a) active power b) reactive power c) power factor

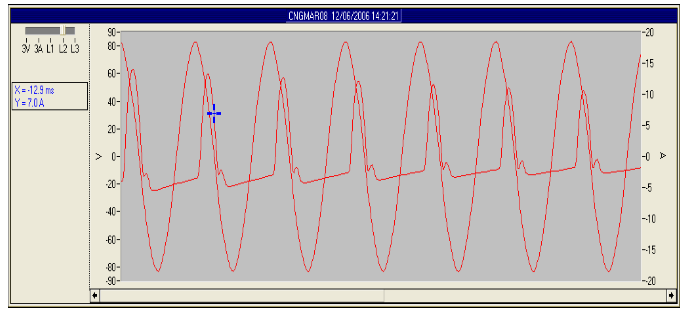
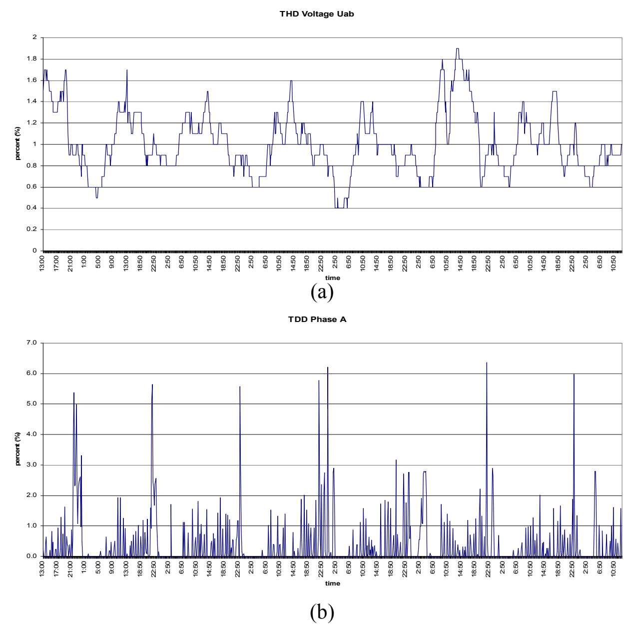


Fig. 3: Field data, voltage and current transient

One of the effects of voltage/current harmonics is overheating transformers. Therefore, the harmonic content of line voltages and currents are also monitored over the one-week period. The results are summarized in Fig. 4.



(a) (b)

Fig. 4: Field data a) voltage THD b) Current TDD

From Fig. 4, it can be seen that harmonic levels are not high and cannot contribute to any source of system malfunction at steady state. Probability of a resonance at some harmonic is still to be studied. Fig. 4-b shows that line current TDD is changing due to the load change, but the maximum value is always below 8%.

Other power quality parameters such as voltage/current imbalance and voltage flicker are also measured. However, since the results are well within the standard limits, only the statistical indices are presented in the next section.

III. STEADY STATE INDICES

In this section, steady state power quality indices are extracted. The objective is to check the level of power quality parameters against standard limits.

A. Harmonic Indices

A procedure is recommended by IEEE harmonic working group [6]. According to this guide, measurement is taken over a period of one week. Then, the Cumulative Probability of 95% (CP95) of the data is calculated and considered as the pollution level at the test node. Table 1 summarizes voltage THD and current TDD results. As it can be seen, the level of steady state harmonics is IEEE519 complaint. Therefore, the failure of transformers cannot be attributed to the high level of harmonic pollution.

TABLE I

STATISTICAL INDICES, VOLTAGE THD AND CURRENT TDD

	Standard Limit	CP 95	Maximum
THD Uab	5 %	1.6 %	1.9 %
THD Ubc	5 %	1.7 %	2 %
THD Uca	5 %	1.7 %	2 %
TDD Ia	20 %	2 %	6.4 %
TDD Ib	20 %	2.7 %	6 %
TDD Ic	20 %	3.8 %	6.1 %

The procedure is extended to individual harmonics as well. Fig. 5 depicts the results for only one of the line voltages, i.e. Uab. Table II shows the results for all three line voltages. The table shows the CP95 index as well the maximum value for all three phases.

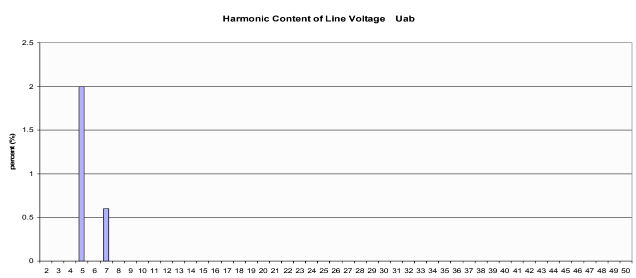


Fig. 5: Individual harmonics for Uab line voltage

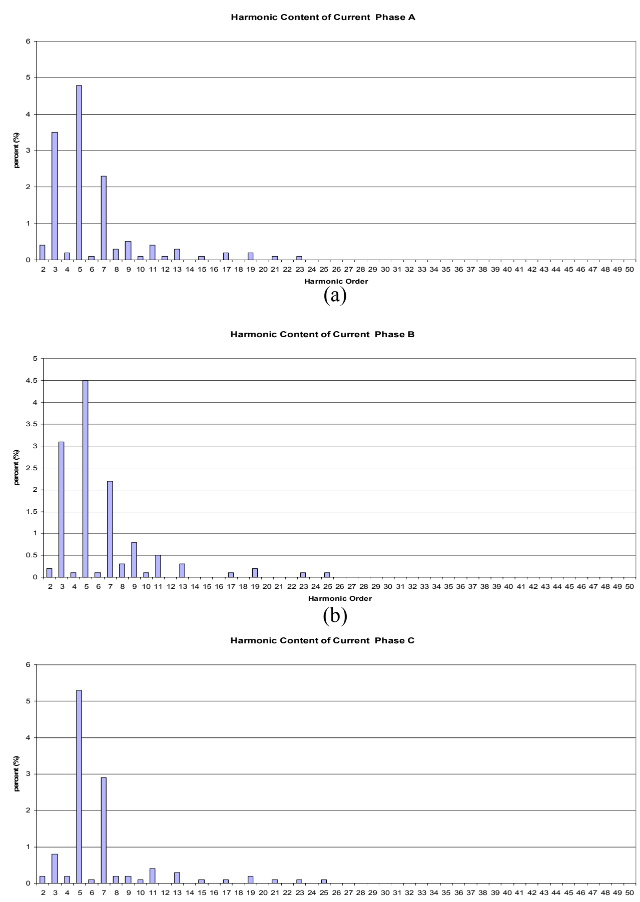
It can be seen from Table II that steady state voltage harmonic indices are within acceptable standard limits. The maximum value occurs at the 5th harmonic and is 2.1% as compared to the maximum permissible limit, i.e. 3%.

Study is also performed to determine the quality of load current at the test location. This study includes current TDD and individual current harmonic level, i.e. HDi. The procedure to determine current harmonic indices is the same as that used for voltage harmonics, i.e. the CP95 value of each parameter is determined. The results are summarized in Table III and Fig. 6. Considering the short circuit ratio at the test location and according to IEEE519, the maximum permitted limit for the TDD is 20% and for the individual harmonics is 15%.

TABLE II

VOLTAGE INDIVIDUAL HARMONICS

	Uab		Ubc		Uca		
H#	**Max**	**Cp95**	**Max**	**cp95**	**Max**	**Cp95**	**Limit**
2	0	0	0	0	0	0	**1.5**
3	0	0	0	0	0	0	**3**
4	0	0	0	0	0	0	**1.5**
5	2	1.6	2.1	1.7	2	1.7	**3**
6	0	0	0	0	0	0	**1.5**
7	0	0	0	0	0	0	**3**



(c)

Fig. 6: Individual harmonics for line currents

From Table III and Fig. 6, one can conclude that level of harmonic is not a concern at steady state operation.

TABLE III
CURRENT TDD RESULTS SUMMARY

Index	Maximum	CP 95	IEEE519 Limit
TDD Ia	6.4%	2%	20 %
TDDI b	6%	2.7%	20 %
TDD Ic	6.1%	3.8%	20 %

B. Voltage Imbalance

Table V shows the analysis results for the voltage imbalance. Based on IEEE1159 Standard limit, the ratio of the negative sequence to the positive sequence is the imbalance ratio. To determine the imbalance index, the CP95 of the imbalance value calculated for each day is calculated and the maximum CP95 is selected.

TABLE IV
VOLTAGE IMBALANCE INDEX

Standard Limit	Imbalance Index
2 %	0.3%

From Table V, one can conclude that the voltage imbalance is of no concern.

C. Voltage Flicker

For the flicker level, short term and long term flicker, i.e. Pst and Plt, indices are considered. The flicker level of the bus voltage is also measured and checked with the level defined by IEC 61000-4-15 [7]. The results showed that the flicker level is standard. Fig. 7 depicts the results for flicker determination.

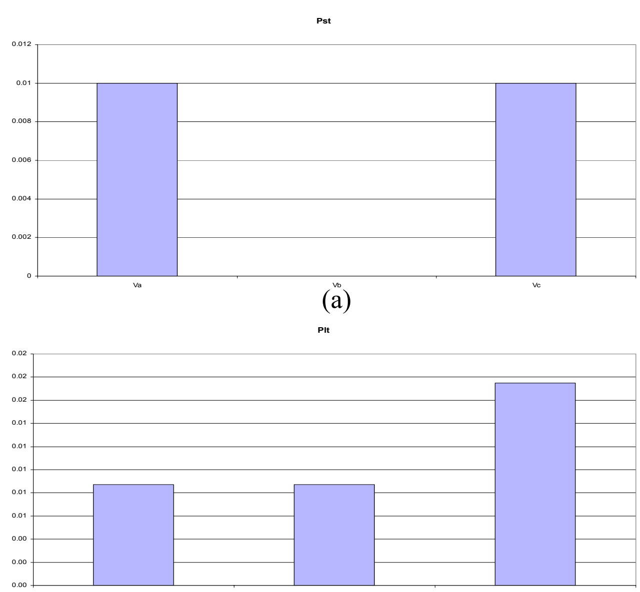


Fig. 7: Voltage flicker a) Pst b) Plt

IV. TRANSIENT ANALYSIS

From Fig. 3, it is clear that the transformer is subjected to transient in-rush currents which occur frequently due to the nature of the load. In a CNG site, electrical pumps and motors are turned on and off very frequently. This behavior can also be seen from Fig. 1-b and Fig. 2. Fig. 3 also indicate that the transformer carry a dc bias as well. Comparing Fig. 3 with Fig. 1-b shows that the transformer is also saturated during transients.

V. DISCUSSION

Studying the results indicate that transformer failure cannot be due to the steady state voltage/current harmonics. According to IEEE519 standard limits, for a voltage level of 20 kV, a maximum of 5% voltage THD is allowed. This standard also defines the permitted TDD limit for a system with the given short circuit capability to be 20%. However, looking at the rate of load change and system power factor reveals that rate of load change is so high that the existing power factor compensator cannot function properly. Also, examining the third harmonic of the transformer shows that occasionally, the level of the third harmonic increases considerably. Therefore, the failure of the transformer can be attributed most probably to the following two reasons:

1. Use of normal transformers at CNG sites may not yield satisfactory results, and special transformers which can tolerate sudden and frequent current change must be employed as in the case of arc furnace loads.
2. Design/selection of transformers subjected to frequent and sudden load changes cannot be done based on normal and routine practices, and the capacity of such transformers in terms of VA and VAR has to take transient need of the load into consideration as well.

VI. CONCLUSIONS

In this paper, the results of a power quality analysis at a CNG site are presented. The results indicate that normal transformers whose VA capacity is designed based on steady state load behavior may not be able to handle highly varying nature of such loads. Also, in designing the load power factor compensator, transient need of the load reactive must also be considered. This may require higher than average load reactive power be installed at load side. Also, due to the highly varying nature of such loads, conventional contactor-based regulators cannot effectively compensate load power factor, and Thyristor-Switched Capacitors (TSCs) banks must be employed. These TSCs achieve better VAR compensation as well as longer capacitor life.

VII. APPENDIX

The power quality analyzer used for this project is a CA8334 device with the following specifications:

256 samples/cycle

Accuracy:

±0.5% for rms calculation

±1.5% for power calculation

±1.5% for power factor calculation

±1% for harmonic and imbalance calculation

VIII. REFERENCES

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X. BIOGRAPHIES

MOHAMMAD REZA OSOULI TABRIZI was born in 1957. He received his B.Sc. from Tabriz University in power engineering. He joined Iran Ministry of Power in 1982. He has served in various positions in Azarbayjan Power Electric power Co. including overhead lines and distribution substations office manager, Bonab Electric Power Distribution Office manager, East Azarbayjan Power Distribution Company (EAZ EPDICO) contract and consumer services office manager, and Managing Director of Azarbayjan SAZE Niroo Compnay. He is currently working as the Managing Director of EAZ .EPDICO.

AMIN KHARRADMEHR was born in Marage in 1973. He received his B.Sc. degree in power Engineering from Tehran University in 1987. He has been with Eastern Azarbayjan Electric Power Distribution Co. (EAZ EPDICO) since 1990. He is the Manager of R&D Office in EAZ EPDICO and has published over 17 papers in international conferences on distribution networks and equipments.

KARIM ROUSHAN MILANI was born in Oskoo in 1967. He received his B.Sc. degree in power electric Eng. from Tabriz University in 1990 and M.Sc. degree in industrial engineering From Sharif University of Technology in 1998. He was employed by Eastern Azarbayjan Electric Power Distribution Co. (EAZ EPDICO) in 1994 as the design manager. He is currently the manager of Supervisory and Design Office in EAZ EPDICO. He has published over 20 papers in international conferences and is the author of 3 books on distribution networks and equipment.

Hossein Mokhtari was born in 1969 in Tehran, Iran. He received his B.Sc. degree in electrical engineering from Tehran University, Tehran, Iran in 1989. He worked as a consultant engineer for Electric Power Research Center (EPRC) in Tehran in dispatching projects. In 1994, he received his M.A.Sc. degree from University of New Brunswick, Fredericton, N.B., Canada. He obtained his Ph.D. degree in electrical engineering from the University of Toronto in 1998. He is currently an associate professor at Sharif University of Technology, Tehran, Iran. His research interests include power quality and power electronics.