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Power Quality Assessment in Electricity Distribution Networks – AADC LV Network Harmonics Distortion Case Study

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ABSTRACT:Monitoring devices are being used for Power Quality (PQ) monitoring and control. The monitoring devices enabled the distribution utilities to analyze the network for certain quality attributes that can have significant effects on power systems. Some of these quality attributes are the frequency, supply voltage variation, flickers, voltage unbalance, harmonic and inter-harmonic, voltage dips/ swells, interruptions on the supply voltage and transient over voltage. Voltage variation (flicker, dip/swell, etc.) and harmonics are considered to have greater effect on the quality of power. This paper discusses the harmonic disturbances in Al Ain Distribution Company (AADC) LV power network (400V) as a PQ assessment for two substations that belongs to different areas and feeding two kinds of customers (commercial and industrial) in a detailed case study. Such evaluation is performed using the power quality analyzer FLUKE 1773 over a duration of one week for each location. The main objective of this assessment is to figure out the need for additional filters to eliminate the harmonics at both medium and low voltage networks. In general, THD level is checked and found meeting the regulations of Abu Dhabi Department of Energy maximum allowed value of 5% at 400V network. Accordingly, no additional filters were required at the studied locations.

KEYWORDS: Harmonic Distortion, Distribution Network, Disturbance, Power Quality (PQ).

I.INTRODUCTION

The Power quality (PQ) is a challenge that has developed increased interest for both electric utilities and clients today. End-user smart devices (for example the personal computers and smart devices, which are sensitive to certain types of voltage disturbances in the power system) nonetheless the nonlinear loads (such as fluorescent lightning and adjustable speed drives) on its turn may produces some current disturbances that, which pollute the electric power system.

Therefore, PQ urgently needs to be monitored and improved. There has been noticeable increase in the amount of power quality monitoring taking place in electric power systems in recent years. Monitoring of voltages and currents gives the network operator information about the performance of their network, both for the system as a whole and for individual locations and customers [1]. There is also higher desire from the customers and the regulatory agencies to provide information on the actual power quality level [2]. In many cases, the monitoring programs end up in massive PQ data which makes analysis difficult. Thus, the development of automatic tools for classification of the measured data is required to help utilities, regulators and customers to have a clear understanding of what is happening in their networks [1]. In addition, Management of power quality (PQ) levels on electricity networks is fast becoming a basic day to day activity for electricity distributors. With the proliferation of modern electronic equipment that create PQ disturbances and in turn are being affected by such PQ disturbances, utilities now have to have robust PQ management and planning processes in order to maintain acceptable PQ levels on their networks. Proactive PQ monitoring provides the essential feedback into the PQ management and planning process. Consequently, many utilities are installing system wide PQ monitoring schemes [3].

However, developments in enabling technology (monitoring equipment, communication technology, and data storage and processing) have made it possible to monitor at a large scale and to record virtually any parameter of interest. The change in types of loads connected to the network and proliferation of nonconventional (power- electronic interface-connected) generators as well as envisaged further increase in non-conventional types of loads/storage (e.g., electric vehicles) puts additional pressure on network operators to monitor and document various aspects of network performance. While many network operators are installing monitoring equipment and while more and more manufacturers have monitors available, there is a lack of knowledge and agreement on a number of aspects of the monitoring process and in particular on processing the recorded data. The users of the data, network operators or their customers, are increasingly asking for

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useful information rather than just large amounts of data to be provided by installed monitors and supporting software [2]. Harmonic analysis is an important application for distribution systems analysis and design. It is used to quantify the distortion in voltage and current waveforms at various buses for a distribution system, and to determine whether dangerous resonant problem exists and how they might be mitigated [4]. Though, such analysis is more important since the use of harmonic-producing equipment is increasing. As harmonics propagate through a system, they result in increased power losses and possible equipment loss-of-life. Further equipment might be damaged by overloads resulting from resonant amplifications.

However, the purpose of this study is to evaluate the PQ at Al Ain Distribution Company (AADC) power LV network in term of harmonic distortion using the FLUKE 1773 in two areas feeding two kind of customers one is commercial and the other is industrial customers. this assessment and careful evaluation will be used to measure the total harmonic distortion for both voltage and current; accordingly, recommendations will be set.

II.THE SIGNIFICANCE OF POWER QUALITY MONITORING

The developed power quality monitoring system gives the user necessary information regarding the types of problems occurring at the installation which, in turn, can help in pinpointing and solving those problems. The system is very simple, user friendly and also cost effective [5].
Monitoring power quality is challenging because of the increasing complexity and size of electrical networks. Regulating authorities and power suppliers around the world usually monitor the amount of energy that is being delivered to the end users by placing settlement meters at different points in the power grid. These meters in addition to energy measure different parameters such as voltage, current, and frequency. moreover, measuring and analyzing PQ is economically very important too since electronic equipment are somewhat sensitive to power supply events and the purity of the supply waveforms, therefore these parameters must be maintained at acceptable levels that will not cause any damages to the electronic devices at the user's side. Monitoring devices are being used for maintaining a reliable and stable power system. The monitoring devices enable the engineers and the network operators to analyze the network for certain quality attributes that can have major effects on the system. Some of these quality attributes are the frequency, supply voltage variation, Rapid voltage change (flicker), Supply voltage unbalance, harmonic and inter harmonic voltage, main signaling voltage, voltage dips/ swells, interruptions on the supply voltage and transient over voltage. Voltage variation (flicker, dip/swell, etc.) and harmonics are considered to have greater effect on the quality of power.

In addition, the monitoring systems help the engineers and operators to detect the previously mentioned power quality attributes and identify their causes placing the monitors smartly in the network helps in reducing the cost of the power quality monitoring system [6].

Moreover, it was found that flicker occurred many times in the system due to some steelwork that was taking place in some construction and industrial locations. Also, it was found that some voltage dips have occurred due to some natural phenomenon like lightening, these disturbances highlight the importance of power quality monitoring in industrial areas.
Furthermore, there is a significance of PQ monitoring in commercial areas, as due to increase in the proliferation of non-linear loads as a result of energy-saving measures, there is a tremendous daily increase in the power quality disturbance created by these power electronics equipment and devices which are the major sources of voltage and current distortions in the distribution networks. Resolving PQ issues also helps in reducing the financial losses to both utility and customer, and major breakdown of the power system equipment [7].

III.METHODOLOGY

The followings are the procedure in performing the measurements from planning stage up to reporting and analysis preparation, noting that in this case study research the device was installed in only two substations feeding commercial and industrial areas:The type of station and location was chosen based on vitality of the area.
The power quality analyzer is connected in the station for seven consecutive days for a complete data as shown in Figure 1.

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Figure 1.*Connection of power quality analyzer device at LV side.*

After one week of measurement, the power quality analyzer is disconnected from the station and the data was extracted for analysis.Collected Data had been validated and had been analyzed accordingly.

IV.HARMONICS AS A POWER QUALITY PARAMETER FOR POWER DISTRIBUTION NETWORKS SECURITY

Harmonics can be defined as the fundamental frequency of the AC electric power distribution system is 50 Hz. A harmonic frequency is any sinusoidal frequency, which is a multiple of the fundamental frequency. Harmonic frequencies can be even or odd multiples of the sinusoidal fundamental frequency [8]. Also, harmonics are defined as the alternating components having frequencies other than fundamental that present in voltage and current signals. There are various reasons for harmonics generation like nonlinearity, excessive use of semiconductor-based switching devices, different design constrains, etc. Harmonics have adverse effects on generation, transmission and distribution system as well as on consumer equipment also [9]. Harmonics are classified as integer harmonics, sub harmonics and inter harmonics. Integer harmonics have frequencies which are integer multiple of fundamental frequency, sub harmonics have frequencies which are smaller than fundamental frequency and inter harmonics have frequencies which are greater than fundamental frequencies. Among these entire harmonics integer and inter harmonics are very common in power system [10].

V. DISCUSSION AND RESULTS RESULT

The harmonic observations and data results obtained from the two distribution substations are analyzed. As highlighted earlier, two different types of loads – commercial and industrial – are investigated where substation 1 is commercial while substation 2 is industrial. The following Figure 2 illustrates the differences between maximum Total Harmonic Distortion (THD) index for both substations using the device (PQ logger FLUKE 1773) where sample data are collected throughout a week. The logger has been installed at the LV side of the distribution transformers owned by AADC to measure the harmonics effect caused by the customers. Usually, such installation is preferred to be at the Point of Common Coupling (PCC); however, in this case study the PQ analyzer is installed at a safe place within AADC premises in the distribution substation that is electrically considered same point of PCC.

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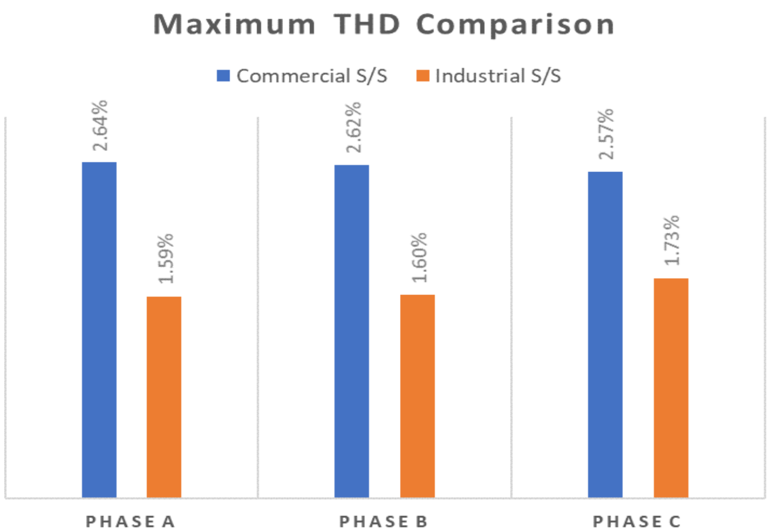

Figure 2. *Maximum THD index for three phases at 400V side of the distribution transformer of both substations1 & 2.*

It's clear that both substations are having THD within the allowable limits of 5% as defined in the Abu Dhabi Department of Energy Code of Limits for Harmonics in the Electricity Supply System [11]. Moreover, it has been noticed that commercial substation is having higher values of THD which can be justified by the strict rules a power utility usually imposes on industrial customers of having required filters. Also, commercial loads are having more non-linear devices that are operating in parallel and resulting in higher harmonics as our case study commercial substation is a shopping mall.

However, we need to have a detailed evaluation for the harmonic's compliance by investigating current distortion limits by calculating the Total Demand Distortion (TDD). According to IEEE 519-2014 [12], TDD represents the amount of harmonics with respect to the maximum load current over a period of time. Assuming a fault level of 10MVA at the LV network or $I_{SC}/I_L<20$ at the point of common coupling (PCC), then the TDD shall be limited to 5% as per IEEE 519-2014. For our case study, we calculated for both substations 1 & 2 the average TDD over the duration of the study (one week). Next table 1 represents the average I_L for all phases and neutrals for both substations.

Table 1. *Average I_L for all phases and neutrals for both substations.*

Substation [a]	**Current (A)**			
	Phase A	**Phase B**	**Phase C**	**Neutral**
1	354	340	337	131
2	191	153	133	52

Substation 1 is commercial while substation 2 is industrial.

The following Figure 3 represents a comparison between TDD for both substations.

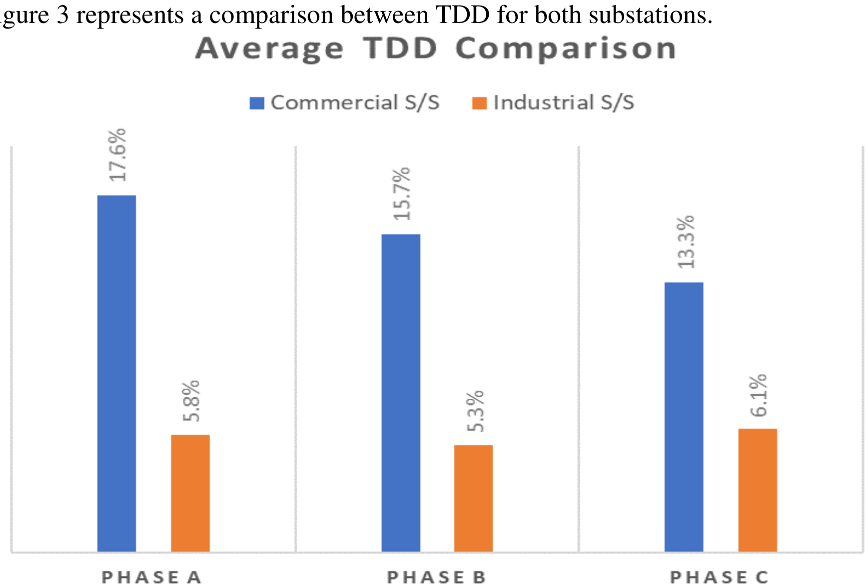

Figure 3.*Average TDD index for three phases at 400V side of the distribution transformer of both substations1 & 2.*

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It's obvious that both substations are exceeding the limit of 5%; however, the industrial substation shows slight violations compared to the commercial substation that significantly violating the permissible limits.
Accordingly, further assessment is required to investigate one of the most common problems occurred in power systems as a result of harmonics which is the Overloading Neutral Conductors. So, we evaluated the TDD at neutrals and found 348% value for substation1 and 23.7% for substation 2. The substation1 is really in critical situation and an urgent action is decided. In this commercial building with large number of electronic devices, the neutral wire is carrying higher current than the wire was designed to accommodate resulting in a potential overheat and fire hazards.
Moreover, such huge TDD values at substation 1 results in overheating the Transformer and accordingly increased associated losses. Eddy current loss in the transformer's windings, is the most dominant loss component when supplying harmonic-producing loads. When a fully loaded transformer is delivering power to a nonlinear load, the overall transformer loss is twice as great as when the load is linear. Due to the increased transformer heating and deterioration of the insulating materials, the transformer finally fails [13].

VI.MITIGATION AND SOLUTIONS CONCLUSION

As the TDD is high while THD is low, then a Passive Harmonic Filter or Active Harmonic Filter shall be used. An active harmonic filter uses a number of transistors and capacitors to remove the bulk of undesirable harmonic components from the current sinewave using inverse currents. The current wave is filtered by passive harmonic filters using an input reactor, output reactor, shunt reactor, and capacitor. They are a more straightforward option for particular pieces of machinery, but they are only compatible with single, steady loads.
In comparison to passive harmonic filters, active harmonic filters are bigger. Even though we are aware that some installations are space-constrained, Active Harmonic Filters can increase power quality to a higher degree. When the active filter limit is reached, Active Harmonic Filters will not overload, however a Passive Harmonic Filter may be susceptible to doing so. Additionally, the motors for which an Active Harmonic Filter is optimizing power won't be impacted if it is disabled. This is as a result of the filter not being used to process the current itself. An Active Harmonic Filter will initially cost more, but over time, it will be more efficient when it comes to sustaining a company's bottom line by ensuring[14]. Accordingly, it's decided to go for Active Harmonic Filter that shall be installed by the customer to stop injecting such harmonics to AADC network.

VII.CONCLUSION

This paper reviewed the PQ disturbances faced in distribution power networks. Analysis of harmonic distortion based on actual measurements collected from Al Ain distribution network is presented to evaluate the PQ compliance to the Abu Dhabi Department of Energy codes and regulation. Two types of customers were investigated through a case study by installing PQ logger FLUKE 1773 at two locations: commercial and industrial substations. Accordingly, the results were extracted where it was found that all types of loads have no voltage issues while the harmonics distortion levels showed somehow high figures that required more detailed analysis. The commercial customers' devices caused higher indices of both THD and TDD. However, both types of loads have THD levels complying with the regulatory requirement. However, commercial substations have very high TDD values. According to the reviewed resources and references, active harmonic filters are more desired and would be cost effective solution to overcome such challenges. In the next stage PQ analysis will be widely implemented to cover all kind of customers feeding from AADC network; moreover, PQ measurements is planned to be part of energization requirements of newly commissioned stations to help ensure that the electricity supply provided to customers is within the company's declared values and parameters. Likewise, this would also help detecting disturbances generated by customer's equipment thus forcing them to install the necessary filters on their system.

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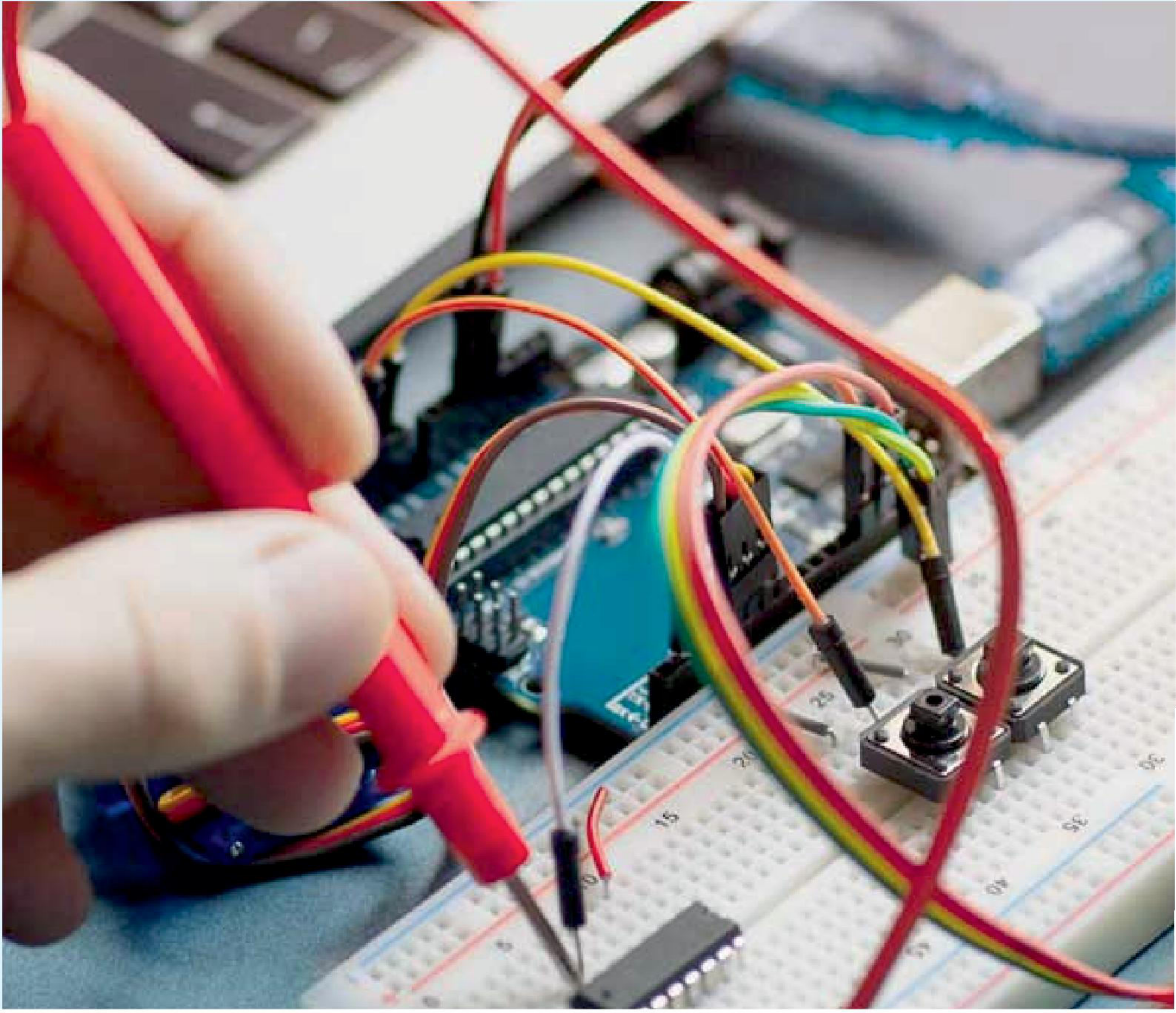

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