ISSN 2229-5518

Critical Factors Facing Implementation of Power Quality Program Framework: Case Study-Libyan Electrical Distribution Networks

S. S. Sultan, M. K. Darwish

Abstract— Researches and concerns in power quality (PQ) gained significant momentum in the field of power electronics systems over the last two decades globally. This sudden increase in the number of concerns over power quality problems is a result of the huge increase in the use of non-linear loads. The purpose of this paper is to present a statistical analysis of power quality surveys conducted in Libyan Distribution Networks. It is also to explore the obstructions faced by Libyan distribution networks in implementing a power quality program (PQP) as well as to state the benefits, which would accrue by implementing a PQP, which would make a major impact on the distribution networks. In order to achieve these objectives, an extensive literature review was conducted to understand the barriers and benefits of implementing a PQP, followed by a power quality survey questionnaire and interviews. Data were collected from Libyan distribution networks (LDNs), both from departments and individual staff members. Both SPSS 15.1 and Nvivo 9 were used in performing the analysis. The results revealed that no power quality program exists. Out of 16 barriers, 12 were statistically significant different since the P value <0.05), which indicated that Libya distribution systems have already surmounted a few of the barriers to implementing a PQP effectively. The overall benefits of PQP implementation, which would have a positive impact on LDNs, are 11 benefits. The analysis also shows the level of awareness of power quality issues with the aim of generating a power quality framework which can be used as guidelines in the field of power quality. The findings of this paper are applied to build a PQP framework guideline to be implemented in LDNs. The PQP framework is consisted three essential phases. Phase one designed to increase the awareness level. Phase two is involved in preparation of PQP, which contains seven crucial requirements. Phase three is designed to prevent the outstanding problems from phase 1 and 2 of not reoccurring again to determine both the weaknesses and obstacles facing the implementation. The progress of this framework and moving through from phase to other will be depended on the level of awareness, knowledge, skills gained respectively after each phase performed.

Index Terms— Power Quality Surveys, Statistical Analysis, PQP Barriers, PQP Benefits, Libyan Distribution Networks, PQP Framework guideline.

1 INTRODUCTION

Since 1980, power quality issues have been causing disturbances to distribution systems internationally, and have attracted global concern [1], [2], [3], [4]. This rapid increase in power quality issues was due to deregulation, of electrical power industry [5], [6]. Furthermore, Electronic devises are one critical factor, which have brought significantly bad power quality variations to power systems supplies [7]. Demand for electricity is another factor causing poor power quality, due to the poor network design, which does not accommodate for economic growth [8] . Lack of awareness of the concept of power quality is one more aspect, which propagated power quality events. As a result, since the early 1990s, tackling these events has been a priority for utilities [9], [10]. Therefore, these issues considered as essential concerns for both the utilities and users [11], [12], [13]. Nowadays, these issues have driven both the electrical companies and end users to pay more attention for better understanding of power quality problems [14], [15]. Hence, some utilities describe power quality as critical to business, and have started to implement different programs to solve the problems [16]. The target is to determine the actual level of power quality differences, and the main sources within distribution systems. On the other hand, some electrical companies believe that it is not an area of concern. This is due to the fact they do not anticipate rapid growth of non-linear loads in the future [17]. However, it seems that there is a lack of understanding regarding the causes of these problems. Both electrical companies and end users' views are different [18]. Some electrical companies are forced to solve these problems due the huge number of complaints received from end users and also due to the large costs associated with poor power quality (for example: insurance claim) [19].

A large number of publications have been analyzed in this study to provide a comprehensive review of power quality surveys regarding the implementation of Power Quality Programs (PQPs) in the USA and Europe. However, recent studies [20], [21] shows that some countries like north of Africa and the Middle East are predicting to have a huge growth in power generation, transmission and distribution. This growth is not matched by similar growth in power quality awareness programs. This paper focuses mainly on the power quality survey in one of these fast growing North African countries (Libya).

The rapid growth of the Libyan economy began in 1999 [22]. Therefore, since the early 1999, tackling power quality events has been a priority for Libyan distribution networks (LDNs) [23]. Thus, the increase in peak load was not as rapid as it is nowadays; it was 5,964 MW in 2010, and expected to increase to 18,417 MW by 2025 [24]. Moreover, the level of power delivered was not at its worst level, this is mainly because sensitive equipment's were not yet introduced widely before 1999.

2 Power Quality Programs (PQPs)

PQPs are particularly successful in developed countries rather than developing countries, due to the rapid adoption of sophisticated technology, as well as the higher level of PQ awareness among most of the end users, who recognize its importance. Furthermore, power suppliers in developed regions are trying to establish a high level of PQ standards in a short time, due to pressure from large industrial customers, as the use of sophisticated equipment increases [25].

In contrast, utilities in less developed countries are being pushed by the introduction of new technology from developed countries to improve and address their PQ issues. In response, some distribution companies have contracted a third party to solve PQ issues for their end users satisfaction; this is due to the inability of their engineers and technicians, who lack the skills and experience to solve these problems [17]. Therefore, government-controlled utilities are detached from the situation with regard to PQ issues. The failure to implement PQPs by some distribution utilities in developing countries have resulted in their supplying free power to their customers.

The distribution utilities in less developed countries are not worried about the quality of the power they provide to their clients. They believe that PQ has matured to the point, where it will not be of any importance in the future; moreover, their customers want only to be supplied with electricity, and are not concerned over quality [26]. Therefore, managers from distribution companies have concluded that some international electricity companies view implementing PQP as a business, rather than concerning themselves with issues of power distribution systems [17].

This study is the first to investigate the barriers and benefits of PQP within Libyan distribution systems. It contributes by providing an insight into the overall efforts needed to implement PQP framework and the main reasons underlying its failure. LDNs are among those systems facing poor power quality in under-developed countries. Unfortunately, statistical data show that in the last two decades, LDNs have not implemented power quality program [24]. This is mainly because there is no power quality department established yet, to influence the measurement of power quality disturbances (PQDs). This absence of a power quality department is due to lack of awareness on the part of top management regarding the importance of power quality. As a result, LDNs have faced very significant difficulties in implementing PQP. In addition, lack of power quality awareness has led LDNs to face twelve significant difficulties through not implementing PQP [23], [27].

Four main factors of PQP barriers were determined from this study, namely; lack of awareness (lack of staff awareness, skills and experience, lack of end users' awareness, lack of customer cooperation, lack of long-term strategy and planning); lack of top management attention (lack of top management commitment, lack of network designing, lack of infrastructure for distribution networks, lack of continuing research and study, lack of top management responsibility); lack of resources (lack of training courses and support, lack of financial resources, lack of enough incentives); lack of power quality involvement (lack of PQ measurement, lack of PQ consultants, lack of PQ standards, lack of PQ databases).

3 Barriers to Implementing a PQP

Since 1980, PQ issues have been causing real and significant disturbances to the distribution systems and end users worldwide, becoming a global concern, [28], [29], [30]. Hence, the lack of awareness of PQ could result in utilities still suffering from PQ problems caused by end users' sensitive equipment for industrial, agriculture, residential and commercial [14]. Therefore, providing sufficient introduction, definitions and explanations for the most widespread PQ terms, will help in identifying the more common PQ disturbances that occur. Moreover, those producing or using the power, in particular in less developed countries, should understand what PQ means.

The reason is that as long as the concept of PQ is misunderstood by both the staff of the electrical distribution company and the end users, then the severity of PQ issues will increase every day, because the demand for power will increase and even double [31].

Several authors and researchers have determined different aspects of barriers according to their experience and their studies on the implementation of PQP.

A study in the UK revealed eight major categories of PQP barriers: lack of staff awareness regarding PQ issues; lack of enough resources; lack of PQ training courses; lack of top management committed to implementing good PQP; lack of long-term strategy for successful implementation; lack of end users' awareness; lack of PQ standards and lack of regular maintenance [32].

A study conducted by Ghatol and Kushare found two aspects of PQP barriers in less developed countries; lack of network designing; and lack of end users' awareness regarding power quality [33]. A survey in the USA, conducted for the North American Delivery Systems found two barriers to PQP implementation; lack of customer cooperation i.e. illegal connection made by end users; and lack of top management responsibility to face customer complaints [16]. A study in a Massachusetts distribution system found three barriers to PQP implementation; lack of PQ standards; lack of cooperation by end users; and lack of management commitment regarding end users' complaints [34].

A study by EPRI in the USA pointed out nine components of PQP implementation barriers; lack of top management commitment, support and encouragement; lack of skills, knowledge and experience among engineers' and technicians; lack of proper teams to analyse PQ disturbances; lack of training courses; and lack of a PQ database [35]. Another study in the USA, Asia, Africa, Australia, South America and Europe revealed a lack of power quality awareness among end users; and lack of PQ training courses [17]. A further study in the USA revealed two barriers believed to hinder the successful implementation of PQP; lack of a utilities distribution structure; and lack of suitable management structure and operation [21].

A study in Malaysia found that five barriers to implementing a PQP were a ; lack of education programs; lack of PQ awareness and guidelines; lack of training courses and support; lack of continuing research and development; and lack of financial incentives to encourage the staff to resolve PQ issues [36].

A survey conducted in 8 developed European countries, namely; Austria, France, Italy, Poland, Portugal, Slovenia, Spain and the UK; found that a lack of end users' awareness; lack of employee awareness and skills; lack of management commitment; and lack of PQ measurements and maintenance are the main barriers to PQP implementation. These factors have led to huge economic losses in Europe, exceeding €150bn annually [37]. Another survey in Europe found that the main difficulties encountered during the implementation of PQP are lack of PQ awareness among top management, engineers and end users; lack of network designing, due to increased power demand; lack of PQ standards; lack of PQ measurement [38].

A study in Canada revealed that three main factors impede the wider spread of PQPs; lack of PQ consultants; lack of PQ standards; and lack of PQ awareness on the part of end users [2].

A study in the Netherlands found five significant difficulties in implementing PQP, namely; lack of a distribution networks infrastructure; failure to handle end users' complaints so as to identify the underlying problems; lack of PQ contracts between suppliers and end users; increasing sensitive electronic equipments; lack of PQ training courses to raise the education and awareness levels of engineers to understand consumers' complaints better [39].

Another study in Germany found twelve barriers to PQP implementation; lack of distribution network designing, structure and size; lack of data on end users' load characteristics and structure; inadequate background and experience among employees regarding PQ; lack of PQ standards; lack of PQ measurement; lack of management planning and strategy [16].

A study in India found two major barriers to PQP implementation; lack of PQ measurement; lack of PQ awareness and skills among employees [40]. A second study in India found four significant categories of PQP barriers; lack of planning and designing the distribution network; lack of proper PQ teams; lack of PQ monitoring and databases to analyze customer complaints; and lack of PQ standards [41]. In Pakistan, a study found that lack of understanding PQ disturbances is a major obstacle to the implementation of a PQP to be achieved [42].

A study conducted by Moncrief, Dougherty, Richardson, and Craven found five main barriers to PQP implementation; lack of end users' awareness; lack of PQ equipment standards; lack of PQ awareness among employees; lack of PQ monitoring and databases regarding end users' complaints as a form of assistance to the utilities; lack of PQ measurements [43]. A study in Latin America found three barriers encountered during the implementation of PQP; lack of PQ monitoring and datasets; lack of PQ standards; lack of PQ employee' awareness and experience [44].

A study in Brazil found seven factors as the main barriers to PQP implementation; lack of distribution networks infrastructure; lack of studies and research; lack of distribution network design; lack of management planning; lack of technician and engineer skills and experience; lack of end users' awareness; lack of a clear strategy [45]. Table 1 shows the different and similar barriers by the above researchers.

TABLE 1

THE DIFFERENT AND SIMILAR OF POWER QUALITY PROGRAM DISCERNED BY THE ABOVE RESEARCHERS

Barriers	Country
lack of staff awareness, skills and experience	USA, European, India, Latin America, Brazil, Germany, Pakistan, Austria, France, Italy, Poland, Portugal, Slovenia, Spain and UK,
lack of enough resources	USA, UK
lack of top management commitment	USA, Massachusetts, Austria, France, Italy, Poland, Portugal, Slovenia, Spain and UK,
lack of long-term strategy and planning	USA, Brazil, Germany, UK
lack of end users awareness	USA, Asia, Africa, Australia, South America and Europe, Canada, Brazil, Austria, France, Italy, Poland, Portugal, Slovenia, Spain and UK,
lack of network designing	USA, European, India, Brazil, Germany
lack of training courses, and support	Malaysia, USA, Asia, Africa, Australia, South America and Europe, Netherlands, UK
lack of conducting research and studies	Malaysia, Brazil
lack of financial incentives	Malaysia
lack of customer cooperation	USA, Massachusetts
lack of top management responsibility	USA, Netherlands

lack of PQ standards	Massachusetts , European, Canada, India, Latin America, Germany, UK
lack of PQ measurement	India, USA, Germany, Austria, France, Italy, Poland, Portugal, Slovenia, Spain, UK,
lack of PQ consultants	Canada, India, USA
lack of DNs infrastructure	Netherlands, Brazil
lack of PQ monitoring and database	India, USA, Latin America
lack of regular maintenance	UK, Austria, France, Italy, Poland, Portugal, Slovenia, Spain

4 Power Quality Survey in a Distribution Network

Some of the power quality disturbances include: harmonics, short interruptions, long interruptions, voltage sags & swells, under voltage, over voltage, flicker & unbalance, transient & surge, low power factor and voltage collapse. These disturbances are considered in the statistical analysis presented in this paper. Results obtained from the survey indicate the current status of power quality supply in Libyan distribution utility staff's point of view. Almost 400 responses have been provided by one of the 3 major distribution networks, indicating opinions of the level of power quality among both residential, agriculture, commercial and industrial users.

The survey was mainly aiming:

1. To investigate the main reasons underlying power quality phenomena leading to power quality disturbances in Libyan distribution networks.
2. To identify the most significant factors, that would make a major impact on implementing power quality program in LDNs.
3. To develop a framework as guidelines through which LDNs could maintain and improve the power supply in terms of quality for its customers.

5 Research Method and Survey Instrument

In Libyan distribution networks, empirical research is required to categorize and underline the barriers and benefits of PQP in the context of a distribution utility, which has not implemented power quality programs in the last two decades. The knowledge and results obtained from this study will guide Libyan distribution networks implementing PQP framework, including all departments and staff, who are directly responsible for remedying power quality disturbances, in tackling any power quality problems by setting up clear and long-term strategies, with crucial objectives and serious barriers. Therefore, the implementation of power quality program requires great attention from the top management to assist the distribution networks to achieve their goal of offering and providing a power quality program in practice [46]. The above literature review helps the researcher to understand the different barriers to PQP implementation and the expected benefits of PQP.

The questionnaire was sent to head managers, middle managers, engineers, technicians and employees, with total number of 540 copies and it conducted in April-June 2009. Of 540 copies, 441 copies were returned, of which 397 were appropriate for data analysis, giving a response rate of 81%. The data were analyzed by using Statistical Package for Social Science (SPSS) software, version 15.0.1.1.

In addition, 44 face-to-face interviews conducted in this study to investigate why there were barriers to PQP implementation. The interviewees consisted of head managers, middle managers, engineers, technicians and employees from four departments, mainly those dealing directly with power quality issues. These were Planning, Training, Distribution, and Customer departments in LDNs. After the interviews conducted the data were transcribed and coded by using NVivo 9 [47]. Table 2 shows the 16 PQP Barriers.

TABLE 2

LIST OF POWER QUALITY PROGRAM BARRIERS

No	PQP Barriers
BA1	lack of staff awareness, skills and experience
BA2	lack of end users awareness
BA3	lack of customer cooperation
BA4	lack of long-term strategy and planning
BA5	lack of top management commitment
BA6	lack of network designing
BA7	lack of distribution networks infrastructure
BA8	lack of conducting research and studies
BA9	lack of top management responsibility
BA10	lack of training courses, and support
BA11	lack of financial resources
BA12	lack of enough incentives
BA13	lack of PQ measurement
BA14	lack of PQ consultants
BA15	lack of PQ standards
BA16	lack of PQ monitoring and database

Table 3 shows the type of distribution networks along with the categories of end users involved in the study. Large distribution networks were considered to have more categories of end users; the western distribution network (WDN1), southern-west distribution network (SWDN2) and eastern distribution network (EDN4); whereas small distribution networks had 1 to 2 categories of end users; the central distribution network (CDN3) and southern-east distribution network (SEDN5).

TABLE 3

TYPES OF DISTRIBUTION NETWORKS

Distribution Networks	Residential	Commercial	Industrial	Agricultural

WDN1	√	√	√	
SDN 2	√		√	√
CDN3	√	√		
EDN 4	√		√	√
SDN 5	√			√

6 POWER QUALITY SURVEY RESULTS

One of the points, which was clear, is that there was no power quality awareness program which can at least match the sudden growth in the economy. In response to this, there was significant need to conduct a power quality survey. It is revealed that lack of power quality awareness is the main issue. As a result of that, lack of awareness was found among the four main categories: Top management, Engineers, Technicians and End users. These are the people who suppose to solve Power Quality Disturbances (PQDs) or at least to be aware of the PQDs. These issues are seen as very crucial and fundamental requirements before start mitigation power quality disturbances.

6.1 Main Sources of PQ Disturbances

A summary of the main sources of the PQDs carried out by the survey is illustrated in Fig. 1.

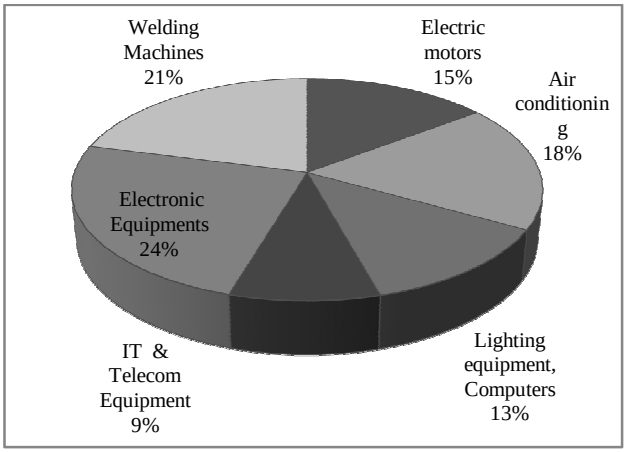


Fig. 1. Sources of PQ Disturbances - by responses %

The figure shows that electronics equipment is the largest source of PQDs. Although electronic equipments can be seen as a small load compare to, say, air conditioning loads; the disturbances generated by electronic equipments is extremely large with total harmonic distortion reaching 200% [31]. All loads shown in Fig.1 are non-linear loads and it is these types of loads which are in the increase.

6.2 PQ Disturbances

Table 4 illustrates the most common PQDs as seen by the people working within the surveyed power distribution network. It shows the industrial/commercial and residential figures as well as the total. In general the table shows that all PQDs are taken seriously (they are all above 25%). In addition, table 4 indicates that around 79% of the participating respondents refer to Long Interruptions as one of the elements which causes PQDs, due to heavy loads such as the Artificial River Project and random private agriculture using large induction motors are connected to this network. Southern distribution network is only fed by one side of the transmission lines, which are driven far away from Alkhoms generation plants from the north to the south. As a result, the end users in this network are connected via different substations by transmission lines over a long distance, very far away from the generation source. For this reason, a 400 KV line was constructed and connected to this network to overcome the problems due to the long transmission distance. However, problems still persisted after the new line was introduced. It is also due to huge numbers of air conditioning units used, especially in summer. Many end users operate their air conditioning using "illegal" connections due to the un-satisfaction of the quality of electricity supplied. In addition, citizens started private agriculture projects, as water can be found at less than 30m below ground. They started cultivating the desert without consideration of the network capacity and the impact their activities would have on power quality. As a result, the network lacks sufficient efficiency and ability to provide good power quality to all sectors, including residential, artificial river, and private agriculture projects. All these projects appeared after 1999 economic blockade, led to major PQDs in the network.

TABLE 4
COMPARISON OF POWER QUALITY DISTURBANCES BETWEEN TWO DIFFERENT CATEGORIES

PQ Disturbances	Industrial & Commercial	Residential	Total
Harmonics	25%	26%	51%
Short Interruptions	29%	25%	54%
Long Interruptions	45%	34%	79%
Voltage Sags & Swells	44%	30%	74%
Under voltage	43%	26%	69%
Over Voltage	33%	27%	60%
Flicker & Unbalance	27%	25%	52%
Transient & Surge	30%	30%	60%
Voltage Collapse	32%	-	32%
Low Power Factor	36%	28%	64%

From table 4, this was clear evidence that both residential and industrial & commercial end users were affected due to long destination of transmission lines. It also due to a number of aspects being combined with varying user's categories and equipment categories in the network. Consequently, as shown in table 4, the unsatisfaction of the end users about poor power quality rose sharply since 1999.

6.3 Consequences of poor power quality

Table 5 shows the most important consequences appeared due to poor power quality between the two categories industrial and commercial, those close to 50% of all

consequences, which are defined as the most significant interrupts by the respondents. The major common consequences occurred in industry group are Transformers / cables overheating, Motors / process equipment damaged, Computers / electronics equipment damaged, and Relays & Contacts tripping, which effects on the operating process . The major elements different from the industry reported are Relays & Contacts tripping, Computers lock up, Computers / electronics equipment damaged , Data loss and Lights flicker for commercial.

TABLE 5

CONSEQUENCES OF POOR POWER QUALITY BETWEEN TWO DIFFERENT CATEGORIES

Consequences of poor power quality	Industrial	Commercial
Relays & Contacts tripping	36%	54.1%
Computers lock up	29%	56.6%
Computers / electronics equipment damaged	44%	43%
Data loss	32%	39%
Motors / process equipment damaged	54%	26%
Transformers / cables overheating	63%	29.5%
Lights flicker	27%	42.8%
Circuit breakers tripping	30%	19%

6.4 PQ Disturbances Measurement

Figure 2 illustrates the measurement history period for the power quality program in the past. It shows that approximately 56.6 % of respondents, who were surveyed, were not aware if there was PQP implemented to measure PQDs. This indicates that most of the engineers, technicians and head managers are not fully aware of power quality problems as a result of not being aware of the importance of it. Whereas approximately 26 % of respondents were knew about PQDs as a result of being aware of definitions of power quality.

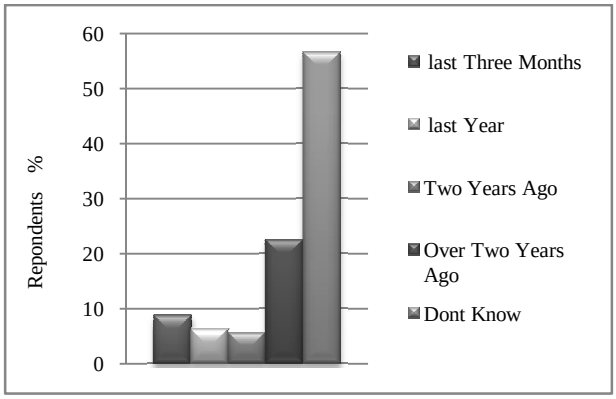


Fig. 2. PQP- by responses %

6.5 PQ Monitoring

Figure 3 illustrates the type of experts, who solved power quality problems in past measurements history.

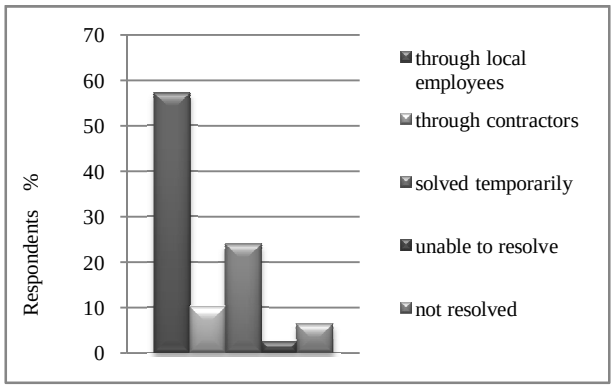


Fig. 3. PQ Monitoring - by responses %

Roughly 60 % of respondents identified that power quality problems were solved by local engineers and technicians, whereas 11 % of the respondents indicated that the problems were solved by contractors. From Fig 2, the engineers and technician surveyed predicted that they were aware of PQDs. It shows that the majority of the respondents (52.4%) comprising the educational qualification of high diploma degree, which considered as minimum education level. In order to deal with power quality events this level of education would felt to enable them to cope with the current level of severity of power quality. As a result, engineers and technicians are needed to be better educated and trained to be able to deal with power quality issues and found the urgent and appropriate solutions that decrease the disturbances. However, Figure 2 shows that almost 56.6 % of all the respondents were not aware of it in terms of definitions and problems.

6.6 Causes of PQ Disturbances

Figure 4 shows the most common group causing power quality problems. Lack of PQ awareness is considerably seen as the highest significant factor of causing the problems, where 31 % of the respondents cited that. As lack of awareness, approximately 26% of the end users connected illegally, as well as it increased the excessive use of electronic equipments, which introduced after 1999 of causing PQDs. This was due to non-linear equipments, which are very sensitive to power supply variation (long interruption 79%). In addition, lack of network designing at higher level as the third factor caused PQDs by 20 %. Therefore, the demand on the power generated has led the industries to demand and share it along with the increase demand in the domestic sector in the same line. These complex combinations required LDN to have power quality programs to make the network more efficient due to the complex interconnection [28]. Figure 4 gives more details about each aspect causes PQ issues with level of percentage by respondents.

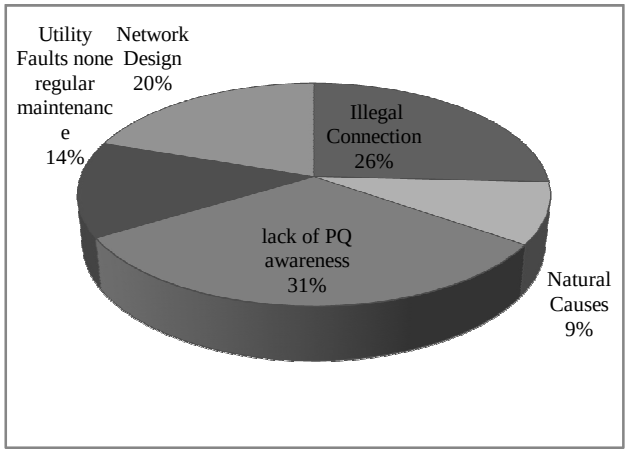


Fig. 4. Causes of PQ Disturbances - by responses %

7 PQ Survey Finding and Discussion

Data gathered by the questionnaire from the distribution system respondents were checked in terms of accuracy, outliers and, normality; then analyzed using (SPSS) software. From the survey results, it appears that, there are significantly power quality issues occurring due to lack of awareness. From the results, there was a lack of awareness regarding the infrastructure for electricity supply between the Libyan government and General Electrical Company of Libya (GECOL) in term of designing LDN. Therefore, infrastructure was not at the level where the network could absorb the increases in demand due to population increases and requirements. Hence, it is one of the real reasons of causing PQDs in LDN, which has not met and adapted to the growing demand and the increase in economic growth. This is due to its cities, villages and remote areas with small populations located far away from each other.

Customer categorization can be of assistance in resolving power quality disturbances if the LDN adopt it not only in urban areas, but also in rural areas, where many villages and remote areas with small populations suffering bad service of power quality. In addition, distribution utilities should be accommodated with varied levels of consumers. As a result, each level of users can be determined separately and easily to diagnose and resolve any issues, which lead to PQDs.

On the other hand, the industrial, commercial, residential and agriculture sectors were found to be one of the biggest users causing PQDs. This has increased power quality problems, and the disturbances are generated constantly due to lack of awareness of the importance of it.

In addition, another cause of power quality problems is highlighted to be among the employees in head managers, engineers and technicians who were not aware of these issues to deal with its sources in increasing the problems as described in Fig. 2. As a result of that both end users complaints and attitudes are raised and caused significant reactions by faulty connect to the distribution networks, which is impacted on the quality of electricity. Thus, both power quality guideline and datasets are required .This database is needed to record PQDs due to enormous use of new technology in electronic equipments , and in addition the framework is needed as guideline to increase the level of awareness for LDNs, including management, employees and end users in order to implement PQP [48].

7.1 PQP Barriers

The Varimax - rotated factor matrix summarized in table 6, which accounted for about 64 % of the total variation. The correlation matrix disclosed the presence of many items <0.5 and items higher were considered to be important. Questions BA 1-4 belong to factor 1 and can be categorized under 'lack of awareness', whereas questions BA 5-9, belong to factor 2 and are categorized as 'lack of top management attention'. Questions BA 10-12 belong to factor 3 and pertain to 'lack of resources' and finally questions BA 13-16 belong to factor 4, dealing with 'lack of power quality involvement'.

The data were measured in order to evaluate the correlations between the barriers to PQP; therefore factor analysis was performed. The Kaiser-Meyer-Oklin (KMO) measure of sampling Adequacy value was 0.82, which exceeds the recommended value of 0.6 [49] and the Bartlett's Test of Sphericity was also highly significant (Chi-Square = 4847.51 with 561 degrees of freedom, at $p<0.001$), reaching statistical significance in the correlation matrix. This implies that the factor analysis of 16 factors of PQP barriers was appropriate and confirms that all the items were statistically significant, which are judged to be an excellent validation of factor analysis.

TABLE 6
THE VARIMAX ROTATED FACTOR MATRIX

Items	Factor 1	Factor 2	Factor 3	Factor 4	Sig
BA1	0.797				0.035
BA2	0.731				0.033
BA3	0.699				0.337
BA4	0.666				0.036
BA5		0.801			0.044
BA6		0.754			0.049
BA7		0.676			0.021
BA8		0.641			0.447
BA9		0.623			0.043
BA10			0.837		0.022
BA11			0.787		0.044
BA12			0.755		0.242
BA13				0.766	0.031
BA14				0.711	0.041
BA15				0.701	0.029
BA16				0.671	0.128

The reliability test of Cronbach's α for all factors in questionnaire is 0.82. Cronbach's α above the cited minimums of 0.70 [50] is considered to be high and acceptable alpha, giving an evidence that the total Cronbach's alpha was judged

to be reliable for the questionnaire.

The ANOVA test results shown in table 6, out of 16 barriers, 12 were statistically significant different at the P value <0.05. The significant barriers are BA1, lack of staff awareness, skills and experience, BA2, lack of end users awareness, BA4, lack of long-term strategy and planning, BA5, lack of top management commitment, BA6, lack of network designing, BA7, lack of distribution networks infrastructure, BA9, lack of top management responsibility, BA10 lack of training courses and support, BA11, lack of financial resources, BA13, lack of PQ measurement, BA14, lack of PQ consultants, BA15, lack of PQ standards, and BA16, lack of PQ monitoring and database.

In addition, a post hoc Least Significance Difference (LSD) test was carried for these twelve barriers. The test found that large distribution networks WDN1, SDN2 and EDN4 faced some particular barriers compared to other small distribution networks in LDNs. SDN2 faces three factors; F1, lack of awareness, F2, lack of top management attention, and F4, lack of PQ involvement, whereas WDN1 and EDN4 face F1, lack of awareness, F4, lack of PQ involvement and F3, lack of resources. As a result, it can be in referred that Libya's distribution systems have so far struggled to implement PQP effectively.

7.2 Interview Results

Table 7 shows the twelve difficulties discussed in the interviews, which are similar to what were obtained from the questionnaire. These results indicate that LDNs have not implemented PQP. It showed that the top management has not paid enough attention, support, commitment and responsibility to setting up long-term strategies to implement PQP. Therefore, LDNs have lost LD 464 million annually due to poor power quality and the failure to implement PQP [51].

TABLE 7

BARRIERS TO PQP FROM ANALYSIS OF THE INTERVIEWS

Barriers	Head Managers	Middle Managers	Engineers	Technicians
BA1	4.5%	69.85%	12.64%	13.01%
BA2	2.85%	56.26%	20.38%	20.51%
BA4	3.9%	60%	17.18%	18.92%
BA5	7.56%	56.68%	17.91%	17.84%
BA6	2.32%	71.44%	16.12%	10.12%
BA7	17.64%	50.1%	16.93%	15.33%
BA9	6.12%	76.75%	17.13%	0%
BA10	16.53%	44.35%	3.72%	35.4%
BA11	2.53%	58.26%	7.5%	31.71%
BA13	0%	95.27%	0%	4.73%
BA15	3.08%	83.28%	2.91%	10.73%
BA16	8.81%	64.18%	16.67%	10.34%

In addition, most of members of staff involved in improving PQDs are middle managers, 52.4% of who held of high diploma qualifications, which is considered the minimum educational level. This means that they are not highly knowledgeable and aware enough to cope with the current severe level of power quality as well; moreover, this level of education would not enable them to understand and participate in implementing PQP. Almost 38% of engineers and technicians have between 6 and15 years of experience, but lack awareness and skills. They should be better taught and trained before they can deal with PQDs improving.

8 PROPOSED PQP FRAMEWORK

Multivariable Linear Regression (MVLR) was conducted to identify which factors have significant impact on PQP implementation [52]. An acceptable model was developed on the basis of these factors. It is clear that all these factors are significantly correlated, since all p values are less <0.05 and are substantially affected by the lack of awareness of the implementation of PQP in Libyan distribution networks as shown in Fig. 5.

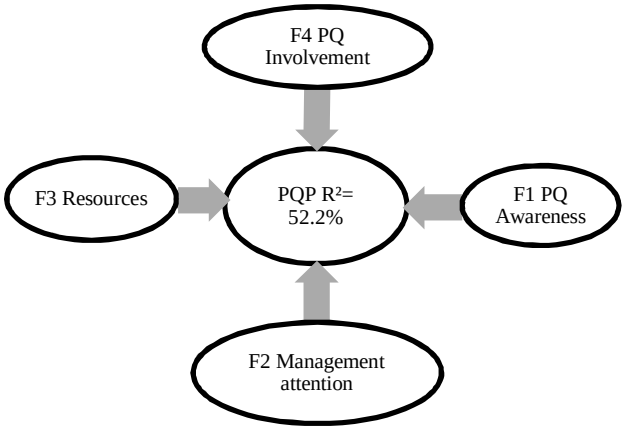


Fig. 5. Power Quality Program Model for LDNs

Table 8 shows the value of R^2 as 52.2% for this model, which indicates how much of the variability in the outcome is explained by the predictors. This also indicates that the validity of this model is very good. Consequently, this model can be accepted and applied for LDN to implement PQP, since all the predictors increase by one unit (see β value). It also indicates that the two factors most highly affected by lack of PQ awareness are F2 (β=34.5%) and F3 (β=31.6%). As a result, the regression analysis shows that the linear relationship between the outcomes, which is PQP, is explained by the model and predictor factors.

TABLE 8

REGRESSION RESULTS OF POWER QUALITY PROGRAM FACTORS

Scale	β	Std .Error	t	P	R^2	Cronbach's alpha
F1	0.202	0.031	4.538	<.001	0.522	0.811
F2	0.345	0.041	7.573	<.001		0.841
F3	0.316	0.029	8.097	<.001		0.806
F4	0.171	0.028	4.427	<.001		0.851

8.1 A Roadmap for Power Quality Program framework

The PQP framework is consisted three essential phases. Phase one designed to increase the awareness level. Phase two is involved in preparation of PQP, which contains seven crucial requirements. Phase three is designed to prevent the outstanding problems from phase 1 and 2 of not reoccurring again to determine both the weaknesses and obstacles facing the implementation, to reach a high level of power quality. Therefore, PQP framework is influenced by top management's awareness, which must move from studies and recommendation to practice. This framework is designed as a guideline for implementation of PQP in the Libyan distribution networks environment. The progress of this framework and moving through from phase to other will be depended on the level of awareness, knowledge, skills gained respectively after each phase performed. Fig. 6 shows the three phases of the proposed model PQP of framework.

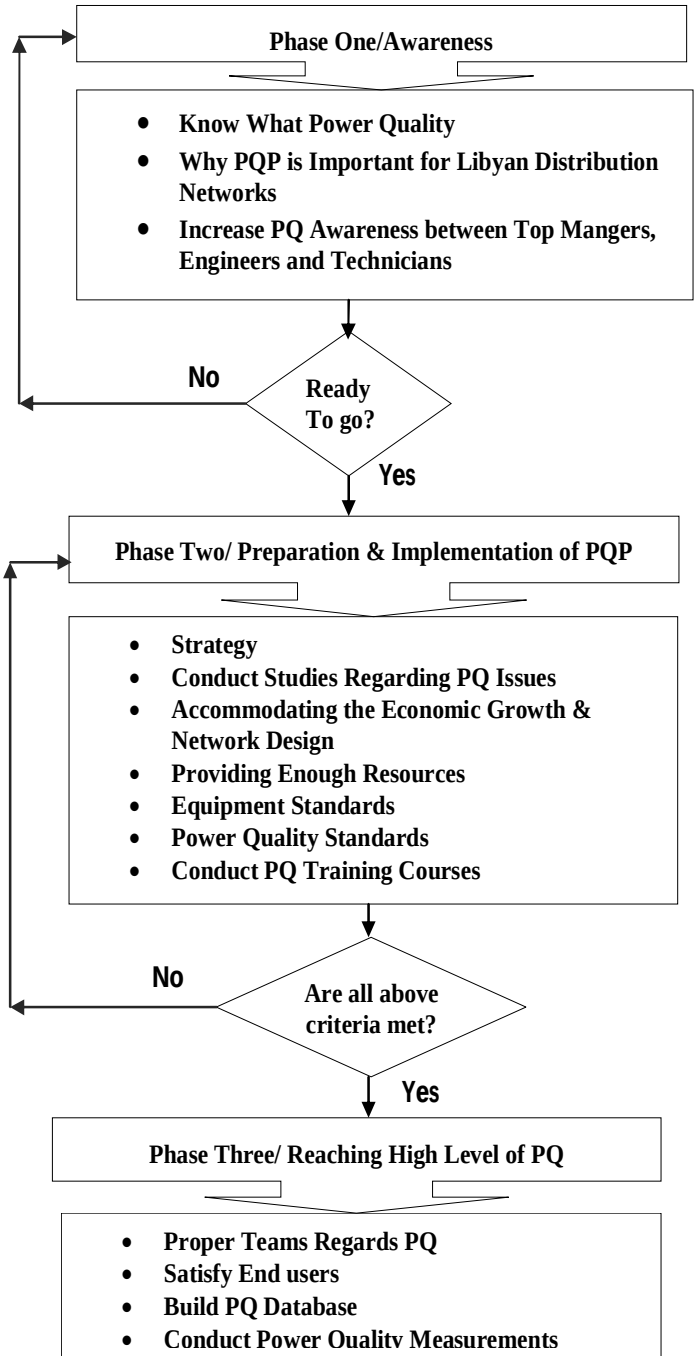


Fig. 6. Flow chart of PQP frame work

8.2 Phase One Power Quality Awareness

Phase one is the fundamental of PQP. The purpose of this stage is to increase the awareness level regarding power quality program. The top management must be endorsed by paid more attention to reach the high level of understanding to prepare clear objectives , along with clear strategy for successful implementation of power quality program. This phase a waking up the top management to be eager and enthusiastic to start performance the program based on the staff level of both knowledge and awareness after understand the importance of PQP and its features. The expected output of phase one is shows in Fig. 7.

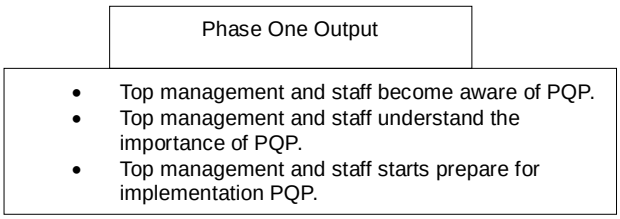


Fig. 7. The output of phase one

8.3 Phase Two Preparation & Implementation of PQP

Phase two is in conjunction with phase one. After the top management becomes aware and understands the importance of PQP, then this phase will enhance the distribution networks to start the implementation for PQP. The most important requirements of this stage is that the top management must set clear and long term strategic to continue built PQP to become one of Libyan distribution networks culture. One of the top management responsibilities is to develop and provide the needs of this phase to reach the high level of power quality program cross its networks. This step symbolizes the most critical factors of this framework and requires both top management commitment and employee's participation for PQP implementation in Libyan distribution networks as success factors. The expected output of phase two is shows in Fig. 8.

No	DN1	DN2	DN3	DN4	DN5	Overall
BN1	3.84	3.96	3.45	3.27	3.8	3.66
BN2	3.91	3.56	3.54	3.73	3.53	3.65
BN3	3.65	3.68	3.54	3.64	3.4	3.58
BN4	3.51	3.52	3.68	3.51	3.47	3.53
BN5	3.48	3.48	3.82	3.53	3.33	3.52
BN6	3.73	3.56	3.67	3.49	3.46	3.58
BN7	3.52	3.48	3.49	3.55	3.66	3.54
BN8	3.76	3.88	3.82	3.77	3.93	3.83
BN9	4.25	3.31	3.75	3.53	3.48	3.66
BN10	3.43	3.68	3.73	3.25	3.52	3.52
BN11	3.48	3.66	3.61	3.52	3.56	3.56

Fig. 8. The output of Phase Two

8.4 Phase Three Reaching High Level of PQ

Phase three would facilitate Libyan distribution networks determine both the weaknesses and obstacles facing the implementation of power quality program. The previous two phases are designed to prevent the outstanding problems of not reoccurring again. The goal of implementing PQP framework is to increase the awareness level to practice and perform PQP framework practically with great attention from the top management. It also Focus on end users needs and satisfy them by considering their complaints in everyday process. Power quality improvements should be conducted by proper teams to measure and analysis power quality disturbances by building PQ database to monitor, measure, analysis and compare it to PQ standards. Fig. 9 shows the output of phase three.

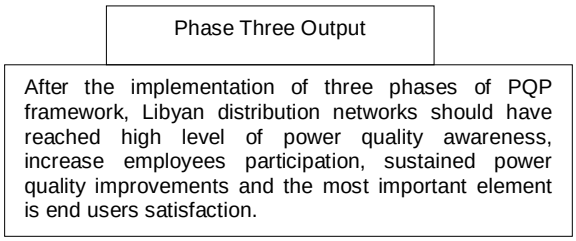


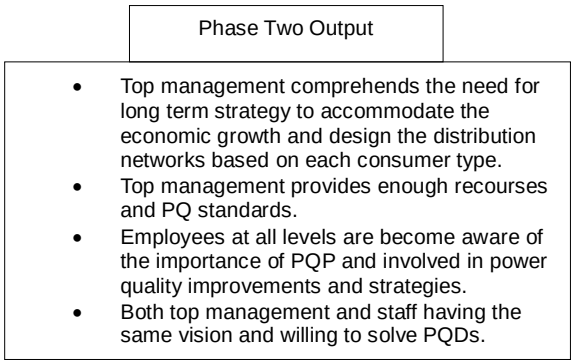
Fig. 9. The output of Phase Three

8.5 PQP Benefits

The overall results of PQP benefits are presented in table 9, which would have a positive impact on increasing end users awareness, increasing their satisfaction, improving PQ performance, reducing end users' complaints, monitoring and measuring PQ disturbances, providing PQ diagnosis systems and databases, reducing the huge losses through PQ costs, increasing top management awareness, increasing the employees' skills and awareness, increasing PQ training courses and providing strategic planning in LDNs.

TABLE 9

LIST OF POWER QUALITY PROGRAM BENEFITS OF SURVEY RESULTS



9 Conclusion

Significant power quality surveys and studies were critically reviewed to determine the critical factors regarding the implementation of PQPs. A power quality survey was conducted in LDNs west, east and south, networks as example one of distribution utilities in less developed countries. The survey provided various conclusions about occurrence of PQ issues, their sources and equipment affected LDNs. The results showed that most power quality issues were due to lack of PQ awareness and knowledge on part of Libyan distribution staff and customers. The rapid economic growth was a very significant factor, which has caused huge PQDs in LDNs after 1999. Statistical data also show that in the last two decades, LDNs have not implemented power quality program. This is mainly because there is no power quality department established yet, to influence the measurement of

power quality disturbances (PQDs). This absence of a power quality department is due to lack of awareness on the part of top management regarding the importance of power quality. This study also reveals poor implementation of PQP in LDNs. As a result, lack of power quality awareness has led LDNs to face twelve significant difficulties through not implementing PQP. According to qualitative analysis, this gap will continue if PQP barriers are not tackled.

One of the main challenges in implementing PQP is to link all the difficulties with both its objectives and strategies set by all departments. Hence, the implementation difficulties should be regularly assessed to identify the hidden reasons associated and causing poor implementation. Thus, without adequate knowledge, awareness, planning, designing, preparation, training, power quality standards, clear strategy, and most important the support of top management for this program, power quality disturbances will never end and their severity will affect all consumers.

The large distribution networks WDN1, SDN2 and EDN4 faced some particular barriers, unlike the smaller distribution networks in LDNs. SDN2 faces three factors F1, lack of awareness, F2, lack of top management attention, and F4, lack of PQ involvement; whereas WDN1 and EDN4 face F1, lack of awareness, F4 lack of PQ involvement and F3 lack of resources. The result of this is that Libya's distribution systems have struggled so far to implement PQP effectively. In general, the finding shows that LDNs suffer the four factors of PQP barriers. These four factors appeared in USA, European, India, Malaysia, Latin America, Brazil, Germany, Pakistan, Austria, France, Italy, Poland, Portugal, Slovenia, Spain and UK.

Approximately 75 % of the interviewees stated that there was no power quality program implemented in the past. From the questionnaire only 26 % of engineers, technicians and head mangers were aware of power quality problems, while 56.6% were not aware. In response to this, new model for PQP framework is developed and proposed for LDN. The regression was sufficiently representative to conclude that the relationship between the model and the depended variables of power quality awareness is very strong and not accident. PQP implementation was found to have 11 benefits, which positively will impact on LDNs to improve power quality disturbances. They are needed because LDNs have not yet implemented PQP due to the failure to establish power quality departments.

REFERENCES

[1] B.W. Kenedy, Power Quality Primer. USA: McGraw-Hill, 2000.

[2] N. Labricciosa. A case study of power quality enhancement in an electrical distribution system. 1996.

[3] R.C. Dugan, M.F. Mcgrranahan, S. Santoso, H.W. Beaty. Electrical Power System Quality (Second ed.) 1996.

[4] E. I. Ortiz-Rivera, "Study of power quality: Problems in commercial buildings in Puerto Rico," in Electric Utility Deregulation, Restructuring and Power Technologies, 2004. (DRPT 2004). Proceedings of the 2004 IEEE International Conference on, 2004, pp. 301-305 Vol.1.

[5] M. H. J. Bollen, "What is power quality?" Electrical Power System, vol. 66, pp. 5-14, 2003.

[6] T. K. K. Forsten. Security, quality, reliability and availability: Metrics definition: Progress report. EPRI. USA. 2005.

[7] M. McGranaghan, D. Brooks, D. Mueller. EPRI reliability benchmarking application guide for Utility/Customer PQ indices: Guide for utilizing the EPRI reliability benchmarking, methodology power quality indices and customer specific indices as service quality benchmarks. EPRI. USA. 1999.

[8] S. S. M. R.S. Vedam. Power Quality VAR Compensation in Power Systems (1st ed.) 2009.

[9] M.H.J. Bollen, Understanding Power Quality Problems "Voltage Sags & Interruption". USA: John Wiley & Sons Inc, 2000.

[10] D. Kottick. Electrical power quality & utilization magazine, power quality monitoring System—Voltage dips, short interruptions and flicker. 3(2), pp. 2. 2008.

[11] W.M. Grady, A.H. Noyola, D. Dorr, P. Nelsen. Results of power quality surveys in the united states: End user and utility perspectives. Presented at Power Quality Business Analyzer Survey Progress Report on PQ Costs. 2000, [EPRI].

[12] I. Chung, D. Won, J. Kim, S. Ahn and S. Moon, "Development of a network-based power quality diagnosis system," Electr. Power Syst. Res., vol. 77, pp. 1086-1094, 6, 2007.

[13] T. K. Abdel-Galil, E. F. Ei-Saadany and M. M. A. Salama, "Effect of new deregulation policy on power quality monitoring and mitigation techniques," in Transmission and Distribution Conference and Exposition, 2001 IEEE/PES, 2001, pp. 554-560 vol.1.

[14] J. V. Milanovic and M. Negnevitsky, "Power quality problems and solutions: Current understanding," in Harmonics and Quality of Power, 1998. Proceedings. 8th International Conference on, 1998, pp. 30-35 vol.1.

[15] L. Freeman, M. Marshall, R. Walling and J. Weiss, "Loss characteristics of local-delivery distribution systems," in Electricity Distribution - Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on, 2009, pp. 1-4.

[16] J. Meyer, P. Schegner, G. Winkler, M. Muhlwitz and L. Schulze, "Efficient method for power quality surveying in distribution networks," in Electricity Distribution, 2005. CIRED 2005. 18th International Conference and Exhibition on, 2005, pp. 1-4.

[17] A. Barnard, A. Van Voorhis. Investigation utility-based power quality programs: Domestic and international perspectives. EPRI. USA. 2000.

[18] B.B. Angelo, Handbook of Power Quality. Italy: John Wiley & Sons Ltd, 2008.

[19] M. R. Wadi, M. F. Bara, O. Carlson and K. M. Elarroudi, "Voltage stability analysis for the south-west Libyan electrical power system: Problem simulation and analysis," in Universities Power Engineering Conference (UPEC), 2009 Proceedings of the 44th International, 2009, pp. 1-5.

[20] O. S. Al-Abaidi, A. B. Bendardaf, "Upgrading the local area network of the 220kV libyan eastern network control center," in Transmission and Distribution Conference and Exhibition: Asia and Pacific, 2005 IEEE/PES, 2005, pp. 1-4.

[21] J. G. D. L.A. Schienbein. Distributed energy resources, power quality and reliability –Background. PACIFIC NORTHWEST NATIONAL LABORATORY. USA. 2002.

[22] A. H. Hadod. Libyan electrical power sector. GECOL. Tripoli, Libya. 2009.

[23] B. T. M. Elobadi, "Power quality report: Voltage profile," GECOL, Tripoli, Libya, 2009.

[24] General Electrical Company of Libya, "Annual report," GECOL, Tripoli, Libya, 2009.

[25] G. Nicholson, "Investigation of Data Reporting Techniques and analysis of Continuous Power Quality Data in the Vector Distribution Networks," 2006.

[26] D.F. Warne. Newness Electrical Power Engineer's Handbook (2nd ed.) 2005.
[27] M. A. Mousa, I. M. Saleh Ibrahim and I. M. Molokhia, "Comparative study in supplying electrical energy to small remote loads in Libya," Renewable Energy, vol. 14, pp. 135-140, 8, 1998.
[28] J. Arrillaga, M. H. J. Bollen and N. R. Watson, "Power quality following deregulation," Proceedings of the IEEE, vol. 88, pp. 246-261, 2000.
[29] O. GUL, "An Assessment of Power Quality and Electricity Consumer's Rights in Restructured Electricity Market in Turkey," Istanbul Technical University, Istanbul, vol. XIV, pp. 29-34, 2008.
[30] Z. J. Paracha, S. A. Qureshi, "Application OF Power Quality Management Techniqes and Methods In Power System of WAPDA PAKISTAN," vol. 4, pp. 1813-419, 2007.
[31] B. E. Kushare, A. A. Ghatol, "Power quality characteristics of industrial electric distribution systems," Institute of Engineering Education & Research, Nashik, India, 2008.
[32] Ph. Ferracci, "Power quality," Cahier Technique Schneider Electric, UK, Tech. Rep. 199, 2001.
[33] G. D. N. Aniruddh. Technical report on power quality management. Electrical and Electronics ENGG. USA. 2003.
[34] B. H. S. McNulty. Power quality problems and renewable energy solutions, analysis of the prospects for renewable PQ solutions in massachusetts. Massachusetts Renewable Energy Trust. USA. 2002.
[35] C. M. D. Dorr. Power quality for satisfied commercial and residential customers field test plan: Monitoring residential power quality. EPRI. USA. 2000.
[36] M. A. Hannan, A. Hussain, A. Mohamed and R. A. Begum, "Methodological Framework for Industrial Flicker Severity Assessment and Awareness," Australian Journal of Basic & Applied Sciences, vol. 4, pp. 5578-5583, 11, 2010.
[37] J. M. R. Targosz, "Pan-european power quality survey," in 9th International Conference on Electrical Power Quality and Utilisation, EPQU 2007, 2007, pp. 1-6.
[38] H. De. Keulenaer, "The Hidden Cost of poor Power Quality," pp. Leonardo Energy, European Copper Institute, 2003.
[39] W. T. J. Hulshorst, E. L. M. Smeets, and J. A. Wolse, "Premium power quality contracts and labeling," Work package 2 of the Quality of Supply and Regulation project, Netherlands, Tech. Rep. 30620162-Consulting 07-0401, 2007.
[40] U. K. Deshpande, P. A. Chitre, "Total power quality management in a large distribution system: A case study national seminar on "Total power quality management"," Mumbai, India, 2009.
[41] N. Rajmani, "ELECTRIC POWER QUALITY: SOME TECHNICAL AND COST PERSPECTIVES " Global Energy Consulting Engineers, INDIA, Tech. Rep. 265, 2008.
[42] S. A. Qureshi, F. Mahmood, Z. J. Paracha, S. A. Kashif, "POWER QUALITY DISTURBANCES IN POWER SYSTEMS AND COMPARISON OF DEVELOPED COUNTRIES STANDARDS," Electrical Engineering Department, UET Lahore, Pakistan, vol. 4, 2007.
[43] W. Moncrief, J. Dougherty, L. Richardson, K. Craven, "Power quality applications guide for architects and engineers," EPRICSG, Palo Alto, CA, USA, Tech. Rep. 113874, 1999.
[44] B. C. A. Abreu, "Power quality site survey process for regulated electricity market," in Transmission & Distribution Conference and Exposition: Latin America, 2006. TDC '06. IEEE/PES, 2006, pp. 1-6.
[45] R. J. R. Gomes, D. O. C. Brasil and J. R. de Medeiros, "Power quality management issues over the brazilian transmission system," in Harmonics and Quality of Power, 2002. 10th International Conference on, 2002, pp. 27-32 vol.1.
[46] W. E. Kazibwe, R. J. Ringlee, G. W. Woodzell and H. M. Sendaula, "Power quality: a review," Computer Applications in Power, IEEE, vol. 3, pp. 39-42, 1990.
[47] D. Silverman, Ed., Interpreting Qualitative Data. Thousand Oaks, California: Sage, 2006.
[48] A. Eberhard, Ed., POWER QUALITY. Croatia: InTech Janeza Trdine 9, 51000 Rijeka, 2011.
[49] A. P. Field, Ed., Discovering Statistics using SPSS: (and Sex, Drugs and Rock'n'Roll). London; Thousand Oaks: SAGE Publications, 2005.
[50] J. C. Nunnally, I. H. Bemstein, Psychometric Theory. New York: McGraw-Hill, 1994.
[51] B. A. Hamilton, "Strategic plan corporate objectives; business, functional unit plans, financial model and lessons learned," GECOL, Tripoli, Libya, 2006.
[52] H. M. S. Chandana Herath, V. J. Gosbell, S. Perera and D. Stirling, "Power quality survey factor analysis using multivariable linear regression (MVLR),"

in Harmonics and Quality of Power, 2008. ICHQP 2008. 13th International Conference on, 2008, pp. 1-5.

Authors' information

Saad S. Sultan is PhD Student with the Department of Electronic and Computing Engineering, Brunel University, Uxbridge, UB8 3PH. UK (e-mail: Saad.Sultan@brunel.ac.uk).

Mohamed K. Darwish is a Senior Lecturer in Power Electronics with the Department of Electronic and Computing Engineering, Brunel University, Uxbridge. UB8 3PH, UK. (e-mail: Mohamed.darwish@brunel.ac.uk).