Power quality assessment of large industrial plant, case study and remedy suggestion

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The growing use of non-linear loads distributed along power systems makes these systems more vulnerable and presenting power quality problems in supplying energy to consumers. Electric authorities are more eager than ever to discuss this problem with utility customers, either to prevent customers from exceeding power quality limits or to apply remedies to harmed customers. This paper presents the results of power quality monitoring of large industrial plant after receiving a concern from the supplying utility. Solutions were also recommended and designed for locations that violated Standards limits.

ان تنوع الأحمال الكهربائية مع بداية العصر الحديث وادخال نبائط الكترونيات القوى أدى الى تشويه شكل وسلوك القدرة الكهربائية المستخدمة فى المصانع وأصبحت شركات توزيع الكهرباء تطالب بضرورة دراسة هذا التشوه لتحديد تجاوزات الحد المسموح به فى الشبكة الكهربائية لهذا التشوه ومن ثم يمكن بحث الحلول الممكنة. فى هذه الدراسة تم القياس عمليا لجميع نمطيات الموزعات الرئيسية لشركة مصانـــــــع النحاس المصرية ودراسة وتحليل و تقييم هذه النتائج بالقياس بالمواصفات القياسية ومن ثم اقتراح وتصميم المرشحات المناسبة للتغلب على هذا التشوه.

Keywords: Power quality, Harmonics, Filters

1. Introduction

Good voltage regulation and power quality are essential to the efficient and reliable operation of sensitive electronic loads. Some types of equipment can be adversely affected by the voltage quality on the distribution system. Utility power quality standards address regulation of the delivered voltage and the quality of the delivered power determined by the *cleanness* of the sinusoidal voltage and current waveforms at the point of delivery. On the other hand some types of equipment and their use in a customer's facility can adversely affect the current and voltage on the distribution system so that sensitive equipment connected to the same circuit or equipment of a nearby customer does not function as it was designed. For example, a dip in voltage caused by a customer starting a motor can cause an adjacent piece of microprocessor-controlled equipment to malfunction or shut down. Sensitive utility equipment is vulnerable as well [1].

power quality standards establish recommended practices for monitoring [2], events classification [3], and limits for power quality indices [3, 4], which when met, allow facilities containing power sensitive and power disturbing loads to operate with a minimum interference to utility equipment or customer loads.

This paper presents the results of power quality monitoring of a case study of "Egyptian Copper Works Company", a large industrial plant located in Alexandria, Egypt, based on a request from Alexandria Utility Company to ensure its compliance to the standards. All points of common coupling (PCC's) were monitored for four days and data were analyzed, checked against limits. Also, corrective filters were designed and recommended.

2. Existing power system layout

Egyptian Copper Works Co., situated at Hagar-Al Nawatieh, Alexandria, is one of the largest metallurgical plants in Egypt. It was established in 1935 with a small factory on an area of 4050 m^2. Today after establishment of many factories, extended on an area of 567000 m^2. The company contains steel plant, non ferrous plant, dolomite and oxygen plants. These are fed from 5 medium voltage distributors (11 kV) which are located inside the company. Those in turn are fed from 2 utility substations, one of them are 66/11 kV and the other is 33/11 kV. Fig. 1 shows a single line diagram for the distribution system with loads and supplies.

3. Power quality monitoring

The aim of the study was to monitor power quality at points of common coupling and at non linear loads. Monitored locations are marked in fig. 1. Compliance to IEEE 519 and IEC 61000 standards is then determined, which leads to identification of corrective actions needed. The duration of measuring procedure is 4 days in every location (7 distributors), one record every 10 minutes, in addition to events recording. Data measured and recorded included Volt, Current, Apparent Power, Active Power, Reactive Power, Power factor, % Total Harmonic Distortion (THD) factor for voltage and current, % Individual voltage harmonic at max load and min load and max V.THD, % Individual current harmonic at max load and min load and max I.THD, Voltage variation, Voltage unbalance, Frequency deviation, Voltage sag, overvoltage and voltage swell, Short time flicker and long time flicker.

4. Results and analysis

Dranetz PP-4300 harmonic analyzer was used, measuring results are presented in table 1.

4.1. Steel distributor (monitoring point 1)

This distributor load is mainly a 2MVA induction furnace which consists of a 6 thyristors converter, smoothing circuit, and 1600 Hz thyristorized inverter. Moreover, the load includes an inductance- capacitance resonated circuit used for steel melting.

The results show the reactive nature of the load (1205 kVA, 1175 kVAR), this is due to the resonant capacitance- inductance cricuit in the load. The rich 5^{th} and 7^{th} harmonic currents (30%, 10%) are also expected due to converter operation. Although the third harmonic current (20%) was not expected, this may be due to unbalance in the converter-inverter bridge or in the feeding transformer itself, or even due to unbalance in the feeding cables which may occur due to unsymmetrical geometrical arrangement of these cables. Through site inspection it was found that the feeding cables were asymmetrically arranged. The load violates both short term and long term flicker limits. This is due to the melting process and the intermittent current drawn by the furnace. The measured harmonic voltages (3.52%), frequency deviation (0.14%), voltage unbalance (0.63%), voltage sags (1), voltage swells (0) do not violate standards limits which means stiff supply. This is verified by a relatively high short circuit level (500 MVA) [5].

Fig. 2 shows both current and voltage harmonic spectrum for maximum load. As a general conclusion, the cell 44 distributor suffers the presence of high 3^{rd}, 5^{th}, and 7^{th} harmonic currents which need to be eliminated by tuned filters.

4.2. 25 Ton distributor (monitoring point 2)

The load here is a 3 MVA arc furnace, which creates high currents to melt the steel via phase to phase short circuit through scrap-steel. Only 2 phases are in S.C. case and the third phase is out then one phase is going out and another going in to create another phase to phase S.C. between the 2 phases. It is a reciprocated action.

The tabulated measured even and odd harmonic currents and voltages are expected due to spark of short circuit. Spark is a rectangular pulse on time domain, in frequency domain it creates infinite number of frequencies multiple of fundamental with variable amplitudes. Also, short term and long term flickering is due to high rate of switching, arcing and shorted circuit current. The major power measured is active, this is due to scrap steel acts as a resistance. Again, the measured frequency deviation, voltage unbalance, voltage sag, voltage swell within limits due to the stiffness of the supply network. Fig 3 shows both current and voltage harmonic spectrum for maximum load. The requirement here would be band pass current harmonics filters.

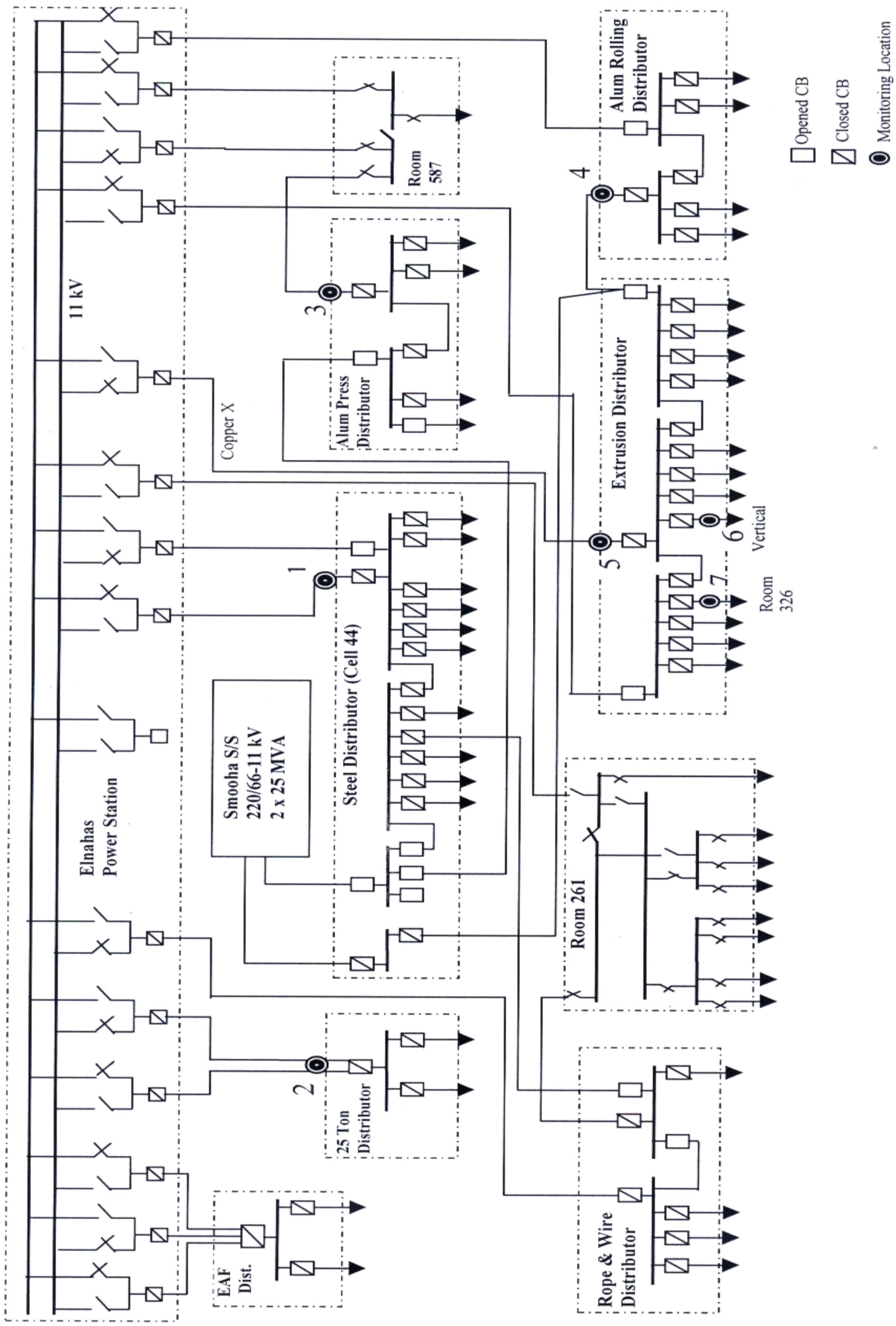
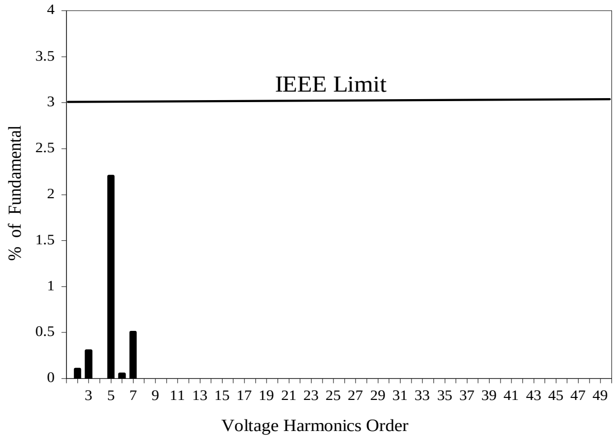


Fig. 1. 11 kV layout for Egyption Copper Works Co.



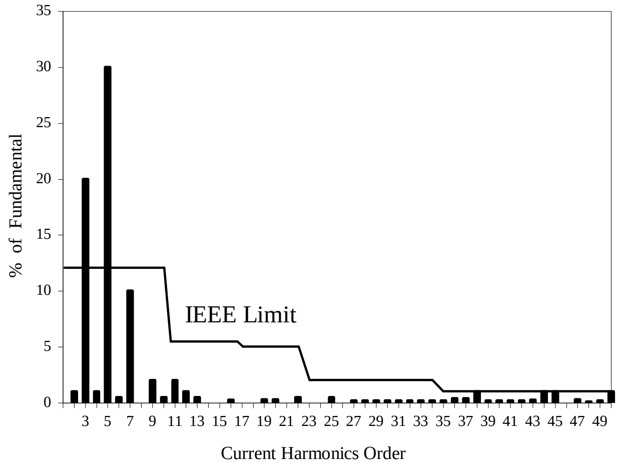
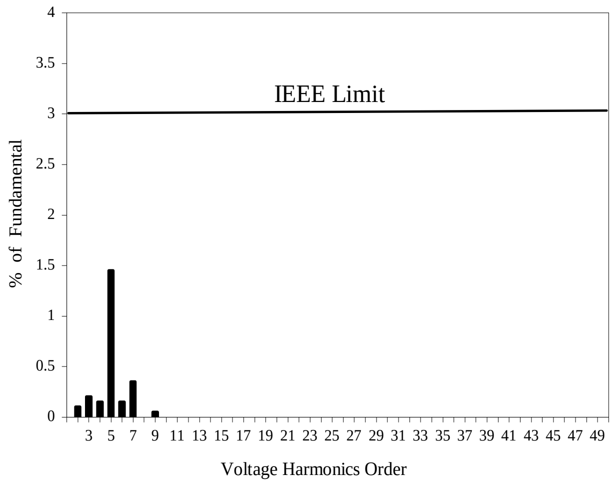


Fig. 2. Harmonic currents and voltages for "Steel" distributor.



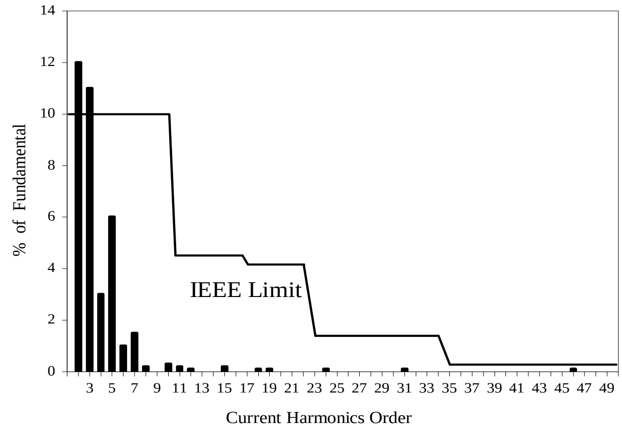


Fig. 3. Harmonic currents and voltages for "25 Ton" distributor.

4.3. Aluminum press distributor (monitoring point 3)

The load here was rougher machines (320 kVA), three dc 4 quadrant motors (72 kVA), 4 quadrant operation finisher (200 kVA), four reheating furnaces (320 kW), and approximately 100 kW DC multiple machines.

The noticed low max current (48.4A) was due to non operation of most of the plant. However, more than (108) thyristors in operation are enough to create harmonics out of allowances. kVAR range (334 to -349) is due to converter - inverter mode of operation in dc motors. Negative sign for kVAR is due to quick break of D.C motors and so change from converter mode to inverter mode. Power factor lied between (1.00 to -0.44) due to four quadrants operation. Short term flickering is over limit (1.47%) due to high rate thyristor switching. Fig. 4 shows the harmonic spectrum for both voltage and current at maximum load. As a general remark, there is no need to any harmonic filter for this distributor.

4.4. Aluminum rolling distributor (monitoring point 4)

The load here consists of three line casters (320) kW, thyristor derived D.C motors and auxiliaries (320 kW), three reheating furnaces (3000 A, 380 V), thyristor derived D.C rolling machine (3500 kW), compressor (300) kW, presses (100 kW), water cooling system (150 kW).

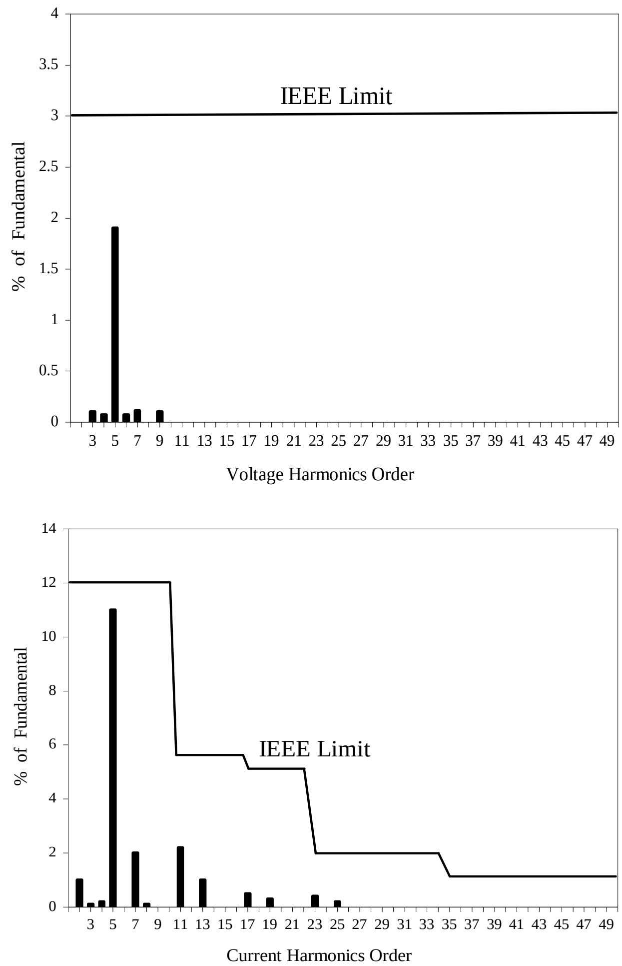


Fig. 4. Harmonic currents and voltages for "Aluminum Press" distributor.

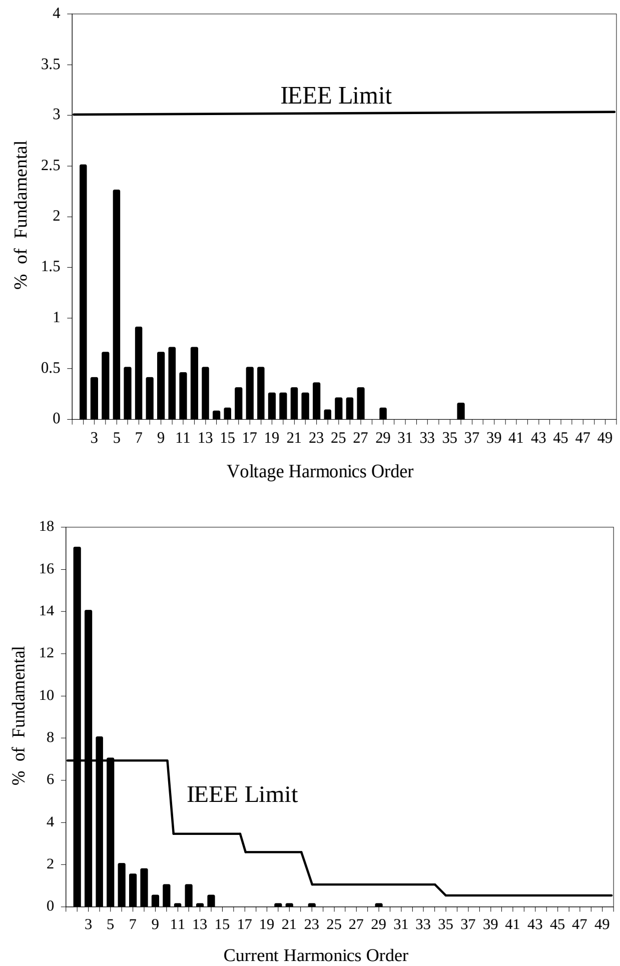


Fig. 5. Harmonic currents and voltages for "Aluminum Rolling Mill" distributor.

The reasons for odd and even harmonics generation is the inverter and converter action and continuous short spark on brushes of big D.C motors. Wide current variations (30-179A) is due to the size of the derived machines. Sags occurred twice with duration of 30 msec, this may be due to simultaneous starting for large machines. Short term flickering is over limit (1.5%) due to heavy thyristor operation. Absence of frequency deviation, unbalance, long and short interruption, over and under voltage are due to network stiffness. Fig. 5 shows the harmonic spectrum for both voltage and current at maximum load. Again, current harmonics issue needs to be addressed for this load center.

4.5. Extrusion press distributor, copper X (monitoring point 5)

The load consists of two induction furnaces 500 kW each, three synchronous motors (drive for pumps) 400 kW each, 3 drawing machines induction motor 220 kW each. Great size drawing machine induction motor, 200 kW**,** resistive reheater furnace 300 kW, inductance furnaces 900 kW, 3 inductance furnaces 250 kW each, and miscellaneous loads.

The relatively small measured value of kVAR (850) compared to higher expected operational value for induction furnace was due to capacitors fitted in induction furnace to increase current and minimize reactive power. Odd current harmonics is due to induction action of furnace and solid state drives. Even current harmonics are due to sparking action in brushes feeding exciter or slip ring resistor in large motors. The high ITHD is due to resonance action of induction furnaces. Power factor variation is small (0.9-1) since the power of the D.C drive is small compared total consumed power. Voltage second harmonic of 4% appeared at max load which indicated a possible brush sparking problem. Fig. 6 shows the harmonic spectrum for both voltage and current at maximum load. No current harmonic filters will be needed for this distributor.

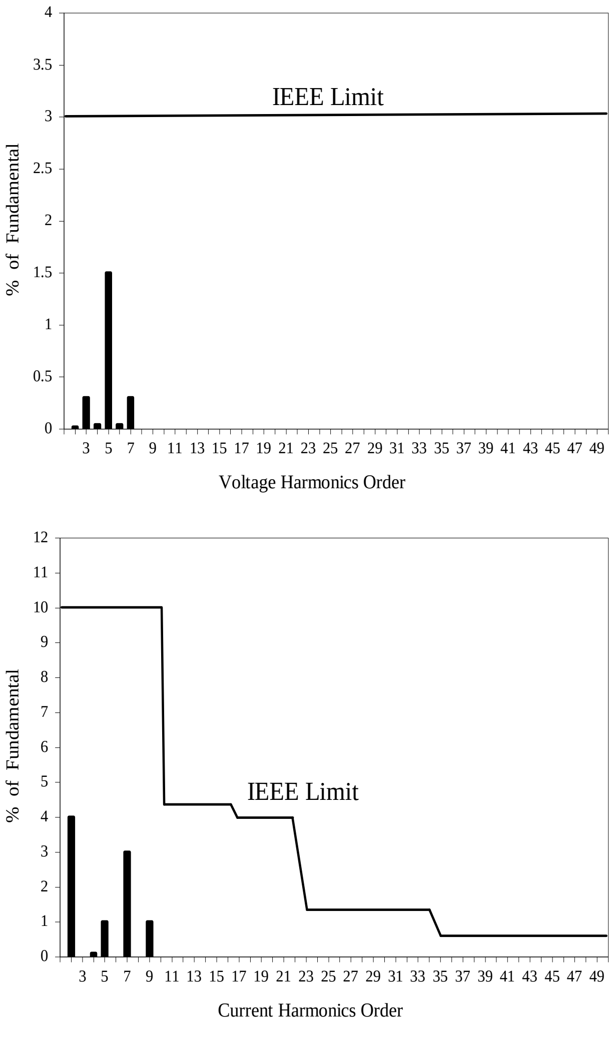


Fig. 6. Harmonic currents and voltages for "Extrusion Press Copper X" distributor.

4.6. Extrusion press distributor, vertical (monitoring point 6)

The load is 6 kV, 350 kW induction motors, one stepped induction reheating furnace 100 kW, and miscellaneous loads.

Reactive power variation (from 22 to -228 kVAR) is due to capacitors of induction furnace may be kept in connection after reheating coil power off. The high current THD (15%) is due to induction furnace action and existence of shaft sparking with motor stator. Short term voltage flickering (1.17%) may be due to both, the pulsating torque, i.e, back EMF on the 6 kV induction motor, and induction furnace action. Fig. 7 shows the harmonic spectrum for both voltage and current at maximum load. No current harmonic filters will be needed for this distributor.

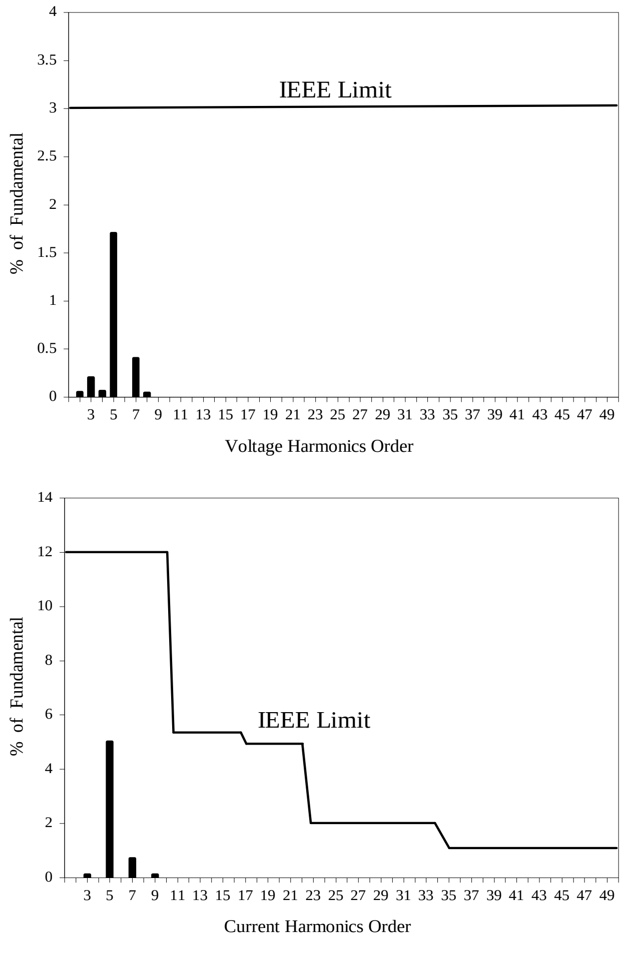


Fig. 7. Harmonic currents and voltages for "Extrusion Press Vertical" distributor.

4.7. Extrusion press distributor, room 326 (monitoring point 7)

The load here consists of Induction motor 350 kW, Reheating furnace 300 kW (resistive load), 5×100 kW induction motors, three D.C rectifiers 6 kV, 360 kVA each.

The low loading of the distributor (26.88A) was due to marketing issues. Current THD (5.4%) is small due to small loading of the rectifier (60 kW) compared to the total consumed power (476 kW). Short time voltage flickering (1.17%) is expected due to existing of 5 motors, 100 kW each with high rate of switching for the nature of the process. At max V.THD, supply fifth harmonic voltage was 12% which is high. By inspection it was found that this occurred only at night when most of big motors are out of service (third shift). Voltage rise may be the origin of this phenomenon. Sags, swells, and long term flicker are not present since there is no high rate of switching. Fig. 8 shows the harmonic spectrum for both voltage and current at max load. No current harmonic filters will be needed for this distributor.

It can be deduced from the above analysis that the supply system is relatively stiff and stable. The impact of this property and manageable level of plant caused disturbance appears as high level of voltage stability, little frequency deviation, minor voltage sags, no swells, good voltage regulation, no voltage interruption, limited over and under voltage. On the other hand, flickering and harmonic currents are noticeable phenomena in some loading centers. The counter measures necessary for mitigation need to be addressed.

5. Filters design

Passive series filters were recommended as common and simple mitigation solutions. The calculations begin with the capacitance needed to improve the power factor. Then, selection of the reactor to series tune the capacitor to the desired harmonic order. The tuned frequency is taken slightly less than the filter harmonic order (3-10%) to reduce the stresses on the filter and to avoid parallel resonance at fewer harmonics. Then, calculation of the voltage and current stresses on the elements of the filter, and finally, checking component ratings to meet these duties. POWEREX software package was used to design filters for Cell44 and Aluminum rolling distributors [6]. For cell 44 distributor, third and fifth harmonic filters were designed on the low voltage side due to the small size of the load (1.2 MVA). For Aluminum rolling distributor, second and third harmonic filters were designed. Software flow chart and results are shown in fig. 9, table 2 and 3.

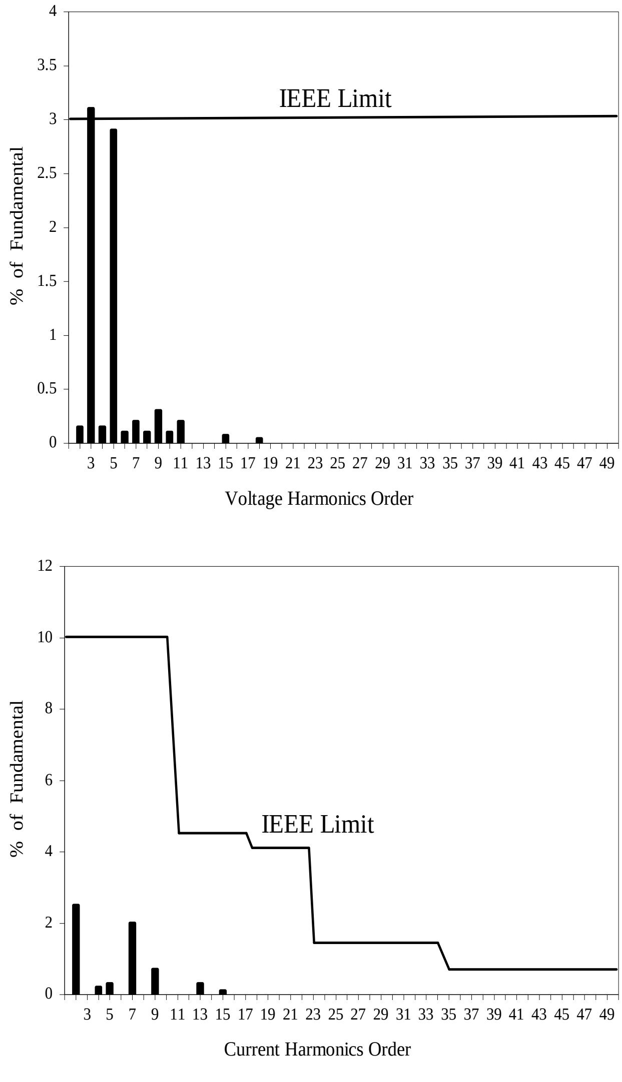


Fig. 8. Harmonic currents and voltages for "Extrusion Press Room 326" distributor.

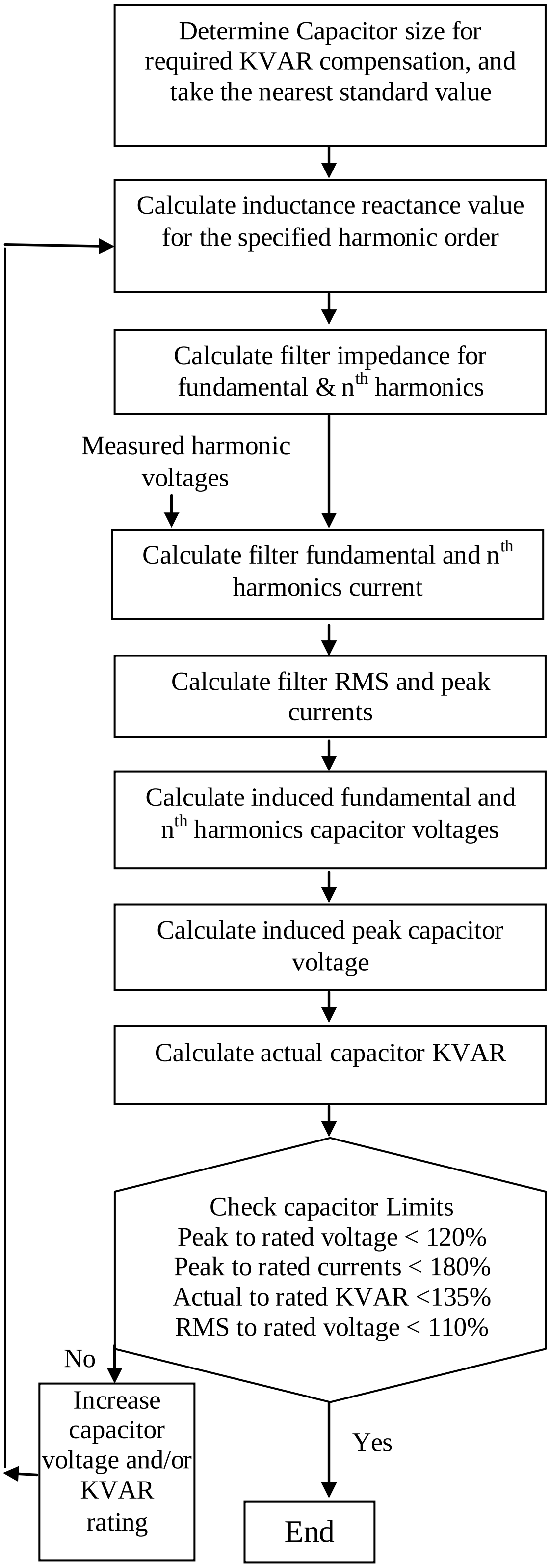


Fig. 9. POWEREX software flow chart.

Table 2
Filter design results for cell 44 distributor

Cell 44 distributor	3rd Harm.	5th Harm.
Fndamental reactor impedance	0.07 ohm	0.023 ohm
Reactor inductance	0.2235 mH	0.0738 mH
Filter resistance	0.0035ohm	0.0012 ohm
Filter capacitance	6220.14µf	6220.14µf
Fundamental filter current	496.62 A	448.81 A
Peak harmonic filter current	392.87A	590.79 A
Filter RMS current	633.23A	741.93A
** Capacitor duties**		
Rated values selected		
KVAR	450	450
Volt	480	480
Capacitor RMS current	633.23A	741.93A
Harmonic capacitor voltage	116.13V	104.78 V
Fundamental capacitor voltage	443.41 V	401.01 V
Maximum peak voltage	559.54 V	505.80 V
Maximum peak current	889.50 A	1039.61 A
** Capacitor limits: IEEE std. 18-1980 **		
Peak voltage (limit=120%)	116.57%	105.37 %
Peak current (limit=180%)	116.99%	137.07 %
KVAR (limit=135%)	111.72%	118.36%
RMS voltage (limit=110%)	95.49%	86.35 %

Table 3
Filter design results for steel B distributor

Steel B distributor	2nd Harm.	3rd Harm.
Fndamental reactor impedance	59.83 ohm	29.62 ohm
Reactor inductance	190.432mH	94.30 mH
Filter resistance	2.98 ohm	1.48 ohm
Filter capacitance	14.74µf	14.74µf
Fundamental filter current	40.66 A	34.07 A
Peak harmonic filter current	20.15 A	15.81 A
Filter RMS current	45.38 A	37.56 A
** Capacitor duties**		
Rated values selected		
KVAR	1500	1500
KVolt	18	18
Capacitor RMS current	45.3883A	37.5655 A
Harmonic capacitor voltage	3770.43 V	1971.63 V
Fundamental capacitor voltage	15217.55 V	12751.80V
Maximum peak voltage	18987.99 V	14723.44V
Maximum peak current	60.82 A	49.88 A
** Capacitor limits: IEEE std. 18-1980 **		
Peak voltage (limit=120%)	105.48 %	81.79 %
Peak current (limit=180%)	94.33 %	78.07 %
KVAR (limit=135%)	82.16%	55.97%
RMS voltage (limit=110%)	87.09 %	71.68 %

6. Conclusions

Based on a request from the local utility company, ELNAHAS WORKS Co. monitored power quality indices at points of common coupling with the utility. The monitoring process revealed acceptable voltage quality due to network stability and modest load influence. However, current harmonics outside standard limits were monitored in few load centers and local filters were recommended and designed.

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