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POWER FACTOR IMPROVMENT FOR CEMENT FACTORY

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Abstract: The cement plant contains nonlinear loads and significant harmonic sources (kiln rectifiers drives) that can flow through the plant, therefore it is necessary to treat both of the harmonics and the power factor reduction problems to improve the system efficiency, power system quality and decrease losses. This work examines the technical feasibility of designing a capacitor filter bank according the level of harmonics in the network, and also achieving improvement for the power factor (Static Compensators).The methodology used for this work is based on the practical measurements of real time operation of the electrical parameters of cement industrial facility, and then the whole system has been modelled (using MATLAB/SIMULINK). A MATLAB code is used to calculate the harmonic filter components required to design the capacitor filter to be then inserted in the simulated model in order to cross check the load operation after insertion filter component via enabling different mode of operations. Also system performance calculations are made after including the harmonic filters is to ensure the operations safety.

Keywords: *Harmonics, Cement factory, Power factor improvement.*

تعديل معامل القدرة في مصنع اسمنت

الخلاصة: يحتوي مصنع الأسمنت على أحمال غير خطية ومصادر توافقية كبيرة (مشغلات مقومات الفرن) التي يمكن أن تتدفق خلال المصنع، ولذلك فمن الضروري معالجة مشكلتي كل من التوافقيات ومشكلة انخفاض معامل القدرة لتحسين كفاءة وجودة نظام الطاقة وتقليل الخسائر فيه . هذا البحث يدرس الجدوى الفنية لتصميم مجموعة منسعات كمرشحات توافقيات وحسب مستواها في الشبكة، وكذلك تحقيق تحسن لعامل القدرة (المعوضات الساكنة) . تستند المنهجية المستخدمة لهذا العمل على القسياسات العملية المأخوذة في الزمن الحقيقي لمعاملات للكهرباء من مصنع اسمنت، وعلى ضوءذلك تم محاكاة النظام بأكمله (باستخدام ماتلاب / سيمولينك). وأخيرا تم كتابة برنامج باستخدام الماتلاب لحساب مكونات مرشح التوافقية المطلوبة لتصميم مرشح مكثف ليتم إدراجها في نموذج المحاكات من أجل التحقق من تشغيل الاحمال بعد ادراج عنصر التصفية وبتمكين نماذج تشخيل مختلفة. كما تم إجراء حسابات أداء النظام بعد تضمين المرشحات التوافقية لضمان سلامة التشغيل.

1. Introduction

The basic idea of improving the power factor is to inject the reactive power into the system in order to compensate the load demand which is loosed due to the operation of the nonlinear loads in that power system.

Many works have been done in the power factor improvement. Joseph [1] Most of mathematical work and simulation for harmonics can be represented by Fourier function.

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Markus Ahrens [2] described several approaches in the design of harmonic filters and power factor compensation installations for cement plants with help of (MATLAB /Simulink) depending on real time measurement of harmonic . Jafar H. Alwash [3] designed a single-phase boost Power Factor Correction (PFC) converter to supply an inverter-motor drive system.

Haider M.U.[4] analyzed the PFC in AL-NAJAF cement plant depending on the information of name-plates of the factory equipment and using the mathematical approach. Jain Sandesh [5] proposed switches banks to inject locally the reactive energy using MATLAB model. Finally Jabber H.Majeed [6] proposed an FPGA model of digital single phase power factor optimizer to reduce the phase shift time between voltage and current waveforms, by using simulated VHDL with FPGA kit.

The specific target of this work can be presented using the following steps:

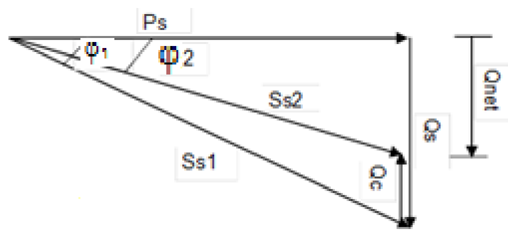
- The first step is to conduct comprehensive measurement at cement industrial facility in order to deduce the harmonics level and facility power performance quality.
- The second step is to model the power system of the cement facility using the (MATLAB/Simulink) package, and then make a cross check the obtained results with the actual measured parameters. The design is conducted with the power ratings and the filter can be run for more than one time with multiple load conditions until reach acceptable performance
- Finally the third step is to build computer program to calculate power factor capacitors for certain harmonic order tuned filtering. The performance results have been investigated with standard qualitative comparison of practical works e.g. those imposed by IEEE standard 519-1992 [7].

2. Basic Idea of Power Factor Correction

The simulation for power factor improvement is presented in "Fig. 1" where the injected reactive power required to achieve the desired value of power factor (PF_2) is Qc which can be calculated as follows:

$$\tan\varphi_2 = \frac{Q_{net}}{P_s} = \frac{Q_s - Q_c}{P_s} \quad (1)$$

$$Q_c kVR = P\,[\tan\,(\cos^{-1} PF_1) - \tan\,(\cos^{-1} PF_2)] \quad (2)$$



Q_{net} =net reactive power
Q_c =injected reactive power.
Q_s =system reactive power.
φ1, φ2 =phase shift
Ss1= total system power

Figure 1. Power Factor Improvement – Phasor Diagram

The sizing of the required reactive power can be evaluate from k- correction factor standard tables [8] for working power factor and the intended power factor. Then for this sized Qc the installation of reactive power compensators is made. In industrial facilities it is normally based on static compensators which are known as capacitor bank.

Industrial equipment uses power electronics components (variable-speed motor controllers, thyristor-controlled rectifiers, etc.) can be considered as one source of harmonics problems that may cause distortions and damages for these equipment [1] and effect on power factor of the supply network [10]. These harmonics are all relative to fundamental frequency 50 Hz (or 60 Hz) and on symmetrical 3-phase power systems are generally odd-numbered: 3rd, 5th, 7th, 9th..., with magnitude decreases as the order of the harmonic increases. Harmonics is been made out to be the distortion of electrical pollution that can cause problems if the sum of the harmonic currents increases above certain standards limits such as IEEE 519–1992 listed in [7] , IEC 61000 -2-1 presented in [9]. The total Harmonic Distortion formula (THD) [1] is :

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{N} I_n^2}}{I_f} \tag{3}$$

$$\mathrm{I_{rms}} = \sqrt{I_f^2 + \sum_{n=2}^{N} I_n^2} \tag{4}$$

Where: I_f = fundamental current; I_n= Current of nth harmonic order
I_{rms}= Root mean square value of measured current (True value)

According to the IEEE STD 519 current and voltage harmonic limits, for current must be below 10% while for voltage 6% for low voltage applications. Harmonic filters have been installed, both for power factor improvement and to meet harmonic distortion limits.

3. Cement Industry – Case Study

Briefly, the process flow diagram of the cement industry is shown in “Fig. 2”.The cement facility under this study is served by its demand via two feeders of 11 kV voltage level. Each feeder is connected to the primary side of a step down transformer of rated 6.7 MVA supply the facility loads through their secondary side.

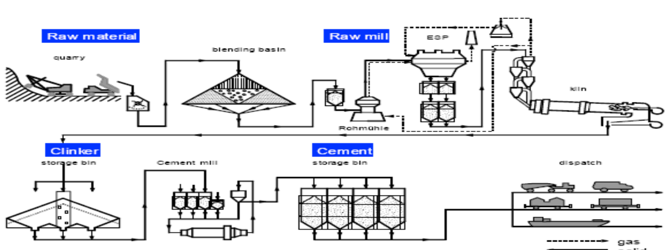


Figure 2. Cement Industry – Process Flow Diagram.

The data was collected for the major loads that have most significant affection on the plant power quality. Table 1 summarizes the data for different motors in the factory.

Table 1. Major Drive Loads of Cement Factory – Case Study

Panel	Load Identification	Load Rating	*Total (kW)*
1	Raw Material Crusher #1	1250kW ; 147A ; 1500RPM ; 6000V	2500 kW
	Raw Material Crusher #2	1250kW ; 147A ; 1500RPM ; 6000V	
2	Raw Mill Drive	2200kW ; 247A ; 1000RPM ; 6kV	6810 kW
	De-dusting- Raw Grinding	1425kW;164A;750RPM;6kV	
	Draught Fan of Raw Mill	1425kW;164A;750RPM;6kV	
	Burning – Pre-heater - Fan Motor	880kW ; 6kV ; 50 Hz ; 3 Phase ; 1151A	
	(EVS1- EVS2)	880kW ; 6kV ; 50 Hz ; 3 Phase ; 1151A	
3	Rotary Kiln - Main Drive	270kW; 671A; 100-1000 RPM; 430V DC	1482 kW
	Clinker Cooler – Fans	160kW ; 282A ; 1500RPM ; 380V	
	Clinker Cooler – Fans	132kW ; 245A ; 1500RPM ; 380V	
	Clinker Cooler – Fans	110kW ; 204A ; 1500RPM ; 380V	
	Cooler De-dusting- Gravel Filter	810kW ; 102.5A ; 750RPM ; 6kV	
4	Cement Grinding Mill #1	1675kW ; 188A ; 1000RPM ; 6kV	3850 kW
	Cement Grinding Mill #2	1675kW ; 188A ; 1000RPM ; 6kV	
	Cement Grinding - Dynamic Separator 1	250kW ; 307A ; 1500RPM ; 6kV	
	Cement Grinding - Dynamic Separator 2	250kW ; 307A ; 1500RPM ; 6kV	

It can be seen from table 1 that the panel 2 (raw mill unit) is the most loading. In order to treat the harmonics problem the feeder of kiln is chosen a dc motor (440 V) derived by the 6-pulses Full wave rectifier that generate odd numbered harmonics.

4. Real Time Measurements

The case study was made in ALMURKEB cement factory/ Libya by installing the measurement equipment on the main feeders (No.1 and No.2) of (11 kV) as well as on the

raw mill and the kiln unit. *VIP/ MK3 System 3 Energy Analyzer* is the measurements device that measures the various electrical parameters such as current, voltage, frequency, phase shift, frequency, and waveform capturing. The measurements for five consecutive days in order to get the plant load profile. The summary of measurements and the overall period is presented in Table 2.

The average current total harmonic distortion for feeders #1 and #2 is 2.3% and 3.5% respectively. The measured true value of current for feeders #1 and #2 is (61.62A/phase and 71.1A /phase respectively). The reactive power required for compensation could be calculated and tabulated in the Table (3).

Table 2. Summary of Measurement Results – Case Study

Day No.	Range	Feeder #1		Feeder #2		Total	
		Active Power	Power Factor	Active Power	Power Factor	Active Power	Power Factor
Day 1	Maximum	1289	0.81	1369	0.80	2643	0.81
	Minimum	464	0.72	510	0.68	973	0.70
	Average	933	0.77	1031	0.76	1964	0.77
Day 2	Maximum	1296	0.81	1484	0.83	2636	0.80
	Minimum	748	0.76	461	0.70	1229	0.74
	Average	943	0.78	1024	0.77	1967	0.78
Day 3	Maximum	1326	0.82	1421	0.80	2643	0.80
	Minimum	439	0.70	818	0.72	1304	0.74
	Average	931	0.77	1079	0.76	2009	0.77
Day 4	Maximum	1414	0.80	1634	0.80	3049	0.80
	Minimum	560	0.69	887	0.74	1513	0.74
	Average	1011	0.78	1200	0.77	2211	0.78
Day 5	Maximum	1106	0.80	1335	0.79	2440	0.79
	Minimum	350	0.73	375	0.69	725	0.71
	Average	704	0.77	812	0.75	1516	0.76
Overall Period	Maximum	1414	0.82	1634	0.83	3049	0.81
	Minimum	350	0.69	375	0.68	725	0.70
	Average	904	0.77	1029	0.76	1934	0.77

Table 3. Summary of Power Factor Correction – Case Study

Item Description	Feeder #1	Feeder #2
Average Demand (kW)	904	1029
Average Power Factor	0.77	0.76
Existing Reactive Power Demand (kVAr)	738	871
Desired Power Factor	0.92	0.92
Required Capacitor Bank (kVAr)	353	432

The summary of measurement with period of five days for raw mill drive is presented in the Table 4. The measurement summary of Kiln drive(for 5-days) is presented in Table 5, while the average values of different harmonic orders that were measured and tabulated in table 5. Reference to the values of harmonic currents in Table 6, the passive filters will be designed for the significant high values (5^{th}, 7^{th}, and 11^{th}).

Table 4 Summary of Raw Mill Measured Parameters – Case Study

Day No.	Measurement type	Maximum	Minimum	Average
Day 1	Active Power (kW)	1076	806	961
	Power Factor	0.79	0.62	0.72
	THD %	0.41	0.26	0.28
Day 2	Active Power (kW)	1154	806	989
	Power Factor	0.83	0.62	0.73
	THD %	0.41	0.03	0.28
Day 3	Active Power (kW)	1172	906	1005
	Power Factor	0.84	0.66	0.75
	THD %	0.37	0.25	0.28
Day 4	Active Power (kW)	1172	864	1012
	Power Factor	0.84	0.65	0.75
	THD %	0.32	0.03	0.25
Day 5	Active Power (kW)	1165	945	1054
	Power Factor	0.84	0.69	0.77
	THD %	0.34	0.03	0.26
Overall Period	Active Power (kW)	1172	806	1004
	Power Factor	0.84	0.62	0.74
	THD %	0.41	0.03	0.27

Table 5. Summary of Kiln Measured Parameters – Case Study

Day No.	Measurement type	Maximum	Minimum	Average
Day 1	Active Power (kW)	237	143	188
	Power Factor	0.87	0.81	0.84
	THD %	30.73	28.15	29.26
Day 2	Active Power (kW)	249	154	196
	Power Factor	0.88	0.82	0.84
	THD %	29.96	26.84	28.82
Day 3	Active Power (kW)	233	142	196
	Power Factor	0.97	0.81	0.85
	THD %	29.95	27.26	29.18
Day 4	Active Power (kW)	215	122	174
	Power Factor	0.86	0.79	0.83
	THD %	32.89	28.57	31.02
Day 5	Active Power (kW)	208	132	173
	Power Factor	0.86	0.80	0.83
	THD %	32.61	29.83	31.27
Overall Period	Active Power (kW)	249	122	185
	Power Factor	0.97	0.79	0.84
	THD %	32.89	26.84	29.91

Table 6 Summary measurements of different harmonic orders

Harmonic Order	Magnitude (A)
Fundamental	303
5	79
7	31
11	25
13	14
17	11
19	9

5. Computer Aided Simulation

MATLAB / Simulink and the Power System Block set were used as simulation tools to develop the system. According to the power single line diagram of the AL-MURKEB cement factory and the related data sheet the rated values of all devices models are fixed in the simulation model. The cement factory simulation model is built by design of the unit (sub-model) of each unit. Then these subsystems are gathered into whole simulation model after getting suitable calibration results over each sub-model.

5.1. Main System Power Supply

The main source of the factory power system is presented in "Fig. 3" The supply voltage is assumed to be sinusoidal. The short circuit ratio (SCR) of the system at the point of common coupling (PCC) is 6.7 MVA. The source impedance has an X/R ratio of 7. The sub system1 contain the measurement tools blocks employed to measure the main supply variations (for V=Voltage, I=current, P= active power, 3P=three phase active power , Q=reactive power, 3Q=Three phase reactive power, PT=total three phase active power , QT=total three phase reactive , PF=Power Factor as shown in "Fig. 4".

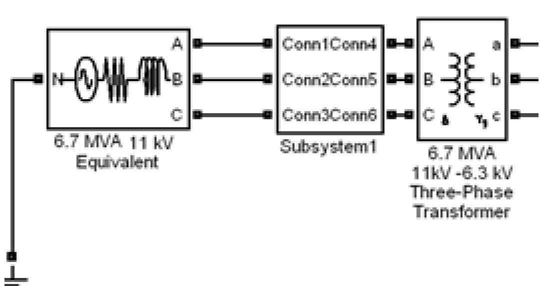


Figure 3. Main Power Supply of the Factory.

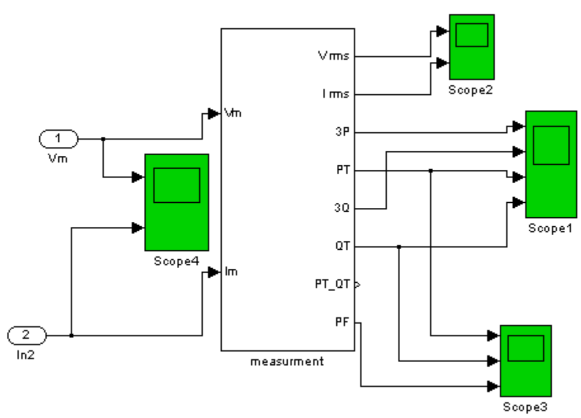


Figure 4. Measurement Block.

5.2. Kiln Unit Subsystem

The model representation of the kiln furnace is shown in "Fig. 5". Kiln Unit is mainly composed of six pulse rectifier and DC motor blocks. The specifications of DC Motor is taken from factory datasheets, also the rectifier firing angle is "29.5^{o}" as presented based on the factory rectifier data sheet.

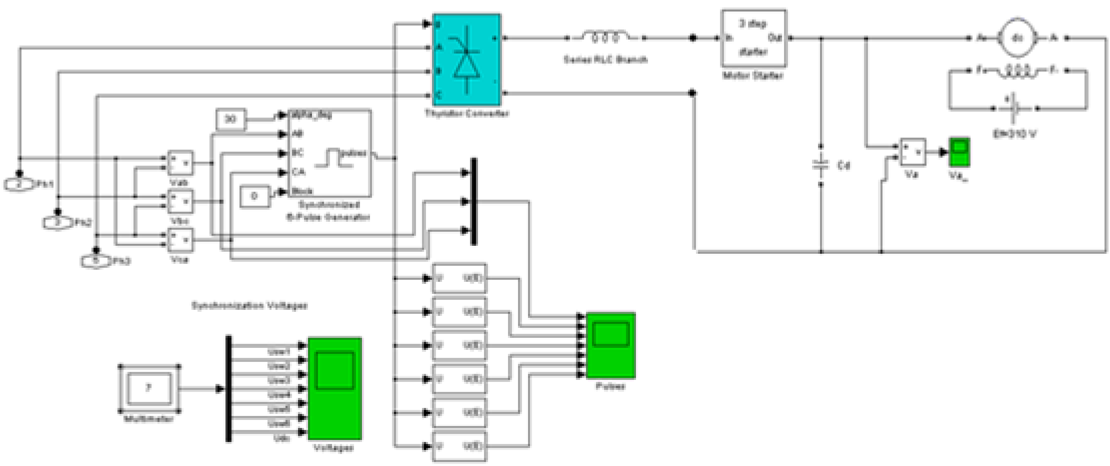
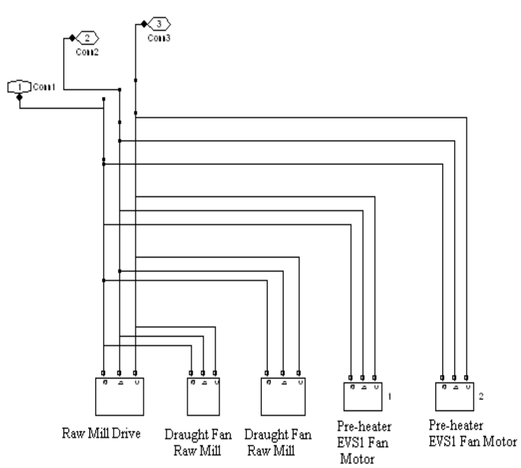


Figure 5. Rectifier Simulation Diagram of Kiln Drive.

5.3 Raw Mill Unit

Raw Mill Unit model is made up from five different rating induction motors listed on the panel 2 as listed in Table 1. (Five induction motors units) . The only different between these units is the rated values of each motor. The simulation of raw mill detail can be shown in "Fig. 6" and "Fig. 7". After testing each sub-system modeling, i.e. kiln and raw mill, the sub-systems modeling is the whole system is built as shown in "Fig. 8" .



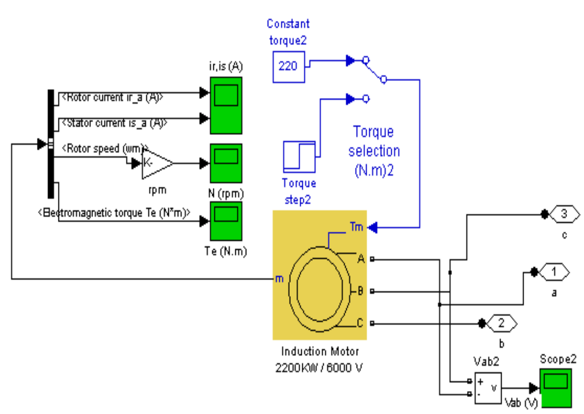


Figure 6. Raw Mill Drives simulation

Figure 7. Induction Motor simulation

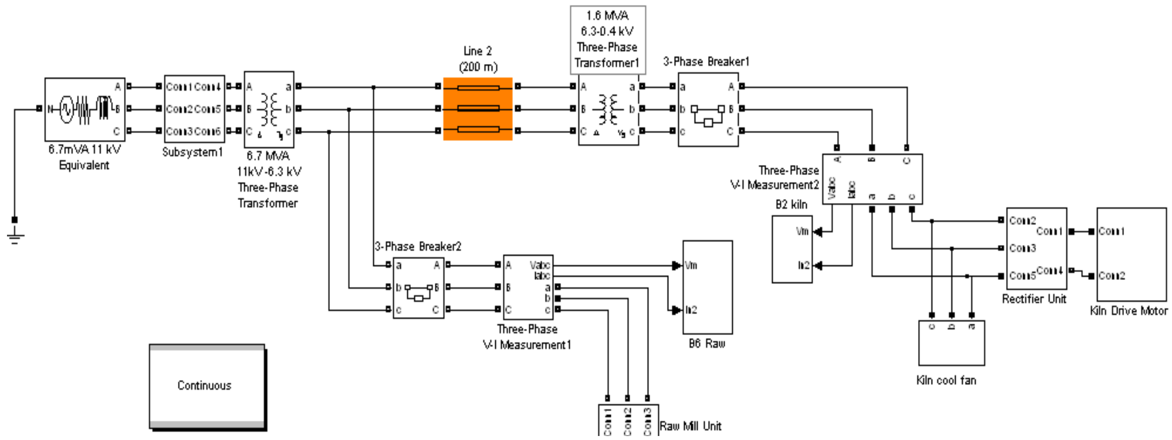
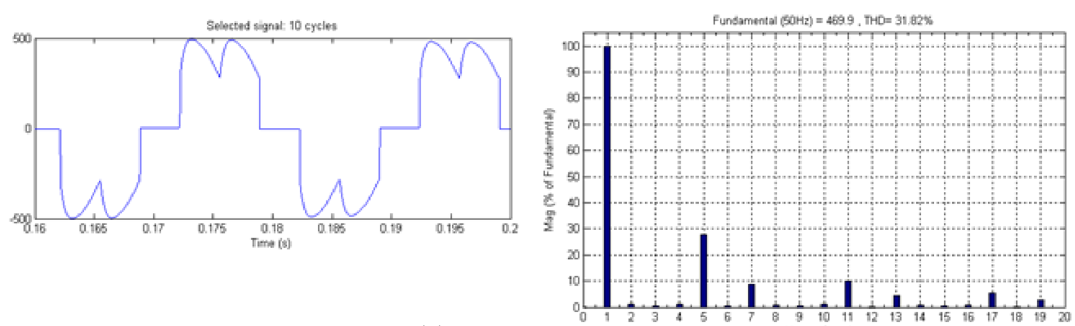


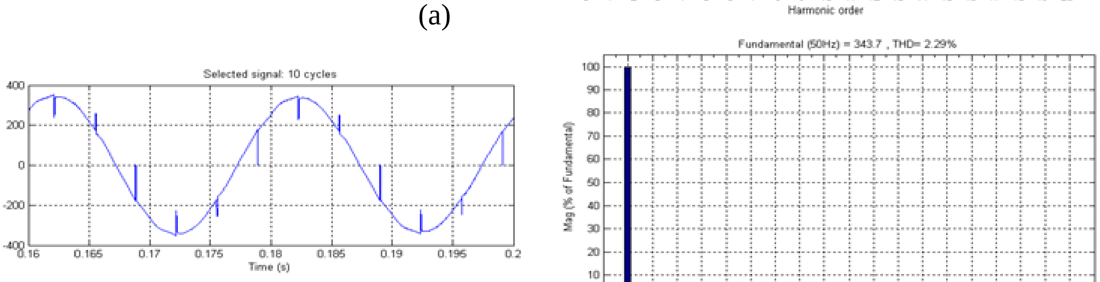
Figure 8. The whole System Modeling Blocks

6. Computer Aided Simulation Solver and Results

After completion the simulation model and defining suitable running parameters to run the simulation for 0.21 seconds and in ode23 mode, two cycle had been selected starting from 0.16, in which the system has reach the steady state .The results are presented in "Fig. 9" and "Fig. 10" for the three phases of the kiln DC drive motor. While "Fig. 11" is for Raw Mill.



(a)

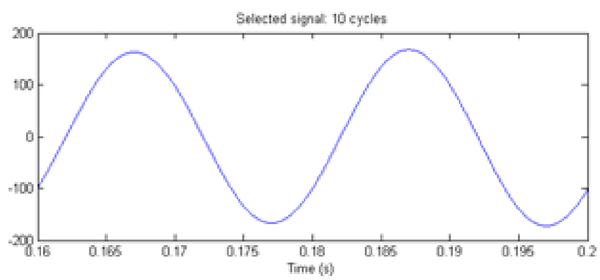


(b)

Figure 9. Harmonic Spectrum of one phase (a) current (b) voltage for Kiln unit

Fundamental =	469.9	467.6	466.1
peak	(332.3 rms)	(330.6 rms)	(329.6 rms)
(THD) =	31.82%	32.01%	32.27%
0 Hz (DC)	0.22 %	0.46 %	0.68 %
50 Hz Fund	100.00 %	100.00	100.00 %
100 Hz (h2)	1.10 %	1.01 %	0.14 %
150 Hz (h3)	0.65 %	0.54 %	0.22 %
200 Hz (h4)	1.17 %	1.02 %	0.43 %
250 Hz (h5)	27.79 %	28.04 %	28.47 %
300 Hz (h6)	0.51 %	0.95 %	1.26 %
350 Hz (h7)	9.93 %	9.95 %	10.27 %
400 Hz (h8)	0.78 %	0.82 %	0.26 %
450 Hz (h9)	0.58 %	0.55 %	0.34 %
500 Hz (h10)	1.05 %	0.94 %	0.46 %
550 Hz (h11)	8.74 %	8.67 %	8.11 %
600 Hz (h12)	0.33 %	0.71 %	0.91 %
650 Hz (h13)	4.34 %	4.12 %	3.88 %
700 Hz (h14)	0.79 %	0.60 %	0.30 %
750 Hz (h15)	0.51 %	0.31 %	0.31 %
800 Hz (h16)	0.92 %	0.68 %	0.47 %
850 Hz (h17)	5.53 %	5.73 %	5.87 %
900 Hz (h18)	0.19 %	0.72 %	0.78 %

Figure 10. Harmonic content list of the all current phases (kiln Unit)



Fundamental =	164.8	164.2	164.5
peak	(116.5 rms)	(116.1 rms)	(116.4 rms)
(THD) =	0.41%	0.51%	0.72%
0 Hz (DC)	0.92 %	0.29 %	0.63 %
50 Hz Fund	100.00 %	100.00 %	100.00
100 Hz (h2)	0.33 %	0.40 %	0.53 %
150 Hz (h3)	0.16 %	0.22 %	0.31 %
200 Hz (h4)	0.09 %	0.11 %	0.19 %
250 Hz (h5)	0.10 %	0.08 %	0.19 %
300 Hz (h6)	0.06 %	0.08 %	0.13 %
350 Hz (h7)	0.05 %	0.08 %	0.04 %
400 Hz (h8)	0.03 %	0.07 %	0.10 %
450 Hz (h9)	0.03 %	0.05 %	0.08 %
500 Hz (h10)	0.03 %	0.05 %	0.07 %
550 Hz (h11)	0.03 %	0.04 %	0.06 %
600 Hz (h12)	0.02 %	0.04 %	0.06 %
650 Hz (h13)	0.03 %	0.03 %	0.06 %
700 Hz (h14)	0.02 %	0.03 %	0.05 %
750 Hz (h15)	0.02 %	0.03 %	0.05 %
800 Hz (h16)	0.02 %	0.03 %	0.05 %
850 Hz (h17)	0.01 %	0.05 %	0.05 %
900 Hz (h18)	0.02 %	0.03 %	0.04 %

Figure 11. Harmonic Spectrum of Raw Mill for 3 Phases currents

The results of harmonics analysis for the kiln drive presents reasonable values compared to the measured values as shown in table7 for different harmonic orders. It could be concluded that the simulation run results are very close to the practical working measured values considering that the measurements were conducted on normal operation mode and based on ideal loading (little fluctuations) for the kiln.

Table 7. Comparison Table for Harmonics Content – Case Study

Harmonic Order	Simulation Results				Measurements
	Phase 1	Phase 2	Phase 3	Average	
F	316.4	314.9	313.7	315.0	303
5	87.9	88.3	89.3	88.5	79
7	31.4	31.3	32.2	31.7	31
11	27.7	27.3	25.4	26.8	25
13	17.5	18.0	18.4	18.0	14
17	13.7	13.0	12.2	13.0	11
19	9.6	10.0	11.0	10.2	9
THD%	31.7%	31.9%	32.3%	32.0%	29.9%

7. Program Algorithm and Flowchart (Filter Design Kiln Derive)

The next step is to formulate an algorithm (program) in designing the harmonic filters for the kiln drive. To apply this design, the nearest market capacitor (reactors) standard is chosen and then filter recalculated accordingly. The network performance is calculated after the implementation of the proposed harmonic filters. The algorithm of the design follows some assumptions to simplify the calculations. These assumptions are:

1 The supply impedance is represented by the transformer impedance.
2 The load drives a three phase balanced current and equilibriums of harmonic content in the three phase, so that symmetrical filter branch will be taken for every phase.
3 The inductive reactance of the system is very high compared to its resistance.
4 The voltage waveform is pure sinusoidal and the only current waveform is distorted by the harmonic.

The data entry to the program is: (Active Power =249 MW; V line-line = 400V; Existing Power Factor=0.84 ; Desired Power Factor=0.95).

The first part of the program concerned on power factor correction task, where the calculation of the required Qvar needed to achieve the desired value of power factor using the equation (2) .This part of the program is applied for kiln unit and for Raw Mill unit to calculate the required reactive power and then the required capacitor bank.

The second step is to design of L-C tuned filter with the highest contents of listed harmonics frequencies (5^{th},7^{th} and 11^{th}). So, three filter arms are installed. Schneider Electric [11] mentioned that: ‘From experience the rated reactive power of the capacitor is proportional to the corresponding harmonic current order in order to get the same rating for each filter reactor’ then the following formula can be expressed as follows:

$$\left[\frac{Q_5}{Q_7}\right]=\left[\frac{7}{5}\right]^2, \text{ i.e } \quad Q_5 \cong 2Q_7 \quad ; \quad \frac{Q_5}{Q_{11}}=\left(\frac{11}{5}\right)^2 \text{ i.e. } Q_5 \cong 5Q_{11} \qquad (5)$$

$$\left[\frac{Q_5}{I_5}\right]:\left[\frac{Q_7}{I_7}\right]:\left[\frac{Q_{11}}{I_{11}}\right]=\left[\frac{Q_{req}}{I_5+I_7+I_{11}}\right] \qquad (6)$$

Where (Q_{req} is the required reactive filter for power factor improvement). For each Q_h (KVR_h) the capacitor of each filter arm (C_h) and corresponding current (IC_h) can be calculated with the relative frequency deviation (δ) as following formulas [12](where V=line nominal filter voltage, ω_1 , ω_h is the fundamental and harmonic angular frequency)

$$C_n=\left[\frac{Q_n}{\omega \cdot V^2}\right] \quad ; \quad IC_n=\frac{Q_n}{\sqrt{3}V} \qquad (7)$$

$$\delta=\left[\frac{\omega_1-\omega_h}{\omega_h}\right]; \quad \omega_h=\frac{1}{\sqrt{L_h \cdot C_h}} \qquad (8)$$

$$X_0=\omega_h \cdot C_h=\frac{1}{\omega_h \cdot C_h}=\sqrt{\frac{L_h}{C_h}} \qquad (9)$$

Where X_o is the reactance of the inductor (or capacitor) at the tuned frequency. Practically it notes the relative frequency deviation (δ) lies between (3% and 10%) to attain good results in tuned filters [13]. The inductance of the filter L_h (for each arm) is:

$$L_h=\frac{1}{(2\pi \cdot 50 \cdot \delta)^2 C_h} \qquad (10)$$

A resonance checking is made and if it is occurred with harmonic existing, the filter trail is not accepted and a new trail of design must be performed with new value of (δ). On other hand, if the there is no resonance, then an over current is checked, I_f must be less than ($I_{fh} < 1.35\ IC_h$). If this test is passed, so next step will be done, if not, then a new calculation is repeated after increasing Q_{req} so that a new Q_h for each arm will be calculated and a new filter component must be done. The over voltage must be checked so that the voltage of the capacitor must be less than or equal 1.1 the nominal voltage of the network ($Vc \leq 1.1$ V) , to get acceptable design.

In case of limits violation, new iteration will be conducted by changing the value of reactive power of the filter of n^{th} order to check the over current till achieving the limits for over current and over voltage as well. If Vc >1.1 V then the required capacitor for the filter must have the rated voltage equal to Vc instead of V. Finally the value of C_h and L_h will be check with standard values [14]. The flowchart that achieves the previously mentions assumptions is shown in “Fig. 12”

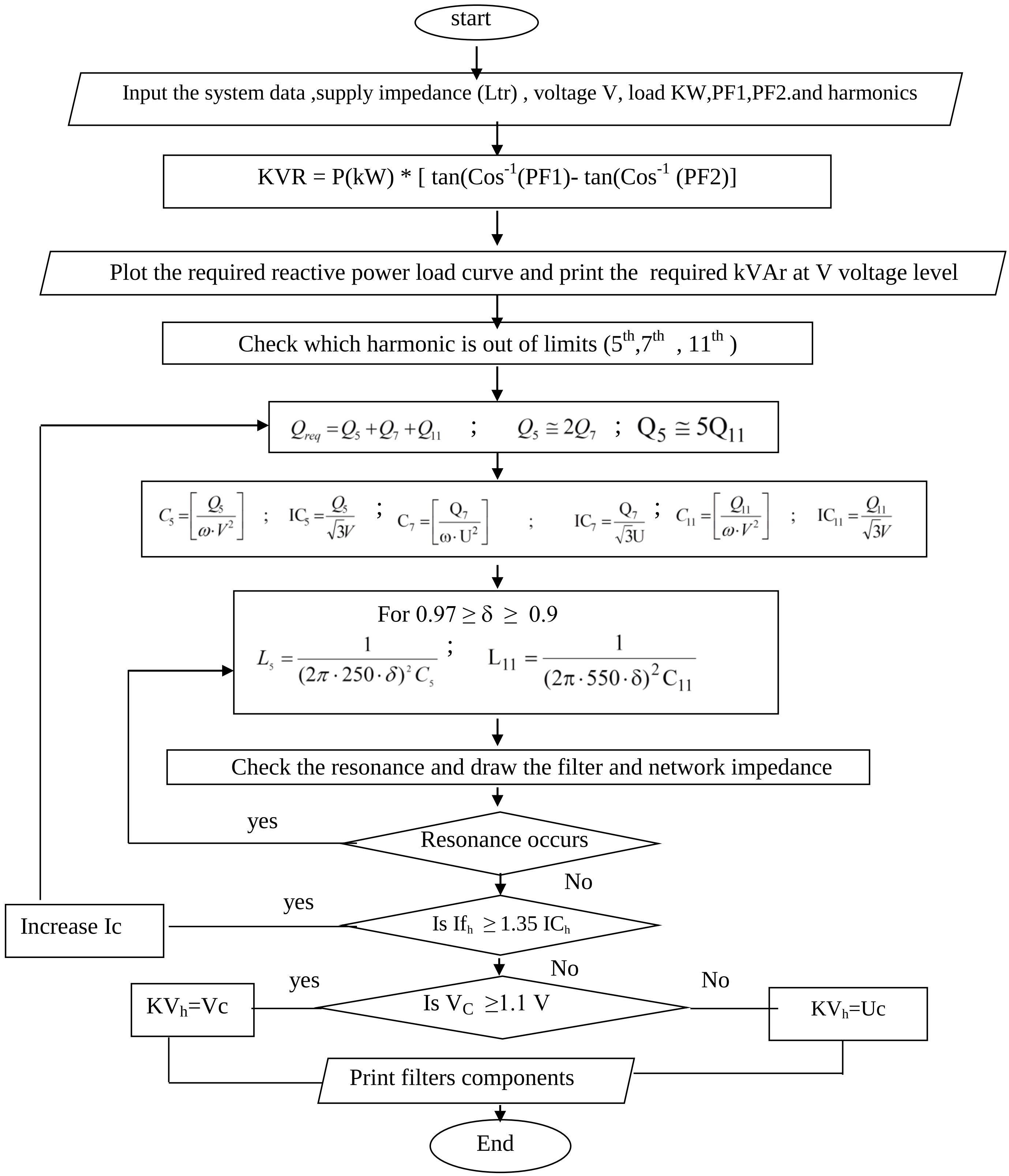


Figure12. Filter Design Flowchart.

8. Results of Filter Design

The program result is summarized in Table 8. The designed filter is composed of three arms (5^{th}, 7^{th} and 11^{th}) harmonics as shown in Fig.13.

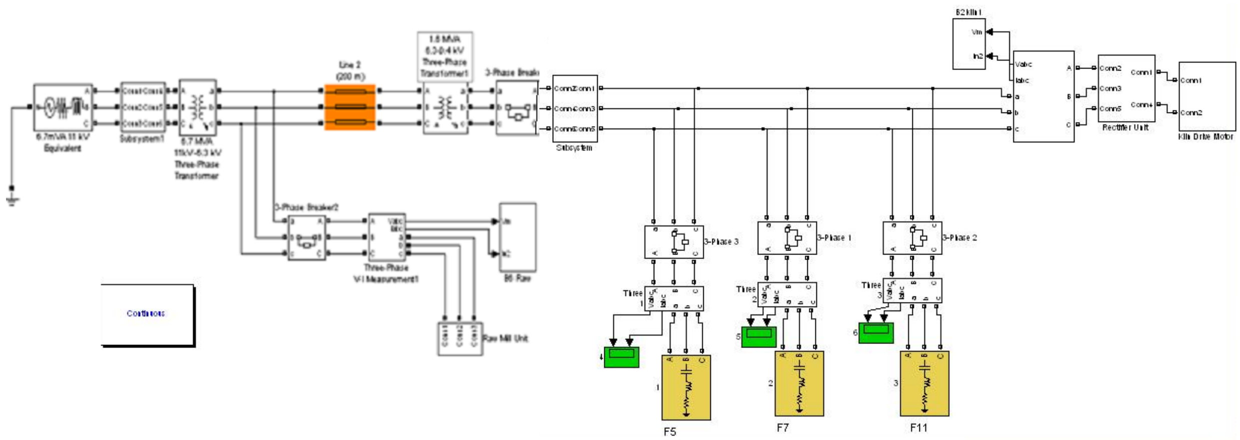


Figure13. Whole system Block Diagram after Filter insertion

The total reactive power for compensation and improving the power factor on the kiln drive is 75 kVAr divided into three harmonics arms. Based on the Table 8, the impedance curves for different harmonics with respect to the supply network impedance are illustrated in Fig 14.

Table 8. Harmonic Filter Data

Filter Data	Fundamental	5^{th}	7^{th}	11^{th}
Current (A)	303	79	31	25
Reactive Power (kVAr)		41	17.5	16.50
Capacitance (m Farad)		815.67	348.15	328.26
Inductance (m. Henry)		0.528	0.256	0.669
Tuned Frequency		242.5	533.5	339.5

It can be seen from “Fig.14” that the operation of tuned filter that is on the 50 Hz the supply impedance Xtr is less than the all filters impedances Xf i.e (Xf >>Xtr) so the current will flow through the system network, so the power will transfer to the load, but for 250 Hz and 350 Hz (Xf < Xtr) so the harmonics currents follow in the filters more than in the network so that the harmonics problems will be decrease.

Moreover, the combination of harmonic filter impedances is illustrated in figure 15, it could be concluded that the possibility of system resonance at tuned frequencies of filters is impossible since the intersection between the supply impedance with the capacitive filters impedance are far beyond the tuned frequencies.

According to “Fig.16” it could be noted that the THD on of current wave form is dropped from 30% to 6.5 % (which is close to the measurements i.e. THD = 7.8%). In this line, the design of the filters could guarantee the practical implementation of the different harmonic filters.

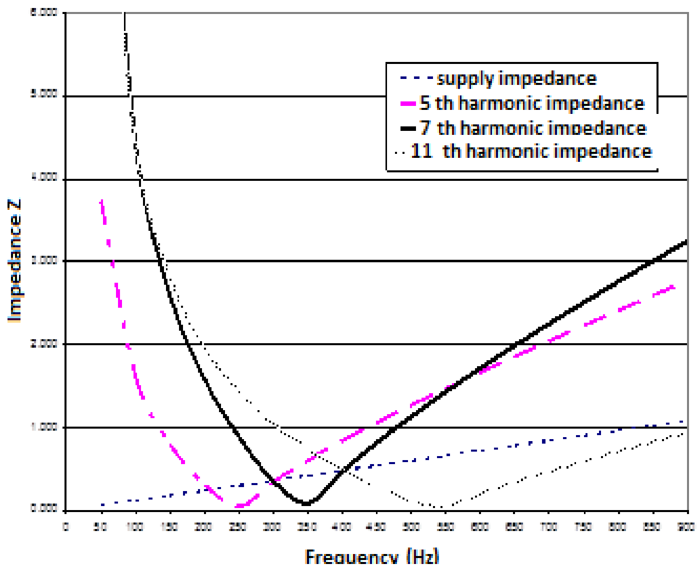


Figure14. Filters Combination Diagram

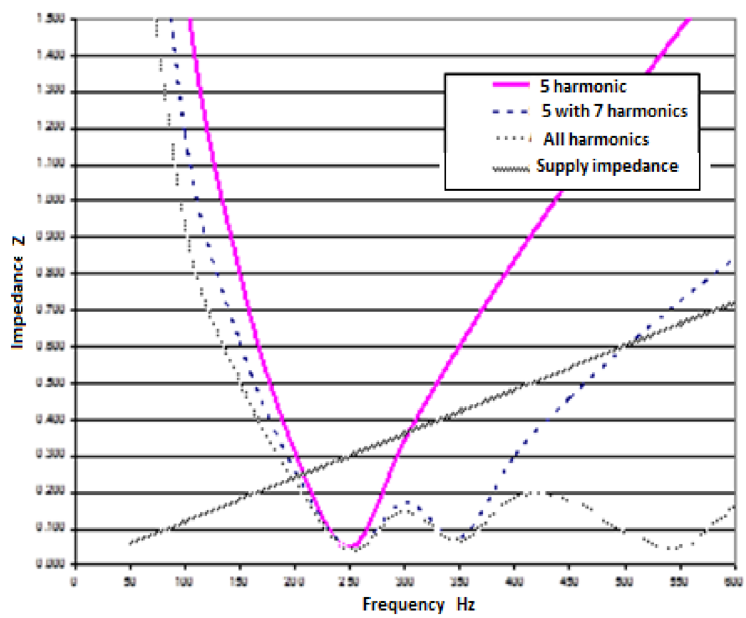


Figure15. Filters Impedance Combination Diagram

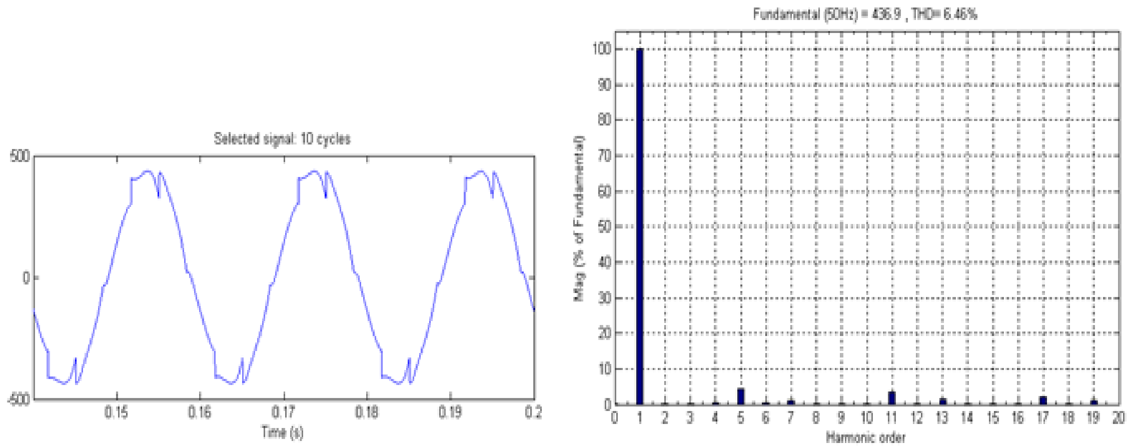


Figure 16. One Phases current spectrum with Filters insertion (Kiln Drive)

Fundamental = 437.1
peak (309.1 rms)
(THD) = 8.60%

0 Hz	(DC)	0.06 %
50 Hz	Fund	100.00
100 Hz	(h2)	0.30 %
150 Hz	(h3)	0.17 %
200 Hz	(h4)	0.13 %
250 Hz	(h5)	7.90 %
300 Hz	(h6)	0.07 %
350 Hz	(h7)	2.65 %
400 Hz	(h8)	0.04 %
450 Hz	(h9)	0.04 %
500 Hz	(h10)	0.04 %
550 Hz	(h11)	1.50 %
600 Hz	(h12)	0.02 %
650 Hz	(h13)	0.96 %
700 Hz	(h14)	0.03 %
750 Hz	(h15)	0.02 %
800 Hz	(h16)	0.02 %
850 Hz	(h17)	0.84 %

Fundamental = 438
peak (309.7 rms)
(THD) = 8.49%

0 Hz	(DC)	0.16 %
50 Hz	Fund	100.00 %
100 Hz	(h2)	0.25 %
150 Hz	(h3)	0.13 %
200 Hz	(h4)	0.09 %
250 Hz	(h5)	7.80 %
300 Hz	(h6)	0.08 %
350 Hz	(h7)	2.60 %
400 Hz	(h8)	0.05 %
450 Hz	(h9)	0.04 %
500 Hz	(h10)	0.04 %
550 Hz	(h11)	1.52 %
600 Hz	(h12)	0.02 %
650 Hz	(h13)	0.96 %
700 Hz	(h14)	0.03 %
750 Hz	(h15)	0.03 %
800 Hz	(h16)	0.02 %
850 Hz	(h17)	0.85 %

Fundamental = 437.8
peak (309.6 rms)
(THD) = 8.50%

0 Hz	(DC)	0.22 %
50 Hz	Fund	100.00
100 Hz	(h2)	0.16 %
150 Hz	(h3)	0.07 %
200 Hz	(h4)	0.05 %
250 Hz	(h5)	7.81 %
300 Hz	(h6)	0.02 %
350 Hz	(h7)	2.62 %
400 Hz	(h8)	0.01 %
450 Hz	(h9)	0.01 %
500 Hz	(h10)	0.01 %
550 Hz	(h11)	1.49 %
600 Hz	(h12)	0.01 %
650 Hz	(h13)	0.97 %
700 Hz	(h14)	0.01 %
750 Hz	(h15)	0.01 %
800 Hz	(h16)	0.01 %
850 Hz	(h17)	0.87 %

Figure 17. Harmonics spectrum for 3 Phases current with Filters insertion (Kiln Drive)

9. Conclusions and Recommendations

This work presents a methodology approach for the power factor improvment and the design for harmonic filters has considering the real measurements with analytical simulation models in order to cross check the deduced electrical parameters.

In this regard, this study could present the following conclusions and recommendations:

1. It is highly recommended to improve the power factor value for inductive loads where extra relief for electrical devices loading can be achieved.
2. The improvement of power factor value is not an easy job where the harmonics presence in power systems must be considered in order to avoid the resonance problems. Therefore, it is highly recommended to study carefully the addition of capacitive loads to any electrical network.

3. The nonlinear loads as harmonics generator must be filtered in order to improve the power quality of the facility network and the utility as well.
4. The controlled drives in cement industry generate high fluctuation in both active and reactive powers. Hence, it is mandatory to consider overall reactive power compensation either at grouped loads or the whole facility. This will lead to stabilize the requirements for the reactive power.

For future work, it is highly recommended to consider the financial impact on harmonic filters implementation subject to the constraints imposed by the standards. Moreover, cost functions could be produced for different harmonic sizes and then compute for the optimized size with respect to achieving the standards applied on power systems.

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