STUDY AND ANALYSIS FOR THE EFFECTS OF POWER FACTOR CORRECTION IN AL-NAJAF CEMENT PLANT

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ABSTRACT

The quality of an electrical power plays an important factor in any industrial process, these factors relate to the economic and technical benefits. The cement industry used many of the miscellaneous equipment's, which are classifying as non-linear loads such as induction motors, transformers and etc. The electrical equipment's are absorbing additional currents called "inductive reactive currents"; the effects of additional currents making electrical network inefficient, result of reducing the power factor. However, the low power factor will affect the increase the loads on the power station on the one hand and on the efficiency of the equipment's, capacity of transformer's, sizes of cables and capacity of switchgears on the other hand this in relation to the cement plant.

In this paper, the effects of low power factor on main motors which use in AL-Najaf cement plant analyzed, such as raw material mill, cement mill and the clinker cooler. The necessary reactive power for the capacitor bank calculated according to practical readings for equipment's information that printed on the name-plates, by using two methods for calculation (the mathematical equations and table of factor K). The influence of power factor correction on the motors, transformers and sizes and losses of electrical cables calculated. The advantages of power factor correction are analyzed for economic and technical sides.

Keywords: Reactive power, Cement plant, Maine equipment’s, Power factor correction, Motors.

دراسة وتحليل تأثيرات تصحيح عامل القدرة في معمل سمنت النجف.

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الخلاصة:

تلعب نوعية الطاقة الكهربائية عوامل مهمة في أيّ عملية صناعية، تتعلق هذه العوامل بالمنافع الاقتصادية و التقنية. تستخدم صناعة السمنت العديد من معدات المختلفة و التي تصنف كأحمال غير خطية مثل المحرّكات الحثية و المحولات.. الخ. تعمل المعدات الكهربائية على امتصاص تيارات اضافية تدعى " التيارات الحثية غير الفعالة"، ان تأثيرات هذه التيارات الاضافية هو جعل الشبكة كهربائية غير كفوءة نتيجة لانخفاض معامل القدرة. على أي حال، ان معامل القدرة المنخفض سيؤثر على زيادة الحمال على محطة الطاقة الكهربائية من ناحية وعلى كفاءة الأجهزة و على سعة المحولات و حجوم القابلوات و سعات قواطع الدورة الكهربائية من ناحية اخرى هذا فيما يتعلق بمعمل السمنت. في هذا البحث، تم تحليل تأثيرات انخفاض معامل القدرة على االمحركات الرئيسية المستخدمة في معمل سمنت النجف مثل محرّك طاحونة المواد الاولية و محرّك طاحونة السمنت و محرّك مبردة الكلنكر. لقد تم احتساب القدرة غير الفعالة الضرورية لمصرف المكثّفات اعتماداً على القراءات العملية للمعلومات المطبوعة على لوحات التسمية للأجهزة بطريقتين (المعادلات الرياضية وإستخدام جدول العامل K). تم احتساب تأثير تصحيح معامل القدرة على المحركات و المحولات و حجوم و خسائر القابوات الكهربائية. تم تحليل فوائد تصحيح معامل القدرة من الناحية الاقتصادية و التقنية.

Nomenclature:

I_R: Active Component of Current.

S_1, S_2: Apparent Power Before and After Power factor Correction.

P_1, P_2: Active Power Before and After Power factor Correction.

$Q_{C\ (Actual)}$: Actual Reactive Power.

C: Capacitor.

ESP: Electrostatic Precipitator.

$P_{1Losess}$, $P_{2\ Losses}$: Power Losses Before and After Power factor Correction.

P.F.: Power Factor.

I_Q: Reactive Component of Current.

Q_C: Reactive Power.

Q_1, Q_2: Reactive Power Before and After Power factor Correction.

$Q_{C\ Total}$: Total Reactive Power.

θ: Displacement Angle.

η%: Efficiency of Motor.

ΔP_{Losses}: Reduction in Power Losses.

1. INTRODUCTION

In recent years, increasing attention has been paid to minimize the cost of energy and inefficiency in electricity generation, transmission and distribution especially in industrial applications. The machineries and equipment which using in cement industry are electrical motors, pumps, compressor, transformers, fans, blowers, conveyors, kilns, transportation, lightings and others. These machines consume different forms of energy according to the cement manufacture processes.
The electrical power received from the high voltage or medium voltage grid has to be distributed to the medium and low voltage loads. This power has to be transformed to the medium voltage level for supplying a large drives; and then by distribution transformers to the low voltage level for smaller drives. The large numbers of electric drives makes the operation of these drives and their power consumption a significant cost factor.
The active and reactive power consumption and harmonics influence on operating costs and efficiency of drive systems, transformer and the cable losses. Therefore, the power factor and harmonics play major role, in improving of the machineries and equipment performance and reduce the cost of power consumption. In all electrical equipment the active power only be useful, whereas the reactive power does not make any useful contribution but it causes additional voltage drops and power losses which appear in the form of heat **[5]**.

There are many researches have been done in the power factor improvement in cement factory. However, **JBV, et al. [6]** proposed thyristor switched capacitor to improve power factor in windmill power plant and used MATLAB software tool to obtain on results. **Ahrens, et al. [8]** designed of harmonic filter and power factor compensation installations by several approaches in cement plants. **Gonzalez, et al. [3]** designed the shunt filters to minimizing voltage distortion caused by nonlinear loads in industrial power systems. **Jain, et al. [5]** use the switches bank to correct the power factor through generating the locally necessary reactive energy for the transfer of electrical useful power. **Nikolic, et al. [2]** designed and implemented of measuring and information system for analysis of power quality in compliance with EN 50160 in different points of power supply network. **Osafehinti, et al. [16]** highlighted the methods of power factor correction in improving electricity supply and generated a table to determine a multiplying factor for all range of the power factor correction in the industrial environment. **Khalid, et al. [12]** presented the power quality problems, issues, related international standard, and effect of power quality problem in different apparatuses in Industry and methods for its correction**. Onohaebi, et al. [15]** studied the power factor correction in improving the efficiency of energy consumption in industries using a medium scale industry in Nigeria as a case study and an overview for power factor correction method and collection of various data relevant.

In this paper, the electrical energy flow, effect of harmonics and the main parts of the for Al-Najaf cement plant are illustrated. The calculations of reactive power is focusing on the big from electrical motors, transformers, electrical cables and power losses in these cables, because they most effective on the power factor. These calculations are based on the practical readings for the equipment's. The controller on the power factor correction discussed and the necessary reactive power is calculated.

2. ELECTRICAL ENERGY FLOW AND MAIN EQUIPMENTS FOR FACTORY

The process of operation of Al-Najef cement plant is called wet process. The main equipment's of cement plant are classified according to the production stages. Therefore, the electrical energy flow in a process of cement production as shown in **Fig.1**.

The electrical energy is not uniform and in some situations require to convert from AC to DC according to the equipment's use in process of cement production. The rated powers of the main equipment's for the factory set out in the table 1.

The electrical power supplies to the factory through one feeder line to the distribution main station by 33 kV. The main power station consists of power transformer with 5 MVA rated power 33/11kV and three main switch with rated 11kV - 630A. The electrical substation includes a number of step-down transformers to supply the loads by 3.3kV and 400V.

In this research, the calculations were achieved only on the main equipment's, such as: motors of the raw mill, the cement mill, the cooler and on some transformer's. Because they much effective in draw of reactive power if compared with other equipment's.

3. HARMONICS

Most the loads which are used in cement factory have resistive and reactive impedances therefore they called by non-linear loads and absorb non-sinusoidal current. These currents will increase the load on the electrical station switchgears and distribution network on the one hand and on the consumer's equipment's on the other hand. Therefore they are causing in voltage drop of non-sinusoidal type from the supply side of electrical network. In consequence the linear loads will supply by distorted voltage **[8],** the fundamental and harmonics waveforms are shown in **Fig. 2.** According to the Fourier theorem, an ideal sinusoidal waveform does not present any harmonics for different order from the fundamental wave. Therefore the presence of harmonics in electrical system is an indication of distortion of voltage or current waveform and this increases the value of total harmonic distortion THD, and may cause disabling equipment's **[17]**, the effects of harmonics on the equipment's are summarized in table 2.

4. POWER FACTOR

The main effective equipment's which using in cement factories are inductive loads. Furthermore in an AC electrical power system the value of total power (the apparent power) which drawn from the electrical station depends on the nature of the connected loads. The apparent power (currents which absorbed by loads) can analyze to two components: the active component (I_R), which be in phase with the supply voltage, is directly related to the output the part of electric energy converted into different types from energy such as mechanical energy, light energy, thermal energy…etc.; and the reactive component (I_Q), in quadrature to the voltage, is used to generate the flow necessary for the conversion of powers through the magnetic fields to produce flux necessary for the operation of induction machines and other. In this case of loads the total current (I) lags with respect to the active component (I_R). Anyway define of a power factor cos θ, as the ratio between the active component (I_R) and the total value of the current (I) as in Eq. 1, **[1]**.

$$\cos\theta = \frac{I_R}{I} = \frac{P}{S} \qquad (1)$$

The phase angle θ is the angle between the voltage and the current or between the apparent power (S) and active power (P) which are shown in **Fig. 3**.

In cement factory, the range of power factor is between of 0.7 to 0.8. This means that a 1MVA transformer can only supply 700 – 800 kW or the loads can draw only 70 - 80 useful Amps from a 100Amp supply. So, improving the power factor means supplying the necessary reactive power to getting on active power or reduce the amount of wasted power (reactive power).

5. REACTIVE POWER CONTROLLER

The power factor compensation system is essential to its application in electrical systems, according to the used machines work cycle which have different electrical characteristics. Capacitor banks are used much to get the corrected power factor. These capacitor banks are operate and controlling it by automatic control relay. The relay maintain the system of power factor at a set value under fluctuating load conditions, by connecting or disconnecting capacitor banks to the 415V bus. The automatic compensation system is formed from some of detection sensors to detecting the current and voltage signals. The micro-controller comparing the measured power factor with the desired value and then, connecting and disconnect the capacitor banks. The electric board contains switches, protection devices and alarm signals. The circuit diagram of the relay as illustrated in **Fig. 4**. **[7]**.

6. CALCULATION OF REACTIVE POWER

In this paper, calculations of the required capacitor to improve the power factor are achieved on the main equipment's. There are two methods to calculate the necessary capacitor bank to obtain a defined power factor by using mathematical analysis and table of coefficient K (KVAR/kW) **[4, 10]**.

6.1. Calculations of Reactive Power for Motor of Raw Mill

The type of raw mill drive is slip ring with the following specifications according to name plate: (50Hz) line frequency, (3300V) three phase voltage, (970kW) rated power, (0.84) power factor and (212.5A) rated current. The power factor will improve up to (0.94) and will watching the effect of this improving on the motor efficiency. The calculation of the reactive power as first step as in the following:

$$\mathbf{Q_C = P\,(\tan\theta_1 - \tan\theta_2)} \qquad (2)$$

Where, $\boldsymbol{\theta_1 = 32.86^{o}}$ **And** $\boldsymbol{\theta_2 = 20^{o}}$

The reactive power per phase is calculate as in Eq. 3:

$$\mathbf{Q_C = \frac{970\ kW}{3} \times 0.282 = 91.18\ \ kvar/phase} \qquad (3)$$

In a 3-phase system, the capacitor bank consisted by three capacitors having the same capacitance value and can be connected delta or star as shown in **Fig. 5**. In this case, the capacitor bank connected in delta mode, to get a small size of the capacitances of each phase **[13]**. Therefore, the total value of reactive power is calculated as in Eq. 4.

$$\mathbf{Q_{C\ Total} = Q_C \times 3 = 273.54\ \ kvar} \qquad (4)$$

The value of the capacitor can be calculated according to the accurate value for reactive power. The practical efficiency of the motor calculates depending on the ratio between actual current (I_1) to rated current (in name-plate) for motor as in Eq. 5:

$$\mathbf{I_1 = \frac{P}{\sqrt{3}\times V\times\cos\theta_1} = 202\ A} \qquad (5)$$

$$\mathbf{\eta\% = \frac{Actual\ current\ of\ motor}{Rated\ current\ of\ motor} = 95\%} \qquad (6)$$

Now, the accurate (actual) value for reactive power is:

$$\mathbf{Q_{C\ Actual} = \frac{Reactive\ power\ obtained}{Efficiency} = 95.98\ \ (\boldsymbol{kvar/phase})} \qquad (7)$$

The value of capacitor is calculating as in Eq. 8:

$$\mathbf{C = \frac{Q_C}{(\frac{V}{\sqrt{3}})^2 \times\omega} = 84.21\ \mu F} \qquad (8)$$

The calculating the value of current which had drawn from the motor of the same rated power after factor improvement as:

$$\mathbf{I_2 = \frac{P}{\sqrt{3}\times V\times\cos\theta_2} = 180.54\ A} \qquad (9)$$

The saving in current about (21.46 A) and the apparent power reduce as shown in Eq. (10 & 11).

$$\mathbf{S_1 = V \times I_1 = 666.6\ kVA} \qquad (10)$$

$$\mathbf{S_2 = V \times I_2 = 595.78\,kVA} \quad (11)$$

The reactive power reduces as shown in Eq. (12 & 13).

$$\mathbf{Q_1 = S_1 \times \sin\theta_1 = 361.69\,kvar} \quad (12)$$

$$\mathbf{Q_2 = S_2 \times \sin\theta_2 = 203.77\,kvar} \quad (13)$$

Active power is calculating before and after power factor improving as:

$$\mathbf{P_1 = S_1 \times \cos\theta_1 = 559.944\,kW} \quad (14)$$

$$\mathbf{P_2 = S_2 \times \cos\theta_2 = 560\,kW} \quad (15)$$

The apparent and reactive power reduced, while the value of active power still constant. However, the saving in current is (21.6A). The connection diagram for the power factor correction with the motors is shown in **Fig. 6**.

6.2. The Raw Material Mill Feeding Cable Size Calculations

The benefits of improving power factor are not only limited in improving of the motor performance and the exploitation of active power fully, but also it exceeding to optimal use of the electrical lines **[1]**. The feeding cable to the raw mill is calculated according to the rated power of the load (motor). Where, the effect of improving of power factor on current carrying capacity for cable is clarified through the calculations below. If is take into account the impact of starting current and effects of other factors on cable capacity, the cable is designed for carrying current the limits of (344.4A) with (0.84) power factor. Under standard conditions, the cross sectional area for XLPE/EPR cable which chosen is (120 mm^2), depending on the current carrying capacity (I) of copper cables as in table 3. Now, the new value of current with (P.F = 0.94) and for the same consideration's, is (307.8 A). With this value of current, the cross - sectional area becomes (95 mm^2).

6.3. The Raw Material Mill Feeding Cable Losses Calculations

The effect of improving power factor on the losses, with the same value of transmitted active power calculated. Where, the power losses of an electric cable are depending on the resistance of the conductor and on the square of the current **[9]**. In this case, the length of cable used is (240m), the cross sectional area (120mm^2) with (0.84) power factor, therefore the resistance of the cable is (0.0204Ω). In a three-phase system the losses are calculated as follows:

$$\mathbf{P_{Losses\,1} = 3\,.\,R.\,I_1^2 = 7.259\,kW} \quad (16)$$

$$\mathbf{P_{Losses\,2} = 3\,.\,R.\,I_2^2 = 5.798\,kW} \quad (17)$$

Now, the reduction in the losses after power factor correction is calculated as in Eq. 18:

$$\mathbf{\Delta P_{Loess} = P_{Losses\,1}.\ [1 - (\frac{P.F_1}{P.F_2})^2\,] = 1.462\,kW} \quad (18)$$

Where, ($P_{Losses1}$ and I_1) are respectively the power losses and current before the power factor improving, ($P_{Losses2}$ and I_2) are respectively the power losses and current after the power factor improving and (ΔP_{Losses}) the reduction in the power losses.

6.4. Calculations of Electrical Transformer for Raw Material Mill

The size of the transformer specifies according to the apparent power (S). By improving the power factor, the value of reactive power (Q) and the apparent power (S) would be reduced but still deliver the same active power (P) **[7]**. The variation of the power for MV/LV of three-phase transformers as a function of the P.F is defined by the table 4. However, the rated power of the transformer which feed raw mill 1500 kVA and the necessary compensation power is (40.5 kvar). The transformer will supply 1050 kW as a total power to the load with (P.F. = 0.7). If the loads absorbed the same power with (P.F = 0.9), it would be sufficient to use a transformer with power (1250 kVA). The necessary reactive power to correct the power factor for (0.94) is calculated as:

$$\mathbf{Q_C = P.(\tan\theta_1 - \tan\theta_2)}$$

$$\mathbf{Q_C = 1050 \times (0.656) = 688.8\ kvar}$$

When taking the necessary reactive power to operate the transformer in account, the total reactive power which delivers from the power factor correction unit becomes:

$$\mathbf{Q_{C\,Total} = Q_{\mathit{C}} + Q_N = 688.8 + 40.5 = 729.3\ kvar}$$

7. CALCULATIONS OF REACTIVE POWER FOR CEMENT MILL

The type of cement mill drive is slip ring with the following specifications according to name plate of motor: (50 Hz) line frequency, (3300 V) three phase voltage, (1900 kW) rated power, (0.84) power factor and (422 A) rated current. The method of calculations in this section will depend on using table of coefficient K (KVAR/kW) to extract the value of required reactive power per/phase as shown in the table 5.

The power factor of motor is 0.84 and the power factor to be obtained is 0.94. The power of the capacitor bank Q_C is:

$$\mathbf{Q_C = P\,.(\tan\theta_1 - \tan\theta_2) = K.P} \qquad (19)$$

The value of K is extracted from intersect the row "initial cos θ_1" 0.84 with the column "final cos θ_2" 0.94, that equals 0.283.
So,

$$\mathbf{Q_C = 179.23\ \ kvar/phase}$$

Where, $\mathbf{Q_{C\,Total} = 537.7\ \ kvar}$

Referring to Eq. (5-15) the results of calculations are illustrated in the table 6.

7.1. The Cement Mill Feeding Cable size Calculations

As illustrated in (6.2), the impact of starting current on cable capacity taken into account. Therefore, the cable is designed for carrying current the limits of (674.7A) with (0.84) power factor. Referring to table 3, the cross sectional area for cable chosen is (300 mm^2). The current with (0.94) power factor become (602.8A), according to table 3; the cross-sectional area for the cable becomes (240mm^2), with increasing a safety factor.

7.2. The Cement Mill Feeding Cable Losses Calculations

The length of cable used is (180m), the cross sectional area ($300mm^2$) with (0.84) power factor, therefore the resistance of the cable is (0.0252Ω). Referring to Eq. (16-18), the results of power losses and reduction in the power losses are illustrated in table 7.

7.3. Calculations of Electrical Transformer for Cement Mill

The rated power of the transformer which feed cement mill (2000kVA) and the necessary compensation power is 54kvar, the transformer will supplying (1200kW) as a total power to the load with (P.F.= 0.6). According to the table 2, if the loads absorbed the same power with (P.F. = 0.9), it would be sufficient to use a transformer with power (1500kVA). The results of calculations for necessary reactive power to correct the power factor for (0.94) as it illustrated in (6.3) are: Q_C is 1163.23 kvar and $Q_{C\ Total}$ is 1217.23 kvar**.**

8. CALCULATIONS OF REACTIVE POWER FOR MOTOR OF COOLER

The specifications of motor which use in the cooler according to name plate are: induction motor, (50 Hz) line frequency, (200kW) rated power, (380V) three phase voltage with (0.84) power factor and (355A) rated current. The calculations of necessary actual value for reactive power to correct the power factor to (0.94), are achieved as illustrated in (6.1). The results of calculations for necessary actual reactive power capacitor, the current (before and after) power factor improvement and the other values are illustrated in table 8.

8.1. The Cooler Feeding Cable Losses Calculations

The actual length of cable used is (60 m). According to the rated current of motor, the cross-sectional area for cable is ($120mm^2$); therefore the resistance of the cable becomes (0.0084Ω). Where, the calculations achieved according to Eq. (16-18). The results of Cable losses calculations are illustrated in table 9.

9. CONCLUSION

In this research, the effects of power factor on performance of the main motors, the electrical cables and transformers which are used in an Al- Najaf cement plant are discussed. The calculations of reactive power for power factor correction has demonstrated several benefits such as: The total value of current which is drawn from the network is reduced with limits of (96.23A) to the equipment's which has been calculated, reduce the power rating of transformers, the reduction in the cross-sectional area of cables and decrease the losses of cables which is about (8.682 kW). The technical benefits of power factor correction are increasing the operational life for equipment's which are host in the factory and utilizing the complete active power. Regarding the economic benefits of analyzing the mentioned equipment's are the reduction of the cross sectional area of the used cables and the rated capacity of transformers and switchgears, this will have a great impact in cost reduction of these equipment's.

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Table 1: The rated powers of the main equipment's.

The Unit in Factory	Rated Power (kW)	Type of Machine
Crusher	**2×130**	Induction Motor
Raw Material Mill	**975**	Slip Ring Motor
Kiln	**410**	DC motor
Cooler	**200**	Induction Motor
Cement Mill	**1900**	Slip Ring Motor

Table 2: The harmonics effect of on equipment’s.

Equipment’s	Effect of Harmonics		
	Current	**Losses**	**Overheat**
Motor	Increased	**1**. The iron losses increase. **2**. Copper losses increase.	Excessive heat in motor windings
Cable	Increased	**1**. Skin effect increased. **2**. Copper losses increase.	Overheating due to: **1**. High load current. **2**. Conductor resistance increase.
Transformer	Increased	Increasing the iron and copp losses due to, stray flux losse	Excessive heat in transformer windings.
Switchgears	Causing false operations and trips, damaging components for no apparent reason.		
Capacitor Bank	The capacitors absorb higher current.	Increasing the losses	Excessive heat and the damage in final.

Table 3: Current carrying capacity (I) of copper cables **[11]**.

	Cu	
	XLPE/EPR	**PVC**
Conductor **cross-sectional area (mm^2)**	**I (A)**	
35	176	143
50	216	174
70	**279**	225
95	**342**	275
120	400	321
150	464	372
185	533	427
240	634	507
300	736	587
400	868	689

Table 4: Power of three-phase transformers as a function of the P.F **[7]**.

Power of the transformer (kVA)	**Power of the transformer (kW)**					
	cos θ					
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**
125	63	75	88	100	113	125
160	80	96	112	128	144	160
200	100	120	140	160	180	200
250	125	150	175	200	225	250
315	158	189	221	252	284	315
400	200	240	280	320	360	400
630	315	378	441	504	567	630
800	400	480	560	640	720	800
1000	500	600	700	800	900	1000
1250	625	750	875	1000	**1125**	1250
1500	750	900	**1050**	1200	1350	1500
2000	1000	1200	1400	1600	1800	2000

Table 5: Factor **K** (KVAR/kW) **[4]**.

	Final P.F												
Initial P.F	**0.8**	**0.85**	**0.9**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**	**1**
0.74	0.159	0.289	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.262	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.235	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
0.77	0.079	0.209	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.678	0.626	0.686	0.829
0.78	0.052	0.183	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
0.79	0.026	0.156	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
0.8		0.130	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
0.81		0.104	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82		0.078	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
0.83		0.052	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
0.84		0.026	0.162	0.190	0.220	0.251	**0.283**	0.317	0.354	0.395	0.443	0.503	0.646
0.85			0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86			0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451	0.593
0.87			0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88			0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89			0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370	0.512
0.9				0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342	0.484

Table 6: Calculation results of necessary reactive power for cement mill.

		Comments
Q_{Actual} (kvar/phase)	191.2	
I_1 (A)	395.7	Saving current is (42.13A)
I_2 (A)	353.6	
C (μF)	16.77	
η%	93.7	
S_1 (KVA)	1306	
S_2 (kVA)	1166.88	
Q_1 (kvar)	708.6	44% Reduction in Reactive Power
Q_2 (kvar)	399.1	
P_1 (kW)	1097.04	The Active Power approximately equal
P_1 (kW)	1096.87	

Table 7: The calculation results of cable power losses for cement mill.

$P_{1(Losses\ 1)}$ (kW)	$P_{2(Losses\ 2)}$ (kW)	ΔP_{Loess} (kW)
34.41	27.47	6.93

Table 8: The calculation results for motor of cooler.

		Comments
Q_C (kvar/phase)	17.05	
$Q_{C\ Total}$ (kvar)	51.2	
I_1 (A)	339.6	Saving current is (32.5A)
I_2 (A)	307.1	
η%	95.7	
$Q_{C\ Actual}$ (kvar/phase)	17.82	
C (μF)	10.64	
S_1 (kVA)	135.84	9.56% Reduction in Apparent Power
S_2 (kVA)	122.84	
Q_1 (kvar)	71.56	41.3% Reduction in Reactive Power
Q_2 (kvar)	42.01	
P_1 (kW)	114.11	The Active Power approximately equal
P_2 (kW)	115.46	

Table 9: The calculation results of cable power losses for cooler.

$P_{1(Losses\ 1)}$ (kW)	$P_{2(Losses\ 2)}$ (kW)	ΔP_{Loess} (kW)
3	2.38	0.29

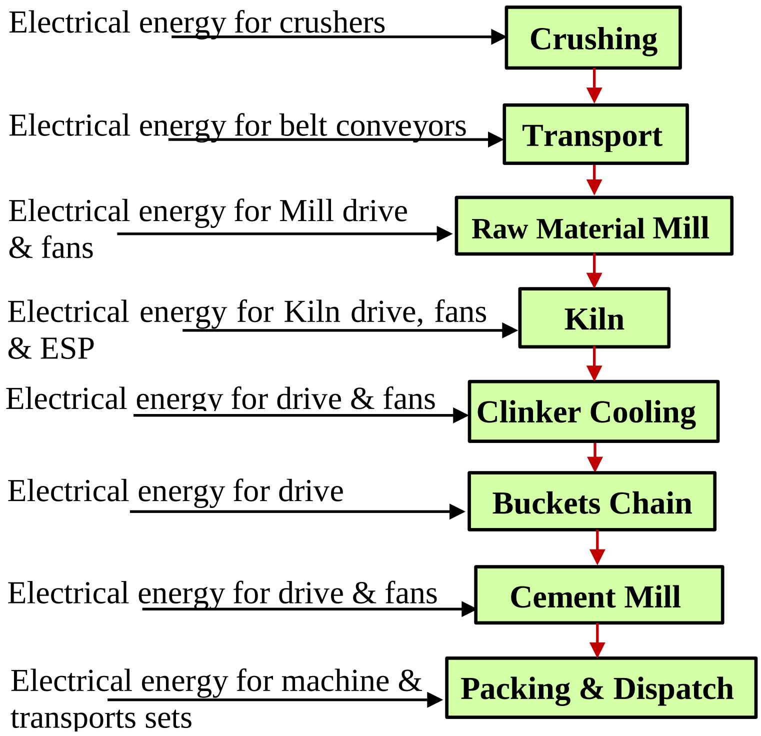

Figure 1: Electrical energy flow in processes of cement production.

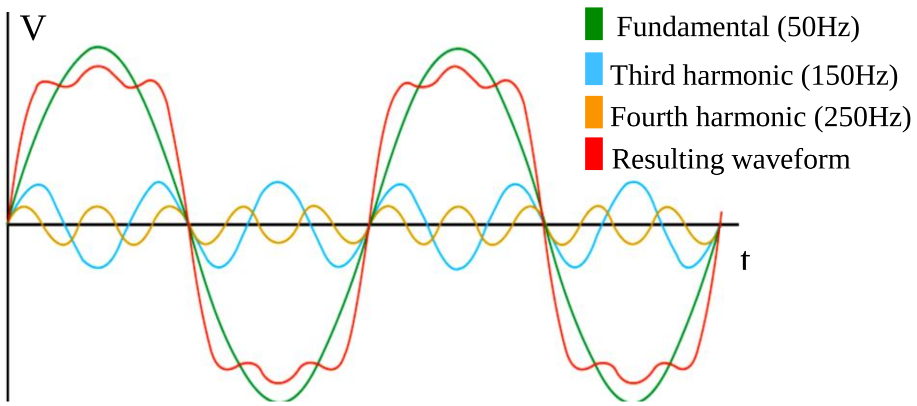

Figure 2: Fundamental waveform and a number of harmonics waveforms.

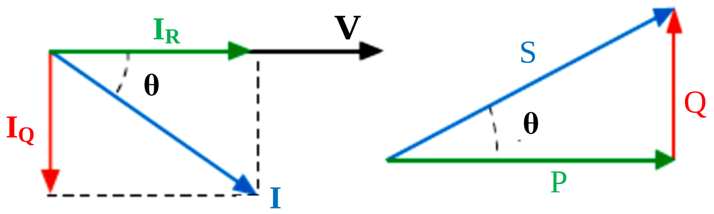

Figure 3: Power factor triangle.

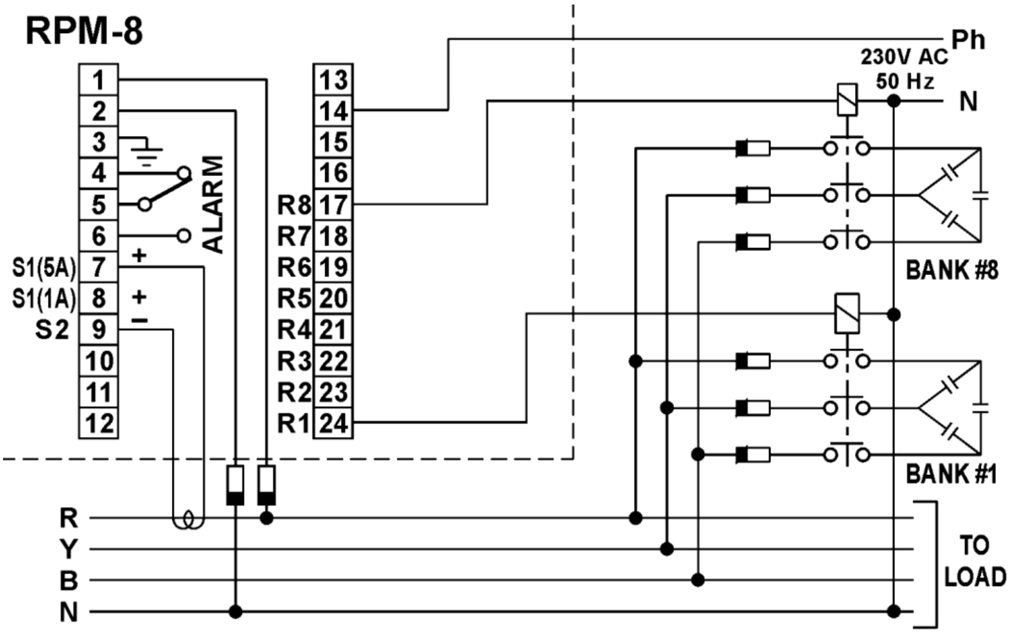

Figure 4: Circuit diagram of the reactive power relay.

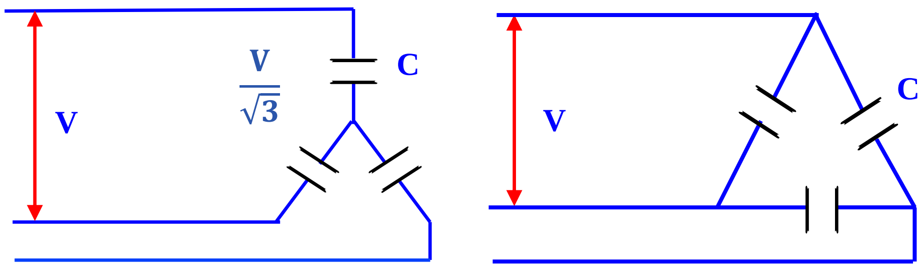

Figure 5: Three phase circuit star and delta connection.

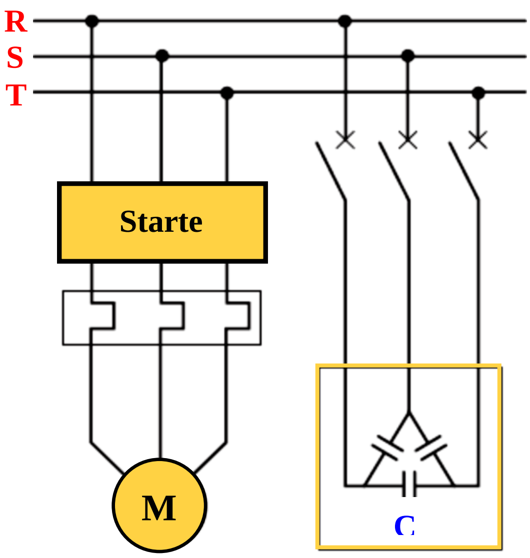

Figure 6: Connection diagram of power factor correction with the motor.