ECONOMICAL ASPECTS OF ELECTRIC ENERGY CONSUMPTION IN CEMENT INDUSTRY

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Abstract:

Various economical aspects of electric energy consumption in cement industry are investigated as part of the overall energy economy. Different cement manufacturing processes are compared.

Basic component of electric energy consumption in cement plant are mentioned for emphasis on areas of main consumption.

Economy of electric power in relation to electric power generation in the plant or outside it with some reference to Arab countries circumstances is mentioned. Electric equipment used in cement industry and some of their economical aspeets in selection procedure are discussed. Electric motors recieved special attention among other equipment with emphasis on modern control methods. Power factor improvement is discussed as a part of proper utilisation of electric energy. Load factor also recieved some attention so that cement industry would aid rather than burden good and ecomomical performance of electric utilities.

Modern process automation can help in good electric energy management in cement plants. However, an overall plant economy with these equipment as integral part is to be considered.

Finally, aspects of management, maintenance, and operation in relation to electric energy economy are discussed. Some reference to examples at running cement plants is made.

1. Introduction:

Cement Industry is a process manufacturing industry which does not use electric energy in its chemical reaction nor for heating, but merely for driving machines.

Motors are used in all parts of the manufacturing process. Modern plants need electrical energy of 80 - 130 KWh per ton of cement produced. Since cement plants are designed to work almost all through the year, and for many years, it becomes necessary to investigate all factors of effect on production economy including electric energy. The electric energy consumption should not be studied alone, but rather among other energy forms consumed in the plant; So that an overall economy of fuel and electricity should be the target rather than electric energy alone.

Two periods are to be investigated for energy consumption study: The first is the period of equipment selection in order to select those of low energy consumption in the long run. Such equipment need not be the cheepest. The other period is at the operation, in order to manage, operate and maintain the plant in the ways leading the best energy economy.

Energy consumption should be looked at further in a view of the overall national interest rather than the plant ownership interest. The economy of the plant should then be an integral part of the national economy. Improvement of daily load curve by proper manipulation of some sections of the plant is an example on this aspect.

2. Types of Cement Manufacturing Processes:

Cement manufacturing processes can be mainly one of three types: Wet, Semi-dry or Dry. Wet process deals with raw materials till the kiln feeding in a wet form (Slurry). In dry process the materials are fed to the kiln in a dry form (raw mix). In semi-dry process, water is added to the raw mix at 10 - 15%. Then the outcome in fed to the kiln. These types of manufacturing process are further subdivided into other types. Table (1) shows six types of kilns (which are the main sections in cement plants defining process types) with figures of energy consumption (in the kiln). The figures show the Kcal/Kg consumption of fuel and KWh/Ton of average electric energy.

Table (1) Fuel and Electric Energy Consumption for different Kilns (1)

Type of Kiln	Fuel (Kcal/Kg)	Ave. Elect. Energy (KWh/ Ton)
1. Dopol Kiln with Recupol Cooler	749	14
2. Gepol Kiln with Recupol Cooler	886	13.5
3. Lepol Kiln Semidry with Recupol Cooler	760	12
4. Lepol Kiln Semidry with Recupol Cooler	925	19
5. Longwet Kiln with Grate Cooler	1362	14.5
6. Longdry Kiln with Grate Cooler	1213	16.5

By experience, the dry process is the most economical one since energy needed for water evaporation in wet process is not necessary here. However, when an overall economical consideration is made for small capacity plants, wet process or semidry may show to be reasonably economical.

Electrical equipment for different types of process are slightly different. Control system of dry process is much more complicated than wet or semidry processes. The modern trand is to go to dry process in medium and large plants. Hence our discussions shall be baised more towards dry process.

Figure (1) shows the development of the energy consumption per ton of Clinker in the last 20 years (12).

Figure (1)
Heat Consumption Kcal/kg Clinker

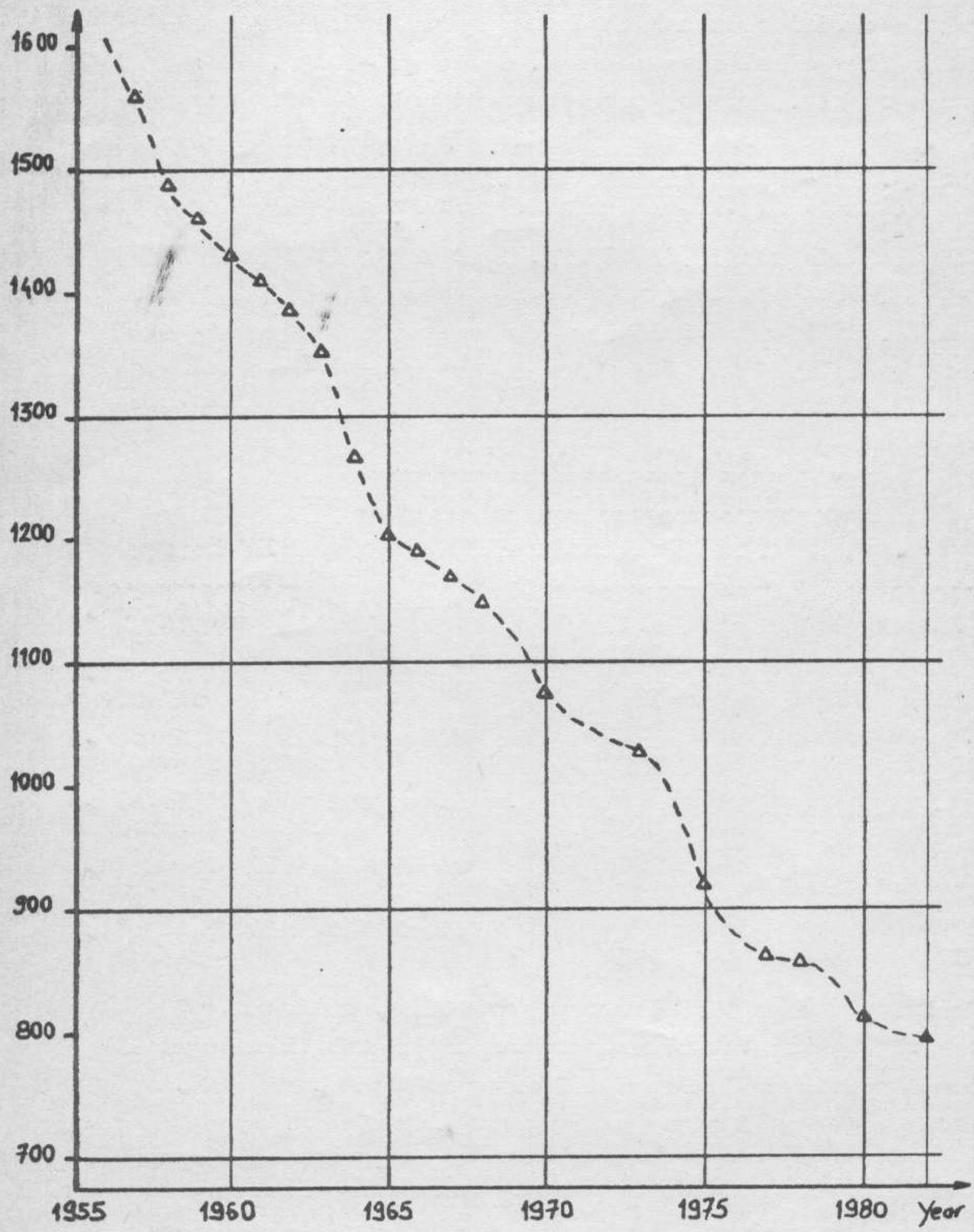


Table (3) Efficiences and Powerfactors for Partially Loaded Induction Motors[9]

EFFICIENCY			POWERFACTOR		
Fuull Load	75% Load	50% Load	Full Load	75% Load	50% Load
95%	95%	93%	0.90	0.88	0.83
90%	90%	89%	0.8	0.75	0.65
80%	80%	73%	0.75	0.69	0.56
70%	70%	66%	0.71	0.62	0.5
60%	58.5%	54%			
66%	52%	47%			

Good performance of mills is attained at their full load as mentioned above. This is clear from Figure (2) which shows [11] practical results obtained from 110 ton/hr. cement mill. Low daily production figures here are not only results of low productivity but could be due to stopping and starting of few times since KWh/Ton at starting period is also high.

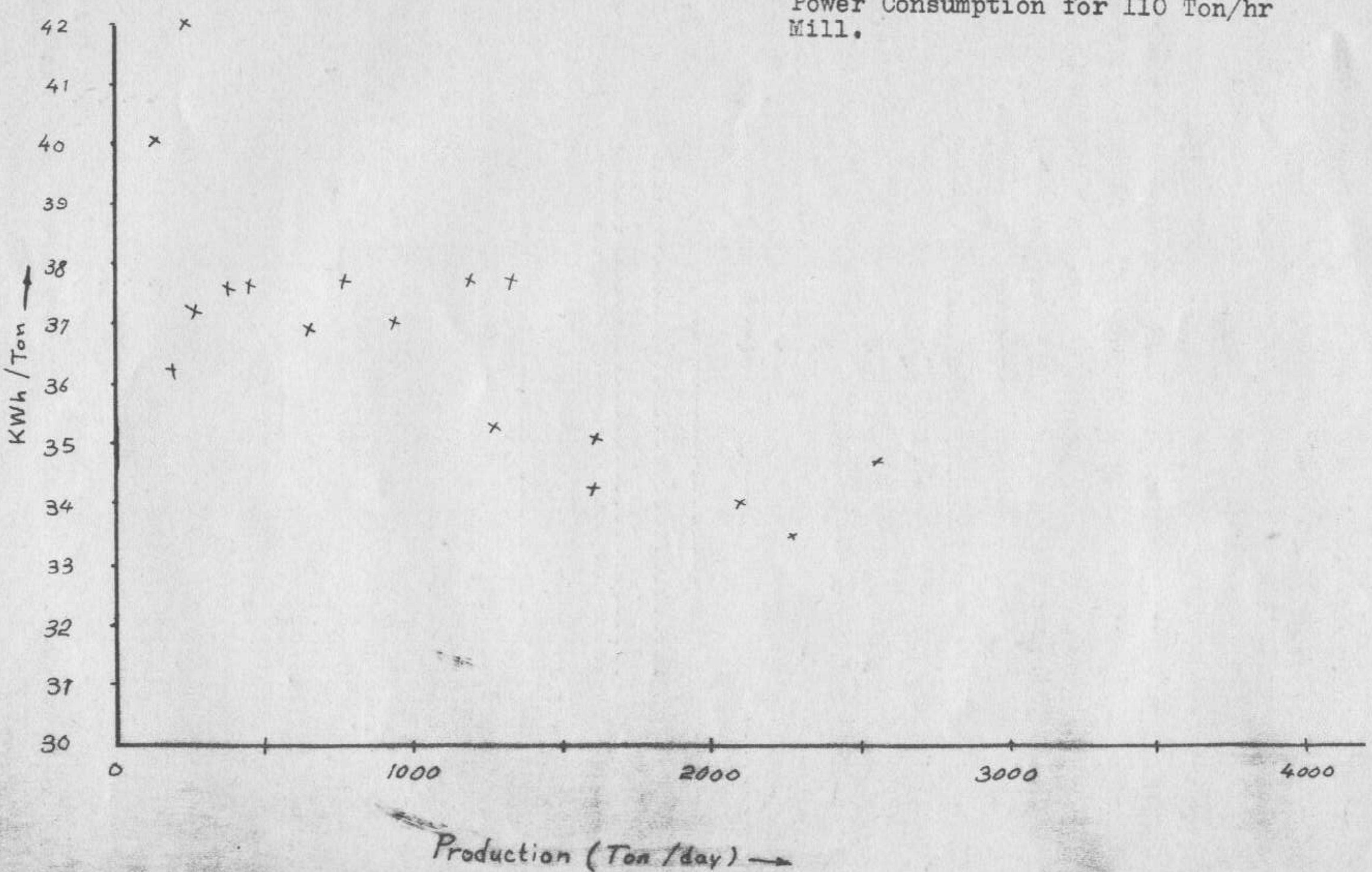
In a modern cement plants the number of motors is usually between 300 - 400 for each production line. Table (4) shows types of motors and their power in a 1500 Ton/Day plant.

Table (4) Type of Motors and their Power Rating in a 1500 Ton / Day Typical Plant (1)

Type of Motor	No.	No.%	Total KW	% KW
Squirrel-cage induction motor under 10 kw.	258	71.87%	588	4.7%
Squirrel-cage induction motor over 10 kw.	77	21.45%	2944	23.62%
Slip ring induction motor	10	2.78%	8537	68.5%
D.C. motor.	14	3.9%	395	3.18%
TOTAL	359	100%	12464	100%

This table shows that 10 slip ring motors (2.78%) of total number of motors are rated upto 8537 kw which makes 68.5% of total rating of motors in the plant. The small squirrel cage motors are numerous in the plant making 71.87% but do not have rating more than 4.7%. Hence attention should be paid to slip ring motors (mainly mills drives) for obtaining high efficiency rather than small size squirrel cage motors. Most of these slip ring motors operate at medium voltages (6600 V in the above case). A total of 8080 kW, motors are operated at such voltages i.e. 64.82% of plant rating. The rest 4384 kw, is consumed at 380/220 V.

Figure (2)
Typical Cement Grinding Electric Power Consumption for 110 Ton/hr Mill.



The selection of generating power station should take into consideration long term plans and fuel availability. Diesel power stations are suitable for small plants while steam power stations are economical for big complexes of future expansion expectation. Gas turbines are economical only if cheap fuel is available on the long run.

4.1.4 <u>Fuel for Electricity Generation</u>:

When electric power is generated in theeplant, the use of variety of fuel becomes limited. When acurate cost analysis is to be made, distination has to be made between actual fuel cost paid and costs based on true prices since governments supports may mislead in some cases.

Central generation of electricity by electric utilities, decreases electricity costs. However, a detailed research should be made for the fuel economy in various Arab countries. Below are only general remarks to highlight the balance between the economy of higher emphasis on fuel or elevtricity inecement plants.

Arab coujtries may be grougped into four categories from electric power generation cost point of view (10) in comparision to fuel costs:-

a) Oil producing countries with no water falls like Kuwait, Saudia Arabia, Libye, Arab Emarates, Bahrain, Qatar and Oman.

Electric power is generated using natural gas got as a byproduct of oil production. Some times fuel oil is used or diesel oil in rare cases. Here it is clear that cost of electricity is higher than its equivalent thermal power of fuel if the same kind of fuel is used in the kiln.

b) Oil producing countries with some water falls like Iraq and Algeria. Electric power is produced from hydroelectric plants as well as fuel mentioned in (a) above. Hence cost of electricity becomes cheaper than (a).

c) Countries with water falls but with no oil export, like Syria, Tunisia, Morrocco, Egypt, Lebanon and Sudan, here electricity generated from hydroelectric stations is generally much cheaper than that using any kind of fuel.

d) Countries with no water falls and are non oil producing contries e.g. N.&S. Yemen, Jorden, Somalia, Mauritania and Djibuti, here electricity produced by imported fuel is more expensive than its thermal equivalence of fuel.

When comparing the above situation with industrialised countries where electric power is generated using nuclear fuel in good proportion, the balance between fuel and electric power is of different scope.

To conclude, the selection of fuel for cement plant and its balance with electric power in the plant should be studied according to the local circumstances of the country and not on data available from industrialised countries which may not hold true for many cases in developing countries.

One ton of cement in dry process requires [12] on the average $\frac{1}{45}$ ton of oil equivelent electric. Which has a conversion rate in France of 2.577 i.e. 0.057 ton of oil thermal. Same process requires on the average $\frac{1}{12}$ ton of oil i.e. a total of 0.1406 ton of oil per ton of cement, calculations similar to that need to be compiled for different Arab countries cement plants to be constructed.

4.2 Distribution of Power in Cement Plant:

Most cement plants are supplied with electric power from Public grid systems. Frequency of such supply is fixed and supply voltage is mostly governed by the power utilities standards.

4.2.1 Selection of Proper Voltages:

Proper selection of voltages is based on economical factors and standard voltages of surroundings. Power to modern cement plants is usually supplied at 10 - 33 kv voltage[2]. This voltage is stepped down or partially supplied directly to medium voltage motors which usually operate at 3 - 10 kv. Low voltage motors and lighting is usually supplied at voltages between 110 - 600 V.

4.2.2 Switchgears:

The design of distribution system and selection of the proper switchgears is done for the purpose of high reliability safety, easy maintenance and economy.

Switchgears in modern layout designs are installed in the so called motor - control - centres distributed in various sections of the plant. Such design provides protection for control equipment from dust which is common in cement plants. Such centres are provided with pressurized systems. Modern installations show full seperation of power and control features.

4.2.3 Transformers:

As transformers provide power at the required voltage, they are kept on-line for all the time (except in case of standby units). Hence high efficiency well protected transformers is always required.

4.2.4 Cables:

Plastic insulated cables are common for low and medium voltages while polyethylene cables are used for voltages above 10 kv. Cross sections of cables should be selected to ensure economical and safety requirements.

4.3 Motors:

As stated earlier, most motors in cement plant are small squirrel - cage induction motors of less than 10 kw rating. Most of them are 3-phase and of normal outdoor types. Among motors of special types are.

4.3.1 Mills DRives:

THose are usually slipring induction motors operating on 6 - 10 kv voltage. Speed of such motors can be controlled by starting resistors in the rotor circuit. These resistors are taken off gradually after the starting period is over. A large energy is lost in these resistors in this operation. Hence the modern technique is to feed this energy back into the supply through thyristor converter which replaces these resistors. Figure (3) shows a diagram for such a drive [4]. This arrangement of feeding back could not have been achieved without the use of thyristor circuits since the frequency of the rotor current differs from the mains frequency after the rotors starts to rotate.

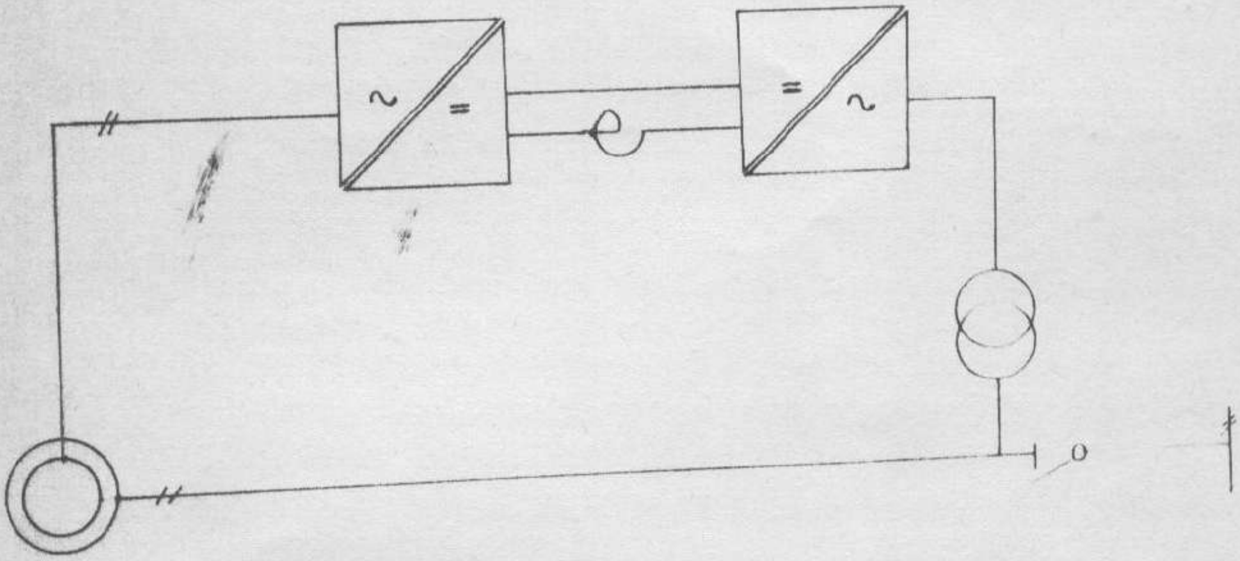


Figure (3)
Thyristor Starting of Slipring Motor

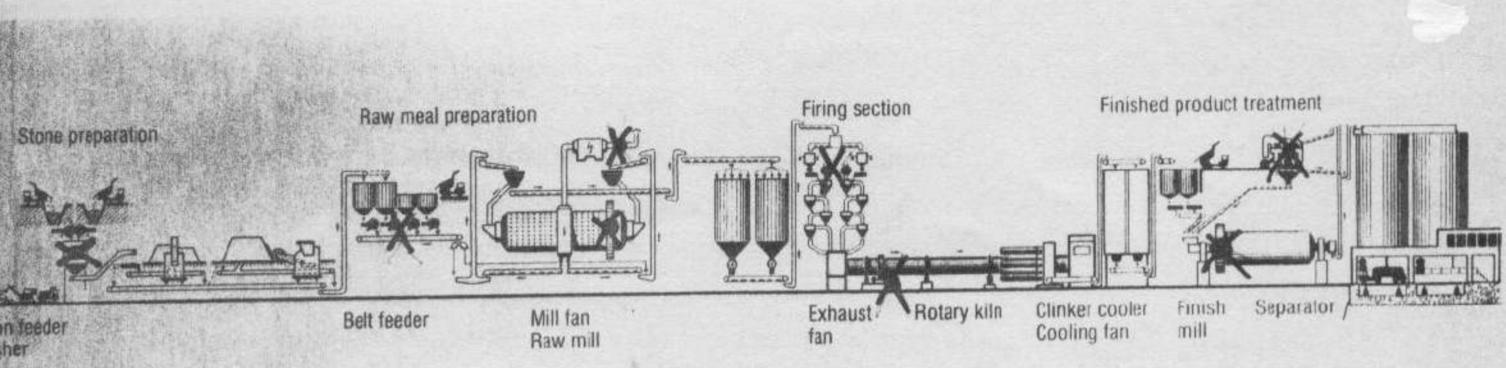


Figure (4)
Thyristor Drives in Cement Plant

The second type of mills drive which finds limited applicationin some cement factories is the GEarless DRIve or the so called ring motor which is merely a synchrom ous motor fed from variable frequency cycloconverter (7). The motor in most cases is constructed circumferentially around the mill tube. The latter with its attached rotor poles thus function as the rotor.

The cycloconverter converts the supply frequency into variable frequency from 0 - 5HZ. The motor has 30 - 40 poles with maximum speed of 15 RPM. This type of drive is extremely costly although it is of considerable advantage for the process to be able to vary speed of the mill with 91 - 93% efficiency and thus always be able to optimise the grinding process. It is expected that more of such drives are going to be seen in future cement plants

4.3.2 Variable Speed Drives:

Most of the variable speed drives used in cement plants are of D.C. type. Thyristor technology have enabled best possible solutions for speed controlled drives. Drives of the rotary kiln, kiln gas exhaust fan, grate cooler, grate cooling fan apron feeders, impact crushers, air seperating distributing plates, mill fan and proportioning conveyors are only part of the list of places where such drives are used in modern cement plants. Figure (4) shows places of such drives in typical dry process plant.

Those drives have to cover wide power range from 100 Kw up to several megawatts. Typical power consumed in such drives is 10 - 15 % of total power in the plant. Hence economical aspects of such drives should be studied well.

Static convertercascade are also used, especially for the driving of large fans. Technique used is similar to that of figure (1) described for mills drive.

4.4 Motor Control:

The problems associated with motors i.e.sequence and interlocks can be solved in either of three methods:-

a) Control based on con tractor and / or relay technology.
b) Control based on hard-wired solid state technology.
c) Control based on freely programmable technology.

The choice between these three types in developing countries is a matter of technology selection rather than merely an economical one. This subject will be furtherly discussed in section (7) later. In general the more sophisticated the control the management of State Enterprise of Cement in Ninevah. Figure are for 1983. It is clearly semn that fuel consumption decreases while Kwh/ton increases with higher technology accompanying change of process to more modern one.

Table (5) Fuel and Electricity at Factories of State Enterprise of Cement in Ninevah for 1983[11]

Factory	Capacity (Ton/Year)	Process	Control	Kwh/Ton	Fuel(L/T)	Cost of electrici and fuel per ton
Old Badoosh	230 000	Wet	Relay	90	232	1860
" Hamman	250 000	Wet	Relay	90	196	1727
New "	130 000	Wet	Semi - conductor Relay	84	188	1640
New Badoosh	900 000	Dry	Semi - Conductor	106	124	1436
Badoosh Ext.	1000 000	Dry	Programmable contrillers	128	88	1389

N.B.: 1) Figures are obtained after some calculations since Clinker and cement production figures were different.

2) Old Badoosh factory does not produce cement but only clinker 90 Kwh/Ton was obtained as 50 Kwh/Ton of Clinker and 40Kwh/tox for grinding and packing in New Badoosh.

3) Cost of fuel was calculated as 5.6 fils per liter and of electricity 7 fils per Kwh.

5. Power Factor Improvement:

Power factor is the ratio of the actual power consumption to the voltage-current product. It approaches unity for resistive loads and usually between 0.7 and 0.9 for Load containing lot of induction motors. When motors are partially loaded, the power factor drops as previousely made clear in Table (3). A motor of 0.71 power factor when operating at its normal load will operate at 0.5 power factor when its load drops to half. This is usual for motors driving pumps or conveyors. The lower the power factor, the higher the current needed for the same load impedance. When current increases, losses in the lines increase by its square. Hence for most economical operation power factor should be kept as near as possible to unity usually 0.9 to 0.95.

At 0.6 power factor, the angle between current and voltage is 53^{o}. At power factor of 0.9, this angle decreases to 26^{o}. Improving the phase angle from 53^{o} to 26^{o} will reduce the amount of current to be transmitted by 33%. Since the transmission losses are Proportional to the square of the current, the losses decreases by 56% as a result of power factor improvement[8].

Transmission losses are not important usually for the cement industry itself since usually transmission losses are not more than 2% of total power consumption. However, these losses are important for electric utilities and hence for national economy.

Low power factor has also other bad effects on electric power systems as they limit generation capacities and reduces stability.

Power factor improvement can be achieved either by using synchronous motor to replace some induction motors as the former gives capacitive reactive power or to use bank capacitors to be inserted in the system either near the motors or at the main substation of the plant (or in both places).

Many public utilities oblige the consumers to improve their power factor above certain level. Some others charge the consumers for their reactive power consumption. The question of how much power factor improvement is to be made is either governed by the regulations of the utilities or by best economical values needed according to the tariff in force. Profit gained over 10 years operation usually is weighed against cost of capacitor banks and their accessories. Modern cement plants compensate for reactive power partially near the medium voltage motors. The second compensation is made at the factory level. The Switching of capacitor banks near the motors is automatically made with the switching of themotors. Usual module sizes of capacitors is 50 KVA to be inserted manually or automatically at the substation level for the overall plant power factor improvement.

6. Load Factor Improvement:

Load factor is defined as the ratio of average energy consumption divided by peak value during the period along which the average has been taken. It may be over a day, a month or a year. Higher the load factor, the beter is the utilisation of the generation of electric power. Many electric power utilities charges extra tariff when load factor is low. Table (6) shows the relathionship between load factor and KWh price in Iraq as an example.

Lighting load is usually of low load factor consequences. But cement industry is one with high load factorusually if the plant continue production without external restrictions. However most cement plants are designed to have extra grinding and crushing facilities, i.e. capacities of crushers and cement mills are higher than that of the kiln, so that one or two shifts only are possible in the former sections. Such arrangement reduces the load factor.

Table (6) Kwh cost and Load Factor Relation in Iraq (11)

Monthly Load Factor	Fils / Kwh
0.05	17
0.10	11.5
0.15	9.65
0.20	8.73
0.25	8.2
0.30	7.8
0.35	7.56
0.40	7.37
0.45	7.2
0.50	7.1
0.55	7.0
0.60	6.9
0.65	6.84
"	
"	
1.00	6.555

Table No. (7) shows the change of load factor in two cemen t Plants in Iraq.

Table (7) Monthly Load Factors in two Cement Plants for 1983 (11)

Month	Badoosh Plant	Hammam Al-Alil Plant
January	0.55	0.55
February	0.47	0.62
March	0.36	0.42
April	0.47	0.40
May	0.48	0.38
June	0.49	0.35
July	0.47	0.36
August	0.57	0.35
September	0.49	0.30
October	0.62	0.35
November	0.52	0.33
December	0.54	0.33
Monthly Average =	0.50	0.40
Yearly Load Factor =	0.44	0.31

Various stages of operation effects the load factor also. However manual (and even automatic) operation can be planned so as to reduce the peak power at any moment by proper schedulling of operation of some sections. Such arrangements can be done but with some incon ven-iences or operational difficulties. Cement mills (and some times raw mills) are usually the most flexib le section .

Electric power utilities usually encorage consumers to take more at off peak and discourage extra loads at peak hours. This is done either by voluntary help of bulk consumers or by a two-prices tariff. Low Prices are offered at off peak consumption. It becomes economical then to operate big machines at off-peak hours.

In cases where both cement plants and the utilities are publically owned, it becomes feasible to improve the daily load curve (i.e. improving load factor) by proper planning of some sections in the plant e.g. crushing and cement grinding.

Table (8) shows yearly load factors for 1979 for Arab countries. Figure (5) shows a hypothatical daily load Curve with two possibilities: one without proper bulk load (of cement plant e.g.) management and the second with proper arrangement. Improvement of load factor in the secondcase is clear.

Table (8) Peak Load Energy Generated and Load Factor for few Arab countries for 1979 (40)

Country	Peak Load (MW)	Energy Generated (GWh)	Yearly Load Factor
Iraq	1811	9385	0.592
Kuwait	1950	3[illegible]16	0.504
Bahrain	306	1249	0.466
Sudan	165	859	0.594
Morocco	801	3625	0.516
Saudia Arabia (for 1399 a h year)	2955	13430	0.519

7. Process Automation:

Process automation began in cement industry when the setting of the first control centres where the local control desks or panels installed near the machines to be controlled were instead accomodated in a room situated at a central position within the plant. Associated with this development was the modification and extension of the measuring and control equipment and the signalling of faults and off-normal conditions, so as to give the operating personel the measuring information for centralized monitoring and also necessary means for interventions in the process.

Hence modern process automation can have the following characteristics:-

a) It enables beter quantity control in the plant.

b) It enables centralized control on various operations in the plant, hence reducing manpower needed.

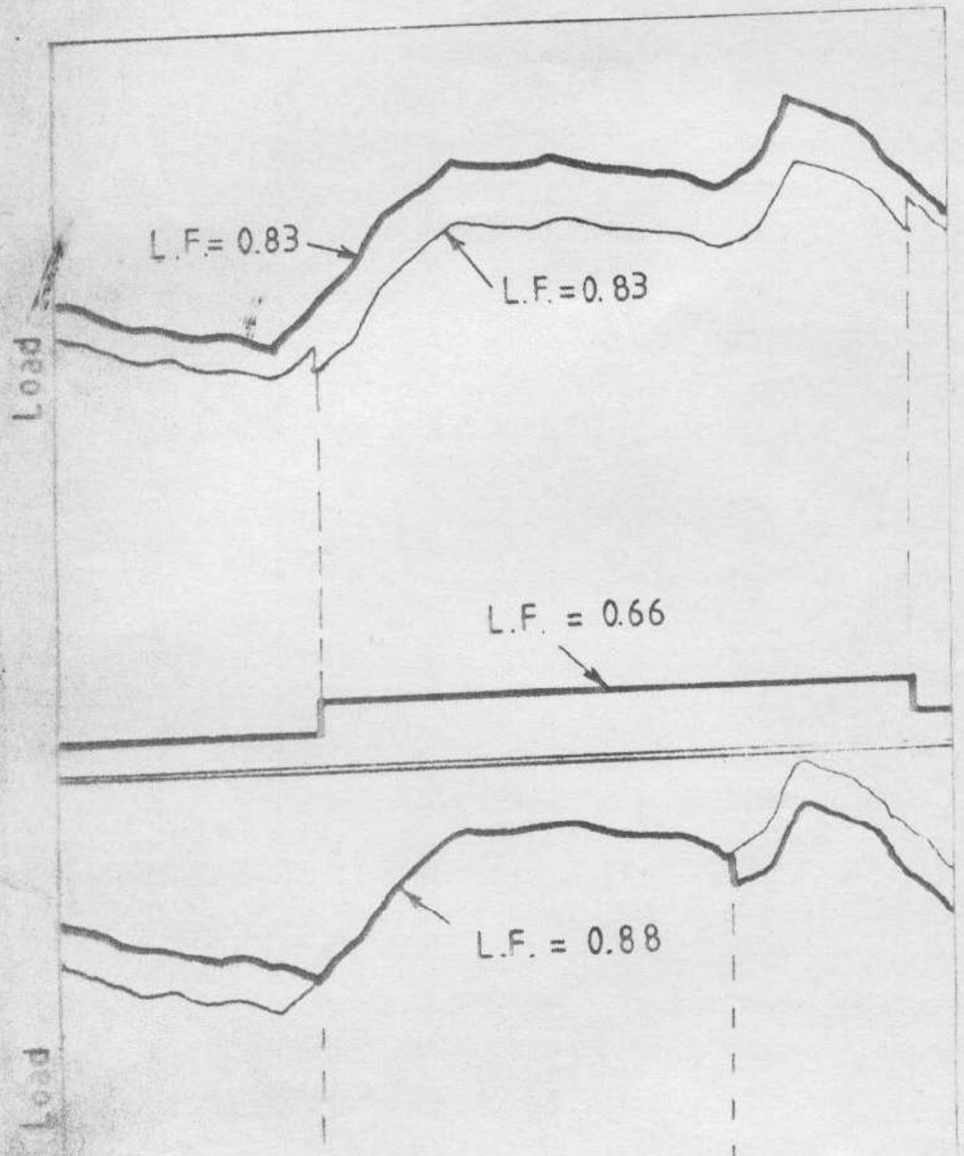


Figure (5)
Load Factor Improvement by Load Manipulation

c) It enables implementation of beter economical procedures and rules because of the provision of lot of data at a central point.

d) Minor control operations are left to equipment degree of automation varies from one system to another. Hence operators are left with decisions of important consequences only.

e) Fault finding can be aided by automation. Hence reducing time maintenance. However higher skill is needed for maintenance of sophisticated electronic equipment.

f) Reduction of fuel consumption is achieved with improvement of operation procedures and practices (6).

Figure (6) shows comparision of performance of a 3200 ton/day kiln with and without computer control [11]. Steady operation which is of many advantages is very clear with computer control over manual operation.

The question of automation is usually attractive leading to unrealistic decisions sometimes. Hence the important question ought to be answered is: What level of automation should be selected? The following are general remarks which may be helpful in this respect:-

1. Type of process (wet, semidry or dry) is to be selected on economical bases such decision is largely related to the plant capacity and fuel availability.
2. When wet process is selected there will be no necessity for sophisticated control systems and the use of computers (except may be for x-ray analysis) would not be necessary.
3. When dry process is selected, complicated control system becomes necessary, susally based on hard-wiredsolid state technology or programmable controllers and computer technology.
4. Decision on technology of electronic squipment should be associated with level of country industrialization since the availability of highly qualified personel for operation and maintenance of such equipment is vital. Strict implementation of modern management systems is very important in process automation based on computer technology. Usually such systems are more difficult to be implemented in developing countries than is industrialised countries. Reliance on foriegn experts should not be execluded in such cases.

Hence for developing countries, less sophisticated equipment could result into a higher overall plant economy than fully computerised systems. However when pilot plants are considered with the transfer of technology is one of the main targets, the picture becomes different. It should be mentioned that modern electronic equipment need extra electric power for their proper use e.g. for airconditioning where less sophisticated equipme nt do not need such facilities. However energy consumption optimisation is necessary in every case.

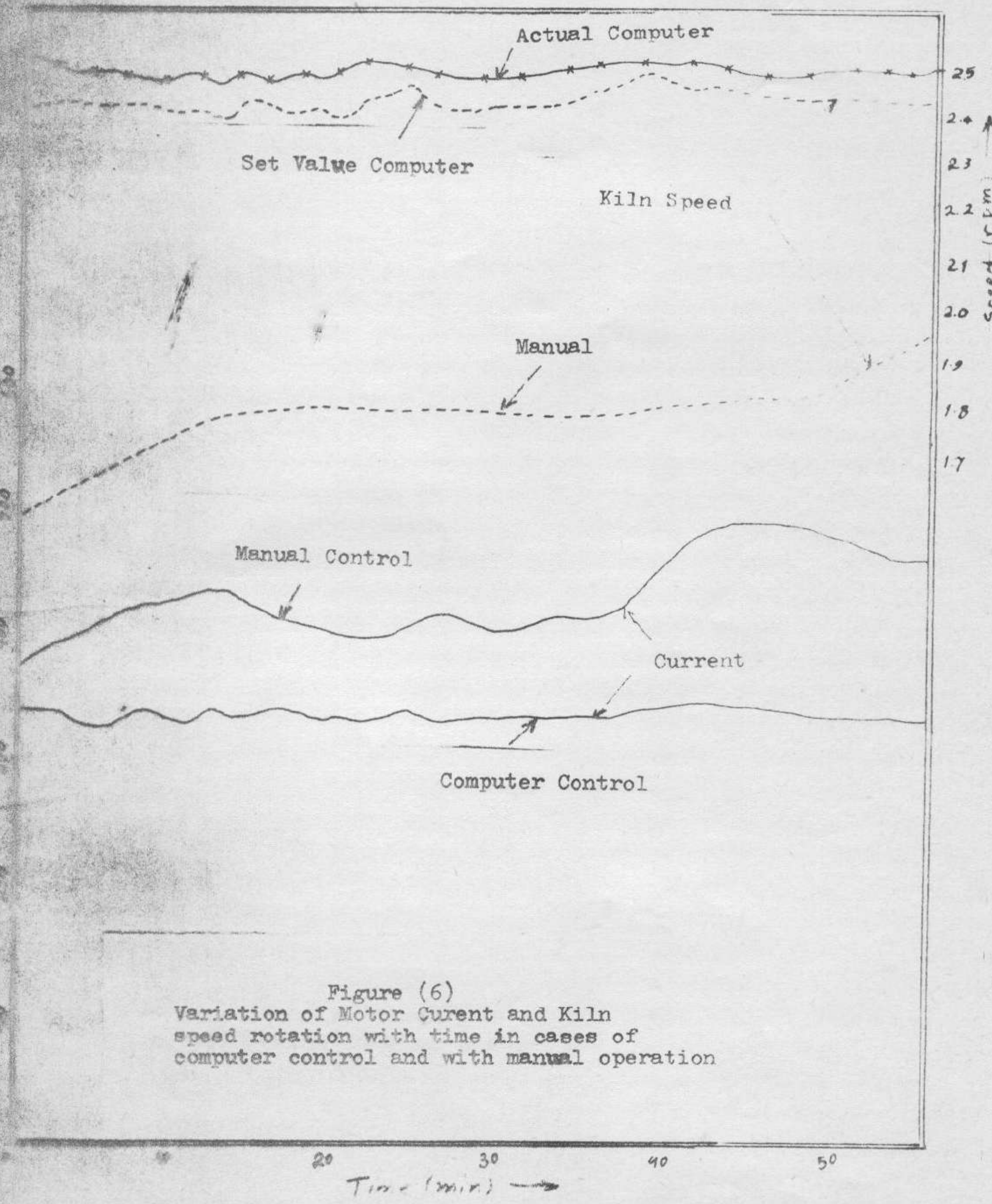


Figure (6)
Variation of Motor Curent and Kiln
speed rotation with time in cases of
computer control and with manual operation

8. Economical Aspects of Management, Maintenance and operation:

8.1 Operations:

Plant operation group have a direct role on production economics. It has been shown that low values of load factors are harmful and costly. Hence to follow the best economical schedulling of the main equipment operation is highly recommended whenever possible. Following the sequence of proper operation practice if this is not included in the hardwired equipment or computer programs, is an operators task which he has to fullfill properly. He has to carry out other operation procedures and rules leading to economy, safety, and long-lasting of equipment, spare parts and consumable materials. Such follow up of regulations has direct effect on electrical energy consumption per ton, fuel consumption and on the overall economy of the plant.

Motors operation, starting and stopping is one of the usual tasks of the operators. It has already been explained how efficiency and power factor are effected by partial loading of motors. Frequent starting and stopping of motors do have bad effects on motors, contactors, starting gears, etc. Hence proper treatments of motors is an important task of the operator.

Pulsating torques have bad effects on motors usually. Some times mechanical faults subject the motors to such circumstance. It is the operators duty to decide when to shut down or restrict or divert certain process or section in the plant.

Hence the operator can play a main role in the energy consumption in the plant through his experience and proper operation.

8.2 Maintenance:

Electrical and electronic equipment are in general delicate sensitive and need good and precise maintenance programs scheduled maintenance as well as remedeal maintenance are both important. Defficiencies in maintenance are reflected on safety, age of equipment, results of defects on other equipment and hence a result of need of longer and more complicated maintenance.

The costs encountened by the need for a good experienced enough number of maintenance personall group, are move than paid-back by the good performance and short down time due to repair. Ofcourse this should be also supported by availability of spare parts, tools and good standard of measurement systems as well of other maintenance groups like mechanical since the mechanical and electrical equipment are of direct effect each on the other.

8.3 Management:

Effect of good manageme nt on economy is obvious. When inventory control is performed properly, training is done continuousely, etc. then work will go smooth with no difficulties for technical personall. In conclusion successfull technical management of cement plant is an intergral part of any plant forcement production on economical bases.

9. Discussions and Conclusions:

It has been shown that economical aspects of electric power are inter-related with many stages of plantactualization starting from plant specification, design, manufacture, erection, commissioning, operation, maintaining, and mamaging of the plan t. At every stage there is a possibility for electric power economy. However the energy consumption should be treated as an integral unit rather than the electric part alone.

The fuel and electricity prices are to be taken into account with their actual cost and prices for most economical energy startegy so that to balance their costs with other factors in the analysis. A forecast of their future prices and availability has to be made. The balance between running cost and fixed cost at the early stages of plant design should be realistic with a background of the energy prices forecast.
Stage of country development should be taken into account at this stage too, expecially for defining the level of process automation needed. When electric power alone is to be considered after the main design features of the plant are fixed, the motors with best economical performance are to be selected. Thyristor control of motors is one of the main features in modern cement plants. Power factor correcting capacitors should be included in design layout. Management of load curve is sometimes necessary when there is shortage of power in electric utility grid especially at peak load intervals.Cement grinding section can help in this aspect usually.

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