South Africa’s main electricity supplier, Eskom, is currently facing challenges concerning the supply of electricity during peak times, especially during the evening peak from 18h00 to 20h00. If large industries can be persuaded to implement DSM strategies in their plant operations, they can help reduce Eskom’s evening peak.

The term Demand-Side Management is focused on tariff-induced load shifting [8], and is used to describe the scheduling and implementation of different activities to influence the time, pattern and amount of electricity consumption in such a way that it produces a change in the load profile of the industry, while still maintaining customer satisfaction [9].

One of the ways in which Eskom encourages the use of DSM is by introducing various pricing structures that are conducive to the intelligent use of electricity by large consumers [10]. The tariff structure used most often by larger consumers is MegaFlex. In this structure, the week is divided into three periods: Peak, Standard and Off-peak periods [11]. The electricity is then billed according to these periods, with peak-time being the most expensive and off-peak the least expensive (higher unit prices are billed during South Africa’s winter months).

Procedures were developed to help identify viable DSM opportunities in a cement factory. These procedures included data gathering and refining, simulation of silo levels and material flows, as well as optimisation of simulation predictions to result in a load shift schedule for different plant systems. An actual cement factory was used as a case study during the investigations.

Results from the case study showed that it was possible to perform a viable load shift of approximately 9 MW from the Eskom evening peak, which could result in an annual electricity cost saving of R650 000. The strategies developed in this study can be expanded to include other equipment in a cement factory, and could be applied in similar cement factories.

Electricity consumption in South Africa is currently growing at approximately 1000 MW per annum [1]. In the past, electricity demand in South Africa was addressed by the erection of large (3000 – 3600 MW) pulverised coal-fired power stations [2]. By 1999 Eskom electrified houses from 50 % in 1995, to 69 % in 2003 [4].

Because of this increase in electricity use, there were some concerns that the current capacity of the electricity system might not be able to cope with the increase. It was found that the electricity demand in South Africa was growing at such a rapid rate, that the current generating capacity would be overtaken by 2007 [5].

The expansion of the network to domestic users is a large driving force behind the formation of an electricity demand curve with two peaks per day, one in the morning between 07h00 and 10h00, and the other in the evening between 18h00 and 20h00 [6]. This can be seen in Fig. 1.

The increase in base load demand is largely influenced by an expanding economy and an increase in energy intensive industries like mines and factories [7]. One of Eskom’s strategies to reduce peak loads is their Demand Side Management (DSM) initiative.

In order to successfully implement DSM, Eskom makes use of energy services companies (ESCOs). By definition, an ESCO is a company that investigates, develops, installs and finances projects designed to improve the energy efficiency and maintenance costs for facilities over a period of seven to ten years [6].
For this article, the focus will be on DSM in the South African cement industry, and possible load shift opportunities that might arise from it.

**Introduction to the South African cement industry**

South Africa currently has 22 cement producing facilities. The cement factories in South Africa vary in age from 3 years to some built in the early 1930s [12]. In a typical cement factory, about 20 - 25 % of costs are attributed to electrical energy consumption.

All the cement companies in South Africa manufacture Portland cement and the basic manufacturing process can be outlined as follows:

- Quarrying for raw material
- Raw milling
- Blending
- Calcining and clinkering
- Cooling of the clinker
- Storage of the clinker
- Finish milling
- Advanced blending
- Packing and loading.

**Developing DSM solutions**

While developing DSM solutions for the cement industry, certain constraints were highlighted by the factory management. These are the following:

- There must be enough storage capacity for production materials.
- The equipment constraints must be taken into account.
- The quality of the products may not be influenced negatively.
- Cement production may not be influenced negatively.
- The downtime of the plant must not be increased because of the cost savings goal.

The raw mills, kilns and finishing mills are the biggest electrical energy users in a typical cement factory. A DSM solution was developed to be applied only in the raw milling circuit. The reason for focusing on this area can be explained by studying the basic layout of a cement factory.

The raw mill is situated between the quarry and the raw mill storage silos. The storage silos feed the kiln through the pre-heater, which feeds into a clinker silo and into the finishing mills to the final product silos.

This involves grinding the raw material into a fine powder by means of horizontal ball mills or vertical roller mills. This is done to achieve the correct particle size for the properties needed in the final cement. This is a cyclical process that uses cyclones and separators to separate coarse and fine particles. The fines continue to the blending silos, while the coarse particles are re-inserted into the mill for further grinding.

Even if the raw mill is stopped for a period of time, the kiln will be able to produce clinker from the raw mill storage silos, which are normally huge enough to accommodate a breakdown occurring in the raw mill circuit.

**Control philosophy**

A control philosophy was developed to realise the DSM potential found in the raw mill circuit. This philosophy had to take into account multiple variables like the electricity pricing structure, material flow, storage silo levels, availability of the mill/equipment, and equipment start up procedures. Control software was developed in order to control the raw mill system accurately according to the DSM control philosophy.

This software utilises the existing supervisory control and data acquisition (SCADA) system of the factory. Automatic dynamic simulation of the raw mill system is conducted in a real-time environment.

The simulation results are then used to optimise the schedule of the raw mill...
circuit for DSM purposes. Through the control software control signals are then conveyed via the SCADA system to the physical equipment in the raw mill circuit.

**Verification of procedures: a case study**

**Background on the factory**

A cement producer situated in the North West Province of South Africa was used as a case study for this research project. The factory receives most of its raw materials by train from a limestone quarry situated a few kilometers away. It currently has two production lines: Line 2 and Line 3. Both of these lines are fitted with the normal equipment such as raw mills, silos, kilns, finishing mills and packing plants.

Line 2 has a hammer mill fitted in front of the raw mill, as the raw mill is of an older design than the mill on line 3. Production is sustained 24 hours per day to satisfy the current high demand for cement in South Africa. It is currently running on the MegaFlex electricity tariff. The following diagram provides a simplified layout of the raw mill systems on the factory.

During normal operation, the limestone is transported from the quarry to the North and South stockpiles. From here, the limestone is transported to the various limestone bins by means of conveyors. The levels of these bins are controlled automatically, ensuring a constant supply of material for the raw mills.

On the way to the raw mills, various additives are added to the limestone. These include sand, clay and iron ore [13]. Raw mill 2 is of an older design than raw mill 3. Raw mill 2 is an air-swept ball mill [14] and also has a hammer mill in series to help with the crushing. Raw mill 3 is a central discharge mill or double rotator mill [14].

This mill also has separators to help separate coarse materials from fine material.

In the raw mill cycle, the material is first milled by means of steel balls known as media. The fine product is discharged from the mill and separated into course and fine material. Those particles of the right size continue on to the blending and storage silos, while the coarse particles are reintroduced into the mill for further milling. The dust is extracted by means of fans.

---

### Table 1: Equipment used in the study on raw mill 2 and 3.

<table>
<thead>
<tr>
<th>Raw Mill 2</th>
<th>Equipment</th>
<th>Installed kW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mill main drive motors</td>
<td>3200</td>
</tr>
<tr>
<td></td>
<td>Hammer mill motor</td>
<td>680</td>
</tr>
<tr>
<td></td>
<td>Hammer mill fan motor</td>
<td>600</td>
</tr>
<tr>
<td></td>
<td>Main fan motor</td>
<td>1020</td>
</tr>
<tr>
<td></td>
<td>RM 2 Total installed capacity:</td>
<td>5500 kW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Raw Mill 3</th>
<th>Equipment</th>
<th>Installed kW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mill main drive motors</td>
<td>3492</td>
</tr>
<tr>
<td></td>
<td>Separator fan motors</td>
<td>436</td>
</tr>
<tr>
<td></td>
<td>Main fan motor</td>
<td>1212</td>
</tr>
<tr>
<td></td>
<td>RM 3 Total installed capacity:</td>
<td>5140 kW</td>
</tr>
</tbody>
</table>

### Table 2: Amount and sizes of the raw mill storage silos on line 2 and 3.

<table>
<thead>
<tr>
<th>Mill</th>
<th>Silos</th>
<th>Capacity (Tons each)</th>
<th>Total Capacity (Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM 2</td>
<td>3</td>
<td>1,530</td>
<td>4,590</td>
</tr>
<tr>
<td>RM 3</td>
<td>2</td>
<td>7,200</td>
<td>14,400</td>
</tr>
</tbody>
</table>

The finished product is known as raw meal and is blended in the blending silos to the correct average chemical proportions. It is then stored in the raw mill storage silos, from where it is extracted to the kiln by way of the pre-heater tower.

**Identifying major electricity users**

The following equipment was identified in the raw mill sections as being the largest electricity users:

<table>
<thead>
<tr>
<th>Mill</th>
<th>Silos</th>
<th>Capacity (Tons each)</th>
<th>Total Capacity (Tons)</th>
</tr>
</thead>
</table>
The raw mills use approximately 27% of the total plant electricity supply.

The equipment on a specific production line must all run together in order to produce raw meal, as it is a continuous process. This means that all the machines will stop together during shutdowns as well. All this is accomplished automatically in the correct sequence by means of interlocks. This simplifies the control for a possible DSM project.

**Establish the storage potential**

As one of the requirements for successful load shift is storage of product during downtimes, the sizes of the storage silos at the factory was determined. The following table provides the sizes of the raw mill storage silos used in this study:

<table>
<thead>
<tr>
<th>Raw Mill Section</th>
<th>Storage Silo Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Mill 1</td>
<td>5000 m³</td>
</tr>
<tr>
<td>Raw Mill 2</td>
<td>4000 m³</td>
</tr>
<tr>
<td>Raw Mill 3</td>
<td>3000 m³</td>
</tr>
</tbody>
</table>

The two raw mill sections of the factory were determined by using the historical statuses of the material handling system from the limestone bins to the raw mills. These statuses were multiplied with the average running power of the different milling sections. The two baselines are shown in Fig. 4 and Fig. 5.

**Simulating the milling schedule**

A computer program was used to simulate the optimized milling schedules for the raw mill systems. In order to be considered successful, the simulation has to comply with certain constraints. The constraints used for the simulation are the following:

- The Eskom MegaFlex tariffs must be used for the savings calculation.
- The electricity cost must be minimised during the peak times (07h00 – 10h00 and 18h00 – 20h00).
- The maximum electrical load cannot exceed the installed capacity.
- If possible the maximum demand must be kept at, or below the current value.
- The correct material flows and silo capacities must be known.
- The simulation must be energy neutral (the areas under the baseline and the simulated schedule must be the same) to ensure that the same amount of material is milled every day.
In order to simulate the silo levels, the raw mill system was simplified as a control volume. It was known what the inputs and outputs of the control volume should be, and as such, the silo levels could be manipulated as a function of the material going in and out of the system.

Fig. 6 shows a simplified concept diagram of the simulation model that was used to simulate the optimised milling schedule.

This simplified method was used to simulate the material flow and silo levels by means of simulation software. This software allows the user to simulate a process or system by choosing to minimise or maximise a result by changing process values subject to user-defined constraints.

The results obtained by this simulation provide a more accurate description of the actual material flow through the raw mill systems than the energy simulation alone. As the two raw mill systems are fed from separate stockpiles and limestone bins, these simulations were done separately for each line.

**Optimised results for raw mill 2**

The relevant results were plotted to provide a graphic representation of the simulation. The goal is to switch off the mill in the Eskom evening peak period. Fig. 7 provides the newly simulated electrical load for raw mill 2:

**Optimised results for raw mill 3**

The new optimised electrical load schedule was simulated for raw mill 3. The results are shown in Fig. 8.

<table>
<thead>
<tr>
<th>Mill</th>
<th>Annual cost saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill 2</td>
<td>R 360 000</td>
</tr>
<tr>
<td>Mill 3</td>
<td>R 290 000</td>
</tr>
</tbody>
</table>

Table 3: Optimised MW and electricity cost savings.
The graphs showing the silo levels for raw mill 2 and 3 indicate that the levels at the end of one day, is the same as the levels at the start of the following day. This indicates that the material flow should continue undisturbed the following day from the same level where it ended the previous day.

Summary of results obtained during the simulation

Table 3 shows a summary of the MW savings as well as the electrical cost savings of the factory.

According to Table 3, the total optimum load shift on the combined raw mill systems of the factory is therefore 9 MW (this can be achieved by stopping both raw mill circuits in the Eskom evening peak period), and results in a total annual electricity cost saving of approximately R650 000.

Time studies

In order to determine the time available for load shift, it is necessary to understand the production and maintenance schedules of the factory, as well as the breakdowns on the two raw mill systems. The following information is important for the time study:

- The production side of the factory works in shifts; thus producing cement 24 hours per day, 7 days a week.
- The raw mill system undergoes routine maintenance of approximately 8 to 12 hours every second week.
- There are various other unplanned and planned events that cause the raw mills to stand.
- Long scheduled stops of the kilns also result in extended downtime periods for the raw mill, since the silos cannot be emptied.

The actual operational values of the factory were used to determine the relevant hours.

It must be remembered that the time needed for load shift was fitted into the current unplanned and planned stops. This is to ensure that the normal planned maintenance time is not reduced, and so that valuable production time does not suffer.

A detailed time study was conducted for 10 months in 2004. The various stop categories were summarised for each month to see the actual allocation of each part making up the total. These results are given in Table 4.

These results show that, on average, it should have been possible to accommodate the load shift in the normal downtime hours (planned specifically). There is also a surplus of available hours as the above time studies show that it should be possible to shift load for five hours per day, whereas the optimised potential simulation shows that it is realistic to shift two hours per day.

In the months where there are fewer hours, it was suggested that the planned maintenance schedule be moved around in such a manner as to accommodate the relevant peak times as part of the downtime and during the winter.

Conclusion

The following conclusions can be made from this study:

- Milling systems on cement factories can be large contributors to demand side management initiatives.
- Such savings can be major, as illustrated by the 9 MW of load shift and resulting R650 000 of energy cost savings.
- The cement industry in South Africa can play a major role in reducing the peak time electricity usage by utilising intelligent scheduling of major energy users.

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- Such savings can be major, as illustrated by the 9 MW of load shift and resulting R650 000 of energy cost savings.
- The cement industry in South Africa can play a major role in reducing the peak time electricity usage by utilising intelligent scheduling of major energy users.

<table>
<thead>
<tr>
<th>RM2</th>
<th>Jun '04</th>
<th>Jul '04</th>
<th>Aug '04</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours operated</td>
<td>572</td>
<td>582</td>
<td>565</td>
<td>573</td>
</tr>
<tr>
<td>Hours available</td>
<td>720</td>
<td>744</td>
<td>744</td>
<td>736</td>
</tr>
<tr>
<td>Hours off</td>
<td>148</td>
<td>162</td>
<td>179</td>
<td>163</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RM3</th>
<th>Jun '04</th>
<th>Jul '04</th>
<th>Aug '04</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours operated</td>
<td>561</td>
<td>575</td>
<td>539</td>
<td>529</td>
</tr>
<tr>
<td>Hours available</td>
<td>720</td>
<td>744</td>
<td>744</td>
<td>736</td>
</tr>
<tr>
<td>Hours off</td>
<td>159</td>
<td>169</td>
<td>205</td>
<td>178</td>
</tr>
</tbody>
</table>

Table 4. Detailed time study for raw mill 2 and 3.

References

[1] Nortje, T, “South Africa’s Demand Side Management Program: A Savings Opportunity”, Eskom DSM, P.O. Box 1091, Johannesburg, 2000, Gauteng. Tel: 011 892-2204, e-mail: nortjeto@eskom.co.za


[7] Krueger, D: Secretary, South African Association of ESCOs, Personal communication, October 2005, Tel: U12 998 0703, Cell: 084 408 6020.


