

CONTROL OF MAXIMUM DEMAND USING A MICROPROCESSOR SYSTEM

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Abstract

With the rising cost of electricity, there are large incentives to reduce the maximum demand charges incurred at a sugar mill. The advantages of good maximum demand control, the control strategy used to implement such a system and a description of the system developed at Mount Edgecombe are presented in this paper.

Introduction

In any large manufacturing process, electricity plays a major role. The electricity costs are a fixed running cost and can be substantial. There is thus a large incentive to bring about savings in electricity costs by improving efficiency or better operating practices. With good maximum demand monitoring and control, the maximum kVA used during a month can be reduced and consequently money can be saved.

Maximum Demand

The normal 'household' electricity account is structured so that a person is charged only for the amount of electricity used.

For bulk users of electricity, the tariff is structured to take into account two factors: the amount of electricity used, and the maximum amount used at any time (maximum demand).

The first cost is based on the cost of producing electricity which is related to the running costs of the power station. This is dependent on the coal used, maintenance and operating costs.

The second factor depends on the cost of installed plant and machinery because electricity, unlike gas and water, cannot be easily stored and the supplier has little control over the load at any time.

The supplier must thus install sufficient equipment to provide power for the maximum possible load drawn at any time.

The consumer in some areas, is charged at different maximum demand rates, depending on when the power is used. This gives an incentive to the user of electricity, to reduce his power usage during peak periods.

The normal tariff structure is split into two main parts, i.e. the total units (kW) used and the maximum demand used. The maximum demand is further split into four types, namely:

- Daily maximum (05h30 to 16h30 and 18h30 to 21h00)
- Restricted maximum (16h30 to 18h30)
- Night maximum (21h00 to 05h00)
- Weekend maximum (Saturday 05h00 to Monday 05h00)

Each type of maximum demand has a different tariff.

Maximum demand is usually measured as an average over a half hour period. The maximum half hour average reached during the month gives the monthly maximum demand charge.

All sugar mills have their own power stations which produce electricity for the milling and process operations. The capability to produce power enables the maximum demand to be greatly reduced when the mill is crushing. For this reason, if maximum demand costs are to be reduced, this reduction will be most effective when the mill is not crushing, i.e. during the offcrop and during days on which the mill is down for maintenance.

Reduction of maximum demand

There are three main ways in which maximum demand can be reduced;

- power factor correction,
- distributing loads more evenly,
- load shedding (maximum demand control).

Power factor correction

Power factor correction reduces the maximum demand by reducing the amount of reactive kVA used, and savings in kVA can be appreciable, in the order of 20 to 30%. (This saving depends on the original power factor.) Almost without exception, power factor correction results in large savings with pay-back periods of less than a year.

Distributing loads more evenly

If loads are distributed evenly so that the power is used at a fairly constant level, then the maximum demand charges will be close to the average power demand, resulting in maximum utilization of the power available and resulting in a minimum maximum demand charge.

In a sugar mill, it is difficult to distribute loads evenly, but with the irrigation loads, it is possible to irrigate during low demand periods and reduce peak demand. If the mill is crushing, it is also possible to put more domestic/irrigation load on to the mill alternators if it appears as if the maximum demand is to be exceeded.

Load shedding (maximum demand control)

All sugar mills have their own power station. Each mill in turn usually supplies its own estates and houses. This situation enables the mill power station to be able to do a certain amount of maximum demand control whereby if the load starts to rise too high, the power to the estates or houses can be cut. This is not a popular practice, but if these cuts occur only a few times in a month, the inconvenience can be justified by the electricity savings made.

Mount Edgecombe System

At Mount Edgecombe, the power factor is poor as the mill has no power factor correction equipment. The possibility of installing power factor correction was investigated and during discussions, it was felt that some form of maximum demand control was needed to ensure that in the event of power factor correction equipment failure, the maximum demand value would still not be exceeded.

Although maximum demand control equipment was available, it was felt that if a microprocessor system with a terminal and printer were developed for this task, then the microprocessor could also be used in the power station to give extra information on the turbines and the loads drawn by each of the power station breakers.

Original System

The original maximum demand metering used conventional meters with current transformers. The meter worked on a 15 minute average with a pointer which indicated the maximum reached since the last time the pointer was reset.

This system suffered several drawbacks:

- The meter did not correspond exactly to the supply authority's meter values because of differences in the averaging times and differences in reset times.
- At different times in the day, different maximum tariffs apply. Because of differences in meter timing, one could never be sure exactly when each metering period had changed.
- This meter could not be monitored continuously and high maximum demand values were often recorded when problems occurred on the mill and the operator had failed to notice the excessive maximum demand.
- It was very difficult to discover exactly when the maximum demand had been exceeded due to a lack of any recording.
- It was difficult to predict the effects of adding or removing load.

Before the new system was started, a specification was drawn up to describe what was required from the new system.

Requirements of new system

- The system had to be reliable and accurate.
- The system had to be totally synchronised with the Durban Corporation meters.
- Quantities had to be displayed in a format which was easy for the power station attendant to understand.
- The maximum demand setpoints had to be automatically varied at the correct times during the day.
- Breakers had to be tripped automatically if it appeared that the maximum demand setpoint would be exceeded.
- Breakers had to trip out only once during any half-hour metering period.
- Breakers had to be switched back in as soon as possible (i.e. the actual kVA and the desired kVA at the end of a metering period had to be as close as possible).
- Short duration overloads should not trip breakers unless these overloads would cause the maximum demand to be exceeded.
- All relevant information concerning power usage, power failure, power factor at the time of maximum kVA and when the breakers actually were tripped out was to be logged on the printer.
- Breakers had to trip out in a given priority sequence.
- The system must have battery backup.

With this specification as a guide, work was started on this project at the end of 1982. Many hardware and software problems had to be solved before a good working system was obtained which was as required.

Hardware Problems

- An opto-isolated input/output board had to be developed
- Battery backup had to be provided
- An Eprom programmer had to be built
- VDU, tape, printer and kW, kVA and re-set pulses had to be correctly connected.

Software Problems Concerned:

- writing a real time clock programme
- programming the input handling routine which operates on interrupts
- programming the routine to monitor power failure times
- deciding on a good tripping strategy
- writing the entire programme so that it could compile in less than 4K EPROM.

The problem of synchronizing the meters was overcome after, at the mill's request, the Durban Corporation replaced the conventional meters with pulsed metering. These meters give out pulses proportional to the kW and kVA used. They also give out a pulse whenever the metering period is over (the meter resets). This enables very accurate measurement of the kW and kVA and the system remains synchronised by using the reset pulse.

System Description

The kW, kVA and reset pulses are fed into the microprocessor through an opto-isolated input card and from these pulses, the kW and kVA values can be calculated. By taking the total number of pulses recorded in any half hour period, the maximum kVA can be obtained.

The microprocessor calculates the kVA and kW values approximately every minute and displays these on the VDU for the power station attendant or shift electrician to see. Every half hour, at the end of each metering period (after a reset has occurred), the kVA, kW and power factor recorded during that time, is printed by the printer together with a simple graph comparing the actual kVA with the setpoint. (See Figure 3).

Load Shedding Strategy

To save money, the maximum demand value must be reduced. To do this, load must be shed. The decisions of when load must be shed and when it is safe to switch load back in, is the most difficult function performed by the control system. Many strategies are possible. The one developed for the Mount Edgecombe system can best be explained by examining Figure 1.

The moving average load (AVE) is compared with the setpoint (SP). Whenever the moving average load is greater than the setpoint (ERROR = 0 or less), then the breakers will start to trip out and reduce load.

As is shown in Figure 1, the load at the start of the metering period is greater than the desired final value. This condition is tolerated until time t_1 when the moving average load is greater than the setpoint value. A breaker then trips and reduces the load by an amount (B).

The instantaneous load is reduced and the average load starts to decrease until time t_2 when the average load is equal to the desired final value. The breaker is not switched back at this stage because if this were done, the load would immediately start to rise causing the final kVA reading to be above the desired value.

Instead, the microprocessor predicts when the breaker must be switched back in to ensure that the final average kVA is equal to the desired final value. The breaker is only switched back in when the value of (AVE) is equal to or greater than the value of (B_p) . The prediction assumes that if the breaker were switched back in, the load on the breaker would immediately increase by an amount (B). In practice, this does not happen, as usually it takes a little time to restart pumps so this assumption usually causes the final kVA value to be slightly below the setpoint.

The setpoint function (SP), was chosen to prevent breakers from switching out in the first part of the metering period. This prevents the breakers from tripping in the event of short duration overloads.

All relevant information is displayed on a VDU which is updated every minute. The display format is shown in Figure 2.

In addition to the VDU, all important events relating to the supply of power are logged on a printer. These include:

- Every time a breaker is switched out, it is logged on the printer together with the load being drawn by the breaker at the time of the trip-out.

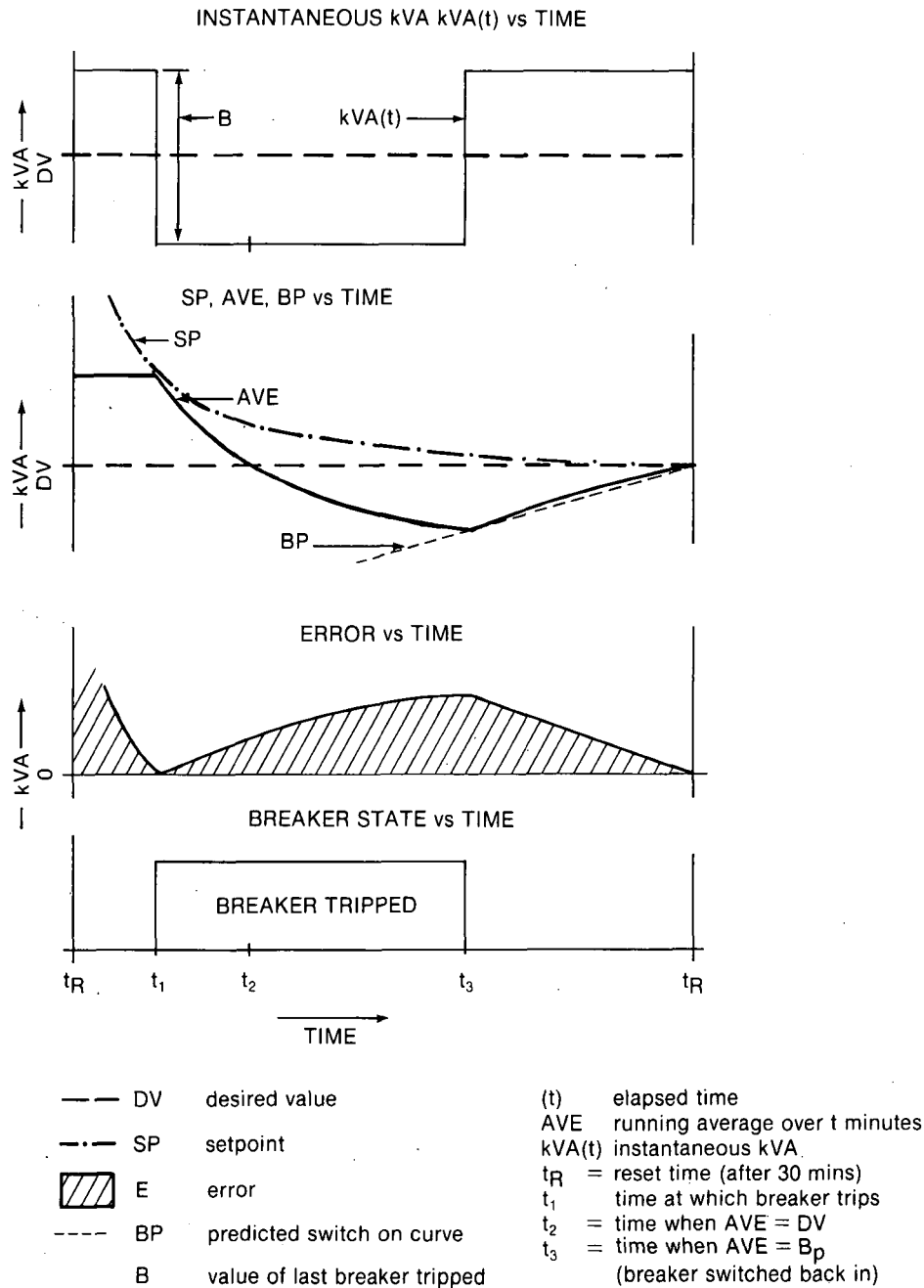


FIGURE 1 Time relationships between the various functions used in the tripping strategy.

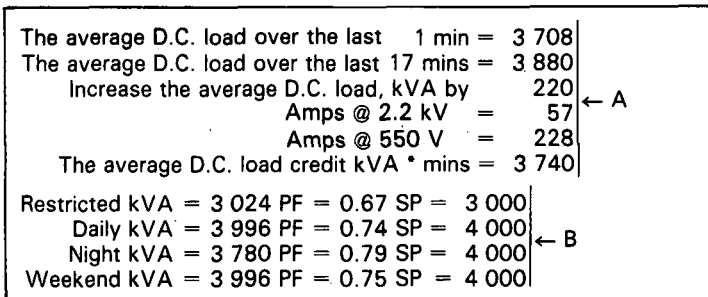


FIGURE 2 The information displayed on the VDU. Information in A is updated every minute B indicates the:

- actual maximum demands occurring since the start of the month (kVA).
- corresponding power factors occurring when these maximums were reached (PF).
- The desired final values (SP).

The values in B are reset every month after the Durban Corporation meters have been read.

- Whenever a total power failure occurs, the time and duration of the power failure is logged.
- Every half hour at the end of each metering period, the power factor, kVA, time and the setpoint value currently in use is recorded on the printer. At the end of each day, a new page is started and the current day and week is printed at the top of the page. At the end of a full day, it is easy to get an idea of the power utilization throughout the day (see Figure 3).

Practical Aspects

The microprocessor used was a Rockwell AIM 65 which has a 20 character display, small printer and a TTY and cassette tape interface all on a single board. It has a keyboard whereby programmes can be entered to start the system.

The programme software was all written in FORTH computer language which proved to be ideal for this project.

Software

The input pulses were worked on an interrupt basis and a real time clock was programmed into the system to enable the different metering periods to be changed and also to enable calculation of the kVA values which are all dependent on real time.

All calculations are done with integer arithmetic as the FORTH software does not do floating point arithmetic. The input and output routines were all written directly in FORTH.

The programme was originally stored in ram which was loaded from a cassette tape but this programme has since been programmed into a 4K EPROM which is resident on board. This programme would have used considerably more memory if it had been programmed in BASIC. The baud rate to the VDU is initially entered from the microprocessor's keyboard; thereafter, all data is entered directly from the VDU.

Hardware

The system layout is shown in Figure 4. The digital input card provides opto-isolation for the incoming pulses which at the same time, provides the necessary interrupts. The output signals are fed to an OPTO 22 board which switches the 110 V DC tripping coils on the breakers when load is to be shed. These breakers cannot be re-closed until the micro gives the necessary permission. The breakers are at present, switched back manually although provision is being made to do this operation automatically.

The VDU is a MICRO BEE which was used because it provides a spare for the mill's other computer system. The printer works from the auxiliary port of the VDU.

The micro is provided with battery backup which relies on batteries used for the 110 V DC tripping supply.

Costs

The breakdown of costs appears in Table 1. The terminal and printer are by far the greatest cost of the system and these costs could be reduced by buying cheaper equipment.

Labour costs are only included where extra labour had to be employed. All other installation and development costs were not included because this system was installed and developed during normal working hours.

TABLE 1
Cost (in Rands) of equipment

| Item | Cost in Rand |
|--|--------------|
| AIM 65 Micro processor with EPROMS | 710 |
| VDU and Printer | 2 800 |
| 6 Channel input digital board* | 50 |
| 6 Digital outputs | 245 |
| Opto 22 board for digital outputs | 99 |
| Components for EPROM programmer* | 90 |
| Cost of cable from sub-station to power station (including labour) | 1 217 |
| | 5 211 |

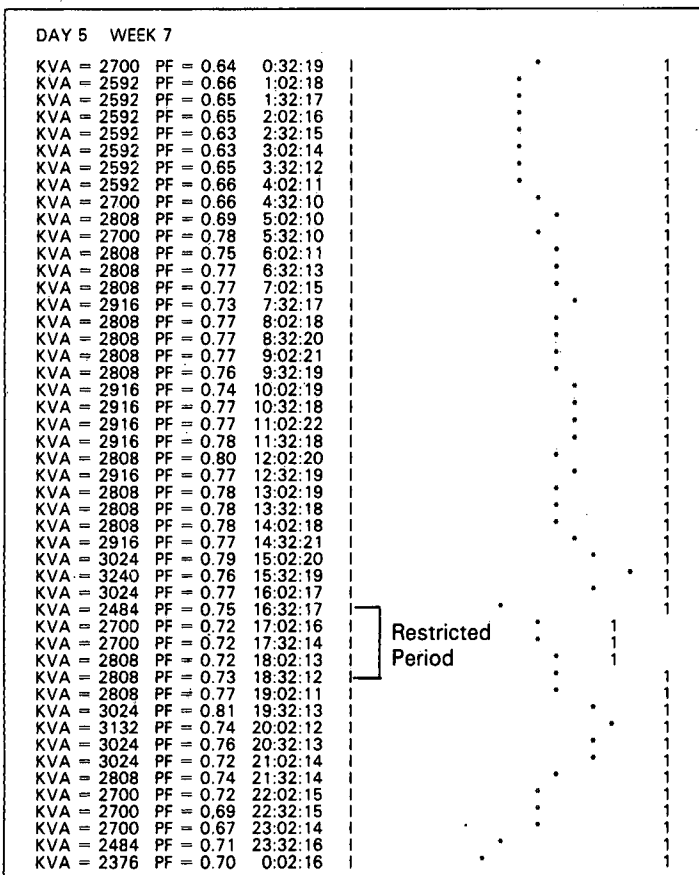
* Made at Mount Edgecombe, hence their low cost.

The mill electricity costs are based on a three part super tension tariff as follows:

$$\text{Total power costs} = [12,32 D + (N - D)\Delta 0,75 + 2,15 (W - D) - 2,53 Rd + 0,0181 U] \text{ Rands}$$

- where:- D = kVA demand reading (between 05h30 and 18h30 and 18h30 to 21h00)
- N = night demand reading in kVA
- W = weekend demand reading in kVA
- Rd = restricted demand reading in kVA
- U = kilowatt hour units.

Δ These two terms only apply when the difference is greater than zero.



l = 0 kVA
 * = Plot of each half hour period
 1 = Desired value

FIGURE 3 Example of what appears on the printer over a 24 hour period. No tripping has occurred.

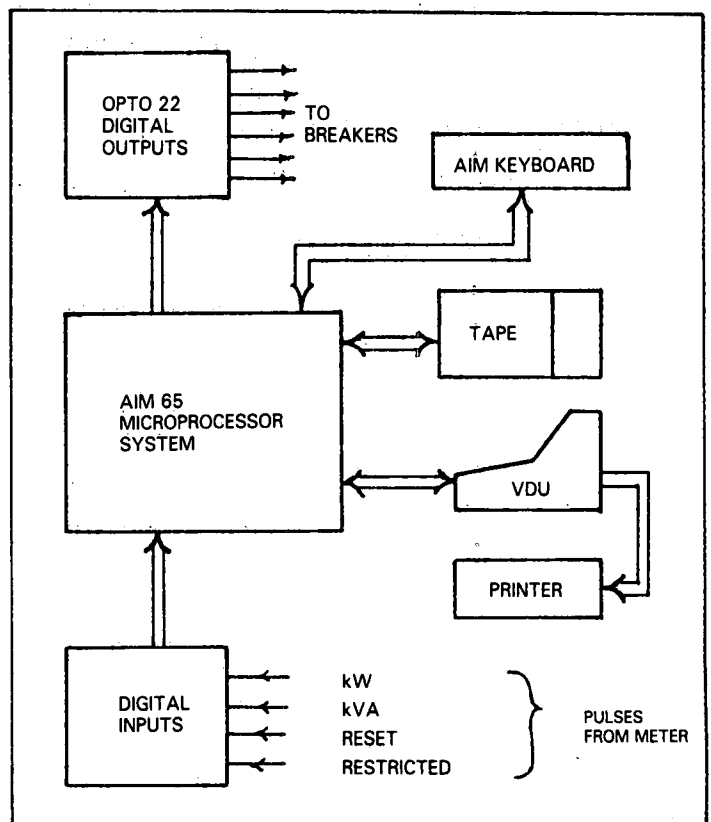


FIGURE 4 Diagram showing maximum demand control system

Typically at the mill, the maximum demand charges represent between 60 and 70% of the total power cost. At Mount Edgecombe, a monthly reduction in maximum demand of only 1,3% is required to pay for the system within a year. It is estimated that during the 1984 offcrop alone, this system paid for itself.

Operational Performance

This system was installed at the beginning of the 1983 crushing season. Initially, it was used to monitor loads and there was no direct switching. The system was developed further and it was fully operational for the first time during June. Intermittent problems were experienced from time to time and the fault was finally traced to a loose wire between the micro and the VDU. Since then, the system has been working very well and is being refined all the time. A plan for the near future is to feed in analog inputs to enable monitoring of the power produced by the turbines.

The system has been totally accepted by power station personnel, so much so that it is difficult to stop the system to make changes for even a few minutes without complaints. The monthly deviation between the maximum demand setpoints and the maximum is usually less than 2%. There has been a marked improvement in power utilization since this system was installed and it has created an awareness of the need to consider maximum demand before stitching is done.

Conclusions

- This project has highlighted the importance of good maximum demand measurement and control and has shown that it is possible to take a cheap, commercially available micro-processor system and develop it into a reliable maximum demand control system.
- Sugar mills have their own power stations and have the ability to cut load which makes it easy to install a maximum demand control system.
- With good maximum demand control, money is saved every month, resulting in a short payback period.
- A maximum demand control system provides backup in the event of power factor correction failure.
- Maximum demand charges become totally predictable resulting in better electricity account budgeting.
- A good record of the load pattern is obtained which enables accurate predictions and better load distribution.
- The capital outlay for maximum demand control is low.
- With good maximum demand indication, it is possible to create awareness of where and when power is used and consequently get greater power utilisation.

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