Power factor correction North Eton mill 1979

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BUREAU OF SUGAR EXPERIMENT STATIONS
QUEENSLAND AUSTRALIA

Division of Mill Technology

POWER FACTOR CORRECTION
NORTH ETON MILL
1979

Director
Owen W. Sturgess

Chief Mill Technologist
P.G. Atherton

August 1979
Staff engaged
R.J. McIntyre
1. **POWER HOUSE LOADINGS**

Instrument readings on the main switchboard on 7/8/79 were:

<table>
<thead>
<tr>
<th>Alternator rating kW</th>
<th>Approx. load kW</th>
<th>Excitation current Rating Amps</th>
<th>Running Amps</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>2600</td>
<td>315</td>
<td>323</td>
</tr>
<tr>
<td>750</td>
<td>600</td>
<td>267</td>
<td>255</td>
</tr>
<tr>
<td>3750</td>
<td>3200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The exciters on both alternators are fully loaded so no increase in factory loading is available without power-factor correction. The temperature of the air from both machines is normal, but it would be unwise to load them further for fear of failure by overheating, particularly in the coming summer months.

2. **POWER FACTOR CORRECTION**

To reduce the excitation current and thereby release the full kilowatt capacity from the alternators requires the following amount of correction:

- Present load: 3200 kW at 0.7 p.f.
- Total alternator rating: 3750 kW at 0.8 p.f.
- Capacitors required to correct 3750 kW from 0.7 to 0.8 p.f.: $3750 \times 0.27 = 1012$

Say 1000 kVAR
3. **COST OF P.F. CAPACITORS**

   The approximate cost of capacitors suitable for this application are set out in Table I.

   **TABLE I**

   **Approximate cost of p.f. correction capacitors**

<table>
<thead>
<tr>
<th>Capacitor type</th>
<th>Capital cost per kVAR</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3 kV single unit</td>
<td>$10</td>
<td>Plus cost of 3.3 kV switch and control relay</td>
</tr>
<tr>
<td>415 V single unit - 50 kVAR</td>
<td>$13</td>
<td></td>
</tr>
<tr>
<td>25 kVAR</td>
<td>$19</td>
<td></td>
</tr>
<tr>
<td>12.5 kVAR</td>
<td>$28</td>
<td></td>
</tr>
<tr>
<td>415 V relay-controlled units</td>
<td>$30</td>
<td></td>
</tr>
</tbody>
</table>

   Clearly the cheapest method of correction would be to install a single 3.3 kV capacitor of 1000 kVAR rating since there is a suitable switch available, the spare 3.3 kV motor vacuum contactor starter. The manufacturers advise that this is suitable for switching up to 2000 kVAR of capacitance.

   Other factors must be considered as well as cost, however.

4. **SELECTION OF CAPACITORS**

   The following aspects limit the maximum size of capacitor which can be switched on the North Eton system:

   (i) voltage surge on switching
   (ii) prevention of resonance caused by transformer-capacitor L-C circuit
   (iii) control of power factor at different load conditions i.e.
         - during start-up on the MEB
         - when using the diesel set
         - slack season

   For these reasons we would suggest limiting the size of the 3.3 kV capacitor to about 600 kVAR and making up the difference in 415 V capacitors. The 600 kVAR unit could be installed initially, and the 415 V units could be installed a few at a time as and when required, to suit the actual load growth as it occurs.

   From the costs shown in Table I, it is best to start with 415 V capacitors of 50 kVAR, wiring them directly to motors to avoid the cost of switch and control gear.
IT IS MOST IMPORTANT TO CAREFULLY MATCH THE SIZE OF THE CAPACITOR TO THE MOTOR TO WHICH IT IS DIRECTLY CONNECTED.

This is to avoid damaging the motor by overvoltage. The maximum size of capacitor is limited to the motor no-load magnetizing current.

From the motor list submitted to us, we have compiled a schedule of p.f. capacitors which can be directly wired to the various motors (Table II). Also shown in this table is the reduced full-load current of the motor with the capacitor connected, for adjustment of the motor thermal overload relays.

Instead of the eight capacitors of 25 kVAR connected to individual motors, you may prefer to install a single bank of 4 x 50 kVAR capacitors, individually switched by a p.f. relay, and connected to a particular feeder. The higher capital cost may well be offset by the reduced installation cost (Refer Table III). This bank would then be available for p.f. correction at the different load conditions described in (iii) above.

The 4 x 50 kVAR bank can be purchased as a complete package including control relay, contactors, wiring and cubicle. Alternatively you may prefer to purchase the various components separately and construct it at the mill, as was done at Racecourse recently, to reduce the cost.

5. CONTROL OF CAPACITORS

The 415 V capacitors wired directly to motors need no additional control and will automatically provide p.f. correction from the moment the motor is started.

The 415 V capacitors in the relay-controlled bank will switch automatically in accordance with the load on the feeder and the settings on the relay.

The 3.3 kV capacitor bank can be switched manually, at the start and finish of each week. However, it would be a simple and inexpensive matter to control it automatically.

A suggested method of control would be to install a current relay on the 3 MW alternator to close the capacitor contactor at about 50 per cent alternator load. Since this will immediately reduce the current on the alternator, it will be necessary to have a differential adjustment on the relay to prevent hunting. The Cutler-Hammer D60 type current relay appears to be suitable, and a calculation is attached showing suitable current and differential settings. (Appendix I).

The capacitor contactor should be inter-locked with the 3.3 kV motor feeder circuit breaker to isolate the capacitor from the 3.3 kV motors following a feeder trip.
An alternative method of control would be to sequence the capacitor contactor with the 3.3 kV motor contactors.

6. **SUPPLIERS OF P.F. CAPACITORS**

Some firms supplying p.f. capacitors and associated controls are:

- ASEA
- ENDURANCE ELECTRIC (TYREE/WESTINGHOUSE GROUP)
- RAMSAY ENGINEERING
- SIEMENS

415 V capacitors would normally be available ex stock Australia from some of the above companies, but the 3.3 kV unit would most likely be on longer delivery or imported.
7. SUMMARY

* 1000 kVAR of p.f. capacitors will be required
* 500 kW of generating capacity approximately will be released
* Install one 600 kVAR 3.3 kV capacitor using the existing spare vacuum contactor motor starter, controlled either
  (a) manually
  (b) by a current relay on the 3 MW alternator
  or (c) by sequencing with the 3.3 kV motor contactors
* Install five 50 kVAR 415 V capacitors wired directly to motors as set out in Table II
* Install either
  (a) eight 25 kVAR 415 V capacitors wired directly to motors as set out in Table II
  or (b) four 50 kVAR 415 V capacitors in a relay-controlled bank, connected to a suitable feeder
* Adjust the motor thermal overloads as indicated in Table II after wiring a capacitor to a motor
* The total capital cost of capacitors is estimated to be approximately $13 000 to $15 000 (Table III). Additional costs will include
  (a) control relay for 3.3 kV capacitors
  (b) installation materials – cable, terminations, supports etc.
  (c) labour

P.G. Atherton,
Chief Mill Technologist.
August 1979.
### TABLE II

Schedule of motors for p.f. correction - North Eton mill

<table>
<thead>
<tr>
<th>H.P.</th>
<th>Volts</th>
<th>Speed</th>
<th>Poles</th>
<th>FLC</th>
<th>Duty</th>
<th>P.F. capacitor</th>
<th>Calculated kVAR</th>
<th>Recommended kVAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RPM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PFLC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>700</td>
<td>3500</td>
<td>1440</td>
<td>4</td>
<td>119</td>
<td>Inj. pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>700</td>
<td>3300</td>
<td>1440</td>
<td>4</td>
<td>119</td>
<td>Inj. pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>450</td>
<td>3900</td>
<td>2900</td>
<td>2</td>
<td>70.6</td>
<td>B.F. pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>415</td>
<td>585</td>
<td>10</td>
<td>444</td>
<td>F.D. fan</td>
<td>250</td>
<td>150 (5)</td>
<td>300</td>
</tr>
<tr>
<td>150</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>275</td>
<td>C.W. fan</td>
<td>59</td>
<td>50</td>
<td>244</td>
</tr>
<tr>
<td>150</td>
<td>415</td>
<td>2900</td>
<td>2</td>
<td>186</td>
<td>Compressor</td>
<td>59</td>
<td>50</td>
<td>158</td>
</tr>
<tr>
<td>150</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>178</td>
<td>Juice pump</td>
<td>32</td>
<td>25</td>
<td>163</td>
</tr>
<tr>
<td>150</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>178</td>
<td>Juice pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>178</td>
<td>Pan stirrer</td>
<td>32</td>
<td>25</td>
<td>163</td>
</tr>
<tr>
<td>150</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>178</td>
<td>Slurry pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>178</td>
<td>Slurry pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>178</td>
<td>Vac. pump</td>
<td>32</td>
<td>25</td>
<td>163</td>
</tr>
<tr>
<td>125</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>150</td>
<td>Juice pump</td>
<td>46</td>
<td>25</td>
<td>142</td>
</tr>
<tr>
<td>125</td>
<td>415</td>
<td>2900</td>
<td>2</td>
<td>160</td>
<td>S.A. fan</td>
<td>46</td>
<td>25</td>
<td>142</td>
</tr>
<tr>
<td>125</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>150</td>
<td>Pan stirrer</td>
<td>30</td>
<td>25</td>
<td>135</td>
</tr>
<tr>
<td>125</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>150</td>
<td>L.G. fugal</td>
<td>30</td>
<td>25</td>
<td>135</td>
</tr>
<tr>
<td>125</td>
<td>415</td>
<td>1440</td>
<td>4</td>
<td>150</td>
<td>L.G. fugal</td>
<td>30</td>
<td>25</td>
<td>135</td>
</tr>
</tbody>
</table>

**TOTAL** 450

Notes:
1. Reduced Full Load Current for adjustment of motor thermal overload protection
2. 3.3 kV feeder corrected by switched capacitor
3. Motor rarely used - emergency or slack only
4. Only one motor run at any time
5. 3 x 50 kVAR units
### TABLE III

**Estimated capital cost of capacitors for p.f. correction**

<table>
<thead>
<tr>
<th>Capacitor connection</th>
<th>Voltage</th>
<th>Capacitor unit size</th>
<th>Qty</th>
<th>Total</th>
<th>Cost per kVAR</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALTERNATIVE 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switched bank</td>
<td>3300</td>
<td>600</td>
<td>1</td>
<td>600</td>
<td>10</td>
<td>6 000</td>
</tr>
<tr>
<td>Motor connected</td>
<td>415</td>
<td>50</td>
<td>5</td>
<td>250</td>
<td>13</td>
<td>3 250</td>
</tr>
<tr>
<td></td>
<td>415</td>
<td>25</td>
<td>8</td>
<td>200</td>
<td>19</td>
<td>3 800</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>1050</td>
<td></td>
<td>$13 050</td>
</tr>
<tr>
<td><strong>ALTERNATIVE 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switched bank</td>
<td>3300</td>
<td>600</td>
<td>1</td>
<td>600</td>
<td>10</td>
<td>6 000</td>
</tr>
<tr>
<td>Motor connected</td>
<td>415</td>
<td>50</td>
<td>5</td>
<td>250</td>
<td>13</td>
<td>3 250</td>
</tr>
<tr>
<td>Relay controlled bank</td>
<td>415</td>
<td>50</td>
<td>4</td>
<td>200</td>
<td>30</td>
<td>6 000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td>1050</td>
<td></td>
<td>$15 250</td>
</tr>
</tbody>
</table>

Note. These costs are for the capacitors only. Additional costs will include:

1. Control relay for 3.3 kV capacitor bank
2. Installation materials
3. Labour
APPENDIX I

CONTROL OF H.V. CAPACITOR

CAPACITOR DETAILS
SWITCHING DEVICE
CONTROL RELAY

600 kVAR 3.3 kV
ENGLISH ELECTRIC VACUUM CONTACTOR TYPE HMC
CUTLER HAMER TYPE D60 WITH ADJUSTABLE
CURRENT SETTING 0-5 AMPS
AND ADJUSTABLE DIFFERENTIAL
(OR EQUIVALENT)

Relay installed on 3 MW alternator circuit and
adjusted to switch capacitor at about half-load.

RELAY SETTINGS:-

Alternator full-load current = 660 amps
C.T. Ratio = 700/5
Relay current setting (0-5A) = 2.5A

Assuming the 3 MW set is operating alone at 0.7 p.f., switching will
occur as follows:-

Capacitor switched on at 2000 kVA load at 0.7 p.f. (θ₁)
Load immediately drops to 1600 kVA at 0.875 p.f. (θ₂)
Load current drops from 350 amps to 280 amps
∴ current differential = \frac{350 - 280}{700} = 10%
∴ differential setting = 15% approx.

CURRENT SETTING - 50%
DIFFERENTIAL SETTING - 15%
ESTIMATED COST OF INSTALLING 5 MW TURBOSET IN LIEU OF P.F. CORRECTION

BSES report entitled "Electrical Augmentation for 1977 - North Eton Mill" estimated the capital cost of installing the 5 MW turboset and associated electrical distribution equipment at $245 000.

This cost included electrical plant only which, while not expressly stated in the report, should have been clear from the cost breakdowns in Appendices I, II and III.

This cost also included the following items:–

(a) transformers to the value of $105 000
(b) spare switchgear panels to the value of $ 24 000

Total $129 000

Since the transformers have been purchased and the spare switchgear panels can be deleted, the net capital cost is then reduced to $116 000.

Allowing for inflation, this figure would now be expected to be about $150 000.

Based on the cost of the latest turbo-alternator installations at mills for machines of twice the rating, an approximate estimate of the overall cost of installing the 5 MW unit is set out below:–

<table>
<thead>
<tr>
<th>Item</th>
<th>Details</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Net capital cost of electrics</td>
<td>150 000</td>
</tr>
<tr>
<td>2</td>
<td>Turbo-alternator foundations</td>
<td>35 000</td>
</tr>
<tr>
<td>3</td>
<td>Power house building (without crane)</td>
<td>65 000</td>
</tr>
<tr>
<td>4</td>
<td>11 kV switchroom</td>
<td>10 000</td>
</tr>
<tr>
<td>5</td>
<td>Steam mains, valves etc.</td>
<td>50 000</td>
</tr>
<tr>
<td>6</td>
<td>Electrical installation materials etc.</td>
<td>30 000</td>
</tr>
<tr>
<td>7</td>
<td>Transformer pads</td>
<td>10 000</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>$350 000</td>
</tr>
</tbody>
</table>

Explanatory Notes:–

Item 1 Cost as indicated in 1977 BSES report, with approximate adjustment for inflation

Item 2 Cost is for contract to supply and construct foundations to design by turbo-alternator manufacturer

Item 3 Cost is for contract to design, supply and construct power house building suitable for overhead crane but not including crane
Item 4  Cost is for contract to build fireproof room.

Item 5  Cost is only a guess as it will depend upon the location of the turboset, valves required etc.

Item 6  Cost is for sundry items associated with the installation of the turbo-alternator, switchgear, transformers, cables etc.

Item 7  Cost is for installing transformers on pads with an oil-ump.