LOAD FLOW STUDY FOR NCHALO MILL

CHAKHWANTHA S G

Electrical Section, Illovo Sugar Ltd, Nchalo Mill, Private Bag 50, Blantyre, Malawi
schakhwantha@illovo.co.za

Abstract

In any production factory, knowledge of the operating power factor (PF) is of great importance because it is included in the electricity tariff by the supply authority, who calculate the maximum demand charge per kilovolt ampere (kVA), to account for the load current's effect on the supply system's efficiency. For a given kilowatt (kW) power demand, a low power factor gives a high kVA maximum demand charge and *vice versa*. The PF value also indicates how much of the designed capacity of installed power distribution equipment is being used to supply useful power to production equipment, and how much capacity is limited as a result of the distribution equipment being used wastefully to transmit ineffective reactive (wattless) current.

The requirement for such information justifies the analysis of a factory's power reticulation system to identify areas for useful improvement(s).

This paper presents the assessment of Nchalo mill's reticulation system, together with the analysis performed on the obtained information. Implementation of recommendations following from the analysis resulted in a reduction in the risk of factory blackouts and damage to critical mill equipment.

Keywords: power factor, capacitors, active power, reactive power, electricity tariff, maximum demand

Introduction

Traditionally, the power reticulation system for most raw sugarcane factories consists of two power supply sources, (i) power from the electricity supply authority, and (ii) internal generation using steam-driven turbo-alternators in the factory powerhouse. Internal generation is used in normal factory operation, with the former acting as a backup source. Both sources are connected to the factory distribution board, from where power is drawn by the different mill loads via step-down transformers. The reticulation system layout for Nchalo mill is shown in Figure 1.

The capacity of the distribution transformer which is used at a given time is partly dependent on the operating power factor (PF) of the system being supplied by the particular transformer. When the PF is poor, the available capacity of the supply transformer is limited, due to high reactive volt-ampere (VAr) loading, i.e. the transformer is pushed toward its designed capacity to generate reactive current (this current is responsible for the energy that circulates between the supply and the load without being used for power by the load). This has the effect of increasing the heating losses in the transformer and reducing its efficiency, as well as reducing the transformer's capacity to accommodate additional loads.

An example of the relevance of PF was in a risk reduction project at Nchalo mill. In order to create a balanced system for injection water supply to the pan floor, it was decided to relocate one 132 kW, 243 A injection pump motor from the centrifuge motor control centre (MCC), which had four pumps, to the diffuser MCC which had two. The objective was to have sufficient water supply for maintaining vacuum in the boiling pans, in the event that one of the MCCs tripped due to a fault, or for any reason necessitating deliberate tripping. However, the proposal could not be implemented immediately, as there was little information regarding the actual transformer loading and the operating PF for the latter MCC.

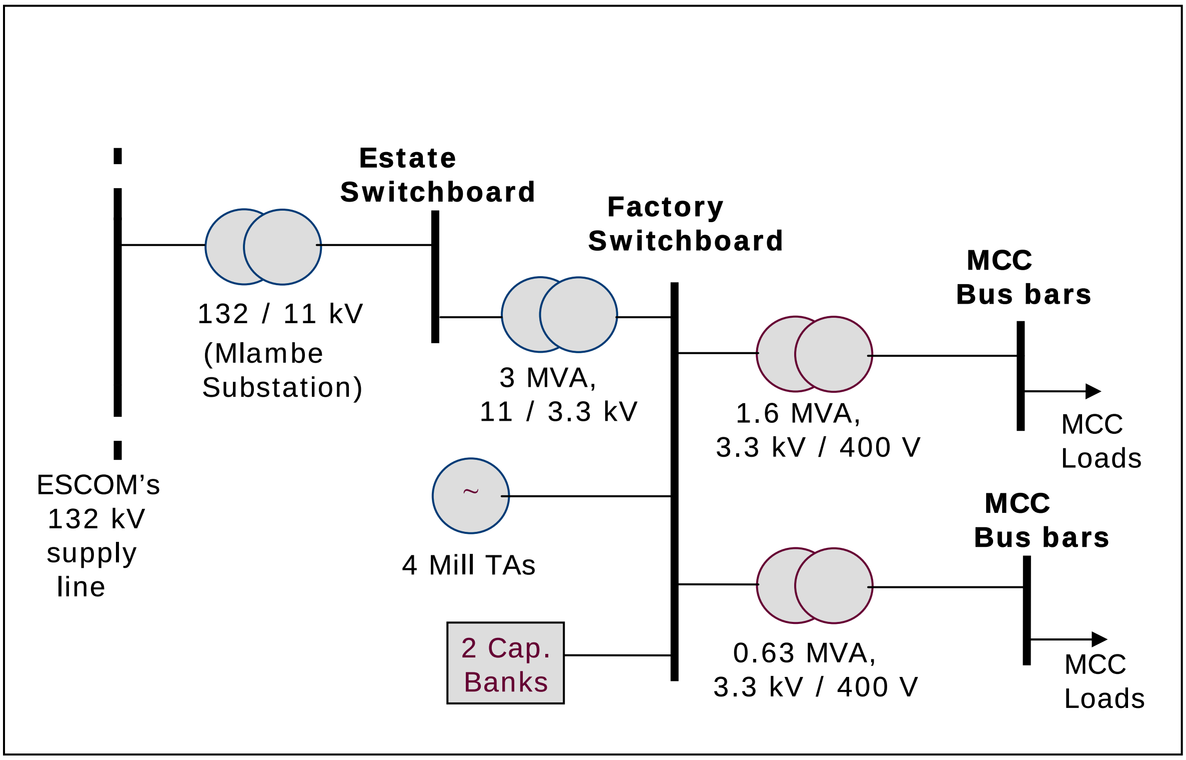

Figure 1. General reticulation system layout for Nchalo mill.

This paper therefore presents the assessment of Nchalo mill's power reticulation system with regard to capacity limitations of the MCC supply transformers, due to the poor power factor. It also looks at the issue of risk reduction from both the operational and equipment point of view. The paper deals with three principal topics. Firstly, reducing the risk of factory blackouts due to tripping of the mill's internal power generating machines is discussed in terms of creating a load shedding system with critical and non-critical loads, where the latter can be switched off to provide load relief to the remaining machines and hence maintain power supply to the mill. Secondly, reducing the risk of damage to critical mill equipment is considered by splitting strategic loads between different MCCs. Thirdly, correcting the power factor, specifically to create extra capacity to accommodate additional loads.

Materials and Procedures

The assessment work was carried out when the mill was in full operation and was completed over a 10-day period, with each day dedicated to data collection on a single MCC, in order to collect data at different times of the day so as to obtain data that was representative of the operating conditions on each MCC.

To achieve the objectives of the project, the following procedures were performed.

Average transformer load current and percentage loading

The average load current being drawn from each MCC supply transformer was obtained by taking five measurements at two-hour intervals. A data logger (TRMS METRA HIT | 26M) and a current clamp (500A~/0.5A~ Chauvin Arnoux Type Y2N) were set to measure and record the current variations over a two-hour period. The data from each measurement interval was then downloaded and analysed on a laptop, using the METRAwin® 10 (v.5.22) measuring PC software, which gave an average value of the current. That value was verified by taking quick readings using a clamp meter as a check system.

Power factor measurement

The operating PF for each MCC was measured using a portable analog PF meter (YOKOGAWA Type 2039) and the clamp meter, both of which were connected in a single-phase measurement format. The clamp was connected to the current terminals of the meter, and clamped to one of the phases. The voltage terminals on the meter were connected to the same clamped phase and the neutral point. The meter then gave a reading of the PF, which was recorded.

At the end of the day, the average value of the five readings of both the current and the PF was calculated and recorded as the value for the average current and the PF for that particular MCC.

Single-line diagram

A list of all the loads connected to each of the 10 MCCs was compiled from existing records and, where such records were not available, by physically checking on the particular MCC panels. For those loads where the ratings could not be found in existing records, an estimate was made, assuming that the overload current on each motor starter had been set at twice the kilowatt (kW) rating of the motor connected to that particular starter.

Projects results

Data collected from all the measurements was compiled in graphical format, showing the difference between the actual average current and rated current values for the MCC supply transformers and the present operating power factor values for each mill MCC, with reference to a standard power factor value of 0.85 lagging (Figure 2).

Mathematical analyses

To determine how much of each distribution transformer's designed capacity is being used to supply the connected loads, the current (A) values from the data in Table 1 were used to calculate the percentage loading as:

$$\%\ \text{loading} = \frac{\text{average load current}}{\text{rated current}} * 100 \qquad (1)$$

Further calculations were done for power factor improvement on all mill MCCs (except Centrifuge #2 and sugar handling MCCs) with 0.85 chosen as the new PF value. These calculations involved finding the active power on each MCC using equation 2:

$$P = 1.73 * V_L * I_L * \text{Cos } \varphi \quad (2)$$

where P is the average active power in kilowatts (kW), V_L is the line-to-line voltage in volts, I_L is the line current in amps and Cos φ is the power factor.

The rating of the required capacitance to improve the PF from the present operating value to the proposed 0.85 lagging value was calculated as the difference between the system's present reactive power loading and the calculated loading after PF correction. The reactive power was calculated using equation 3:

$$Q = P * \text{Tan } \varphi \quad (3)$$

where Q is the reactive power in kVAr, P is the active power as calculated from (1) and φ is the angle between the system voltage and current and calculated from the PF value using equation 4:

$$PF = \text{Cos } \varphi \quad (4)$$

A sample calculation of the percentage loading and the required reactive kilovolt-amperes (kVAr) for PF correction has been done for the diffuser MCC and is included in the appendix. The results for the PF calculation are shown in Table 2.

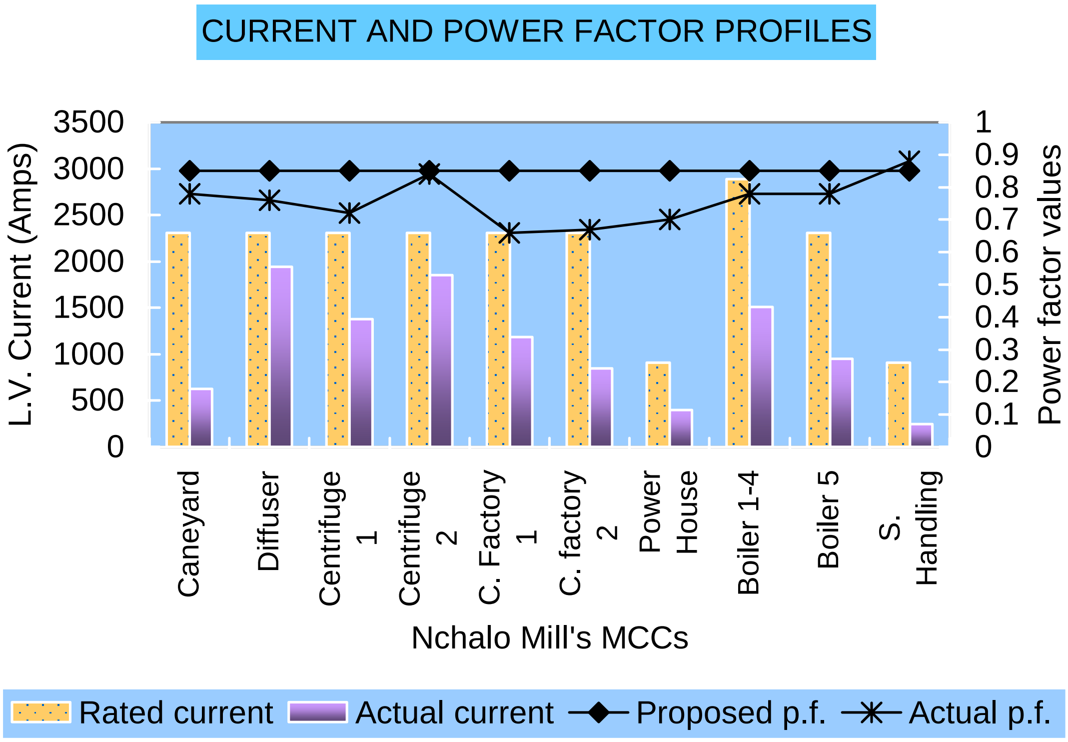

Figure 2. Current and power factor (PF) profiles for Nchalo mill's MCCs.

Table 1. **Transformer loading and power factor data for Nchalo mill's MCCs.**

MCC	Transformer capacity	Rated (FL) current	Average load current	% loading	Present PF
Cane yard	1.6 MVA	2,309 A	630 A	27.28	0.78
Diffuser	1.6 MVA	2,309 A	1,941 A	84.06	0.76
Centrifuge #1	1.6 MVA	2,309 A	1,375 A	59.55	0.72
Centrifuge #2	1.6 MVA	2,309 A	1,855 A	80.36	0.84
C. Factory #1	1.6 MVA	2,309 A	1,183 A	51.23	0.66
C. Factory #2	1.6 MVA	2,309 A	847 A	36.68	0.67
Power House	0.63 MVA	910 A	398.6 A	43.80	0.70
Boiler 1-4	2.0 MVA	2,887 A	1,512 A	52.23	0.78
Boiler 5	1.6 MVA	2,309 A	950 A	41.14	0.78
Sugarhandling	0.63 MVA	910 A	251 A	29.45	0.88

Table 2. **Capacitor ratings for power factor improvement.**

MCC	Capacitor rating (kVAr)	Extra capacity created (kVA)	Current reduction (Amperes)
Cane yard	62.83	36.58	55.58
Diffuser	228.66	135.27	205.52
Centrifuge #1	224.29	138.41	210.29
Centrifuge #2	–	–	–
C. Factory #1	266.45	174.05	264.44
C. Factory #2	174.01	105.60	160.44
Power House	73.52	46.29	70.33
Boiler 1-4	134.16	77.28	117.41
Boiler 5	89.01	51.49	78.23
Sugar handling	–	–	–

Mill single-line diagram

From the compiled list of all the loads on a particular MCC and the current and PF data, a single-line diagram was produced, showing all 10 MCC supply transformers, their rated capacity (kVA), rated current, average current drawn, percentage loading, and the present operating PF All the loads on a particular MCC were shown connected on the low voltage (LV) side of each transformer. The objective of this diagram was to represent all the collected information in a compact form for quick reference when required.

The format that was used in compiling the information is shown in Figure 3 and is applicable to all mill MCCs.

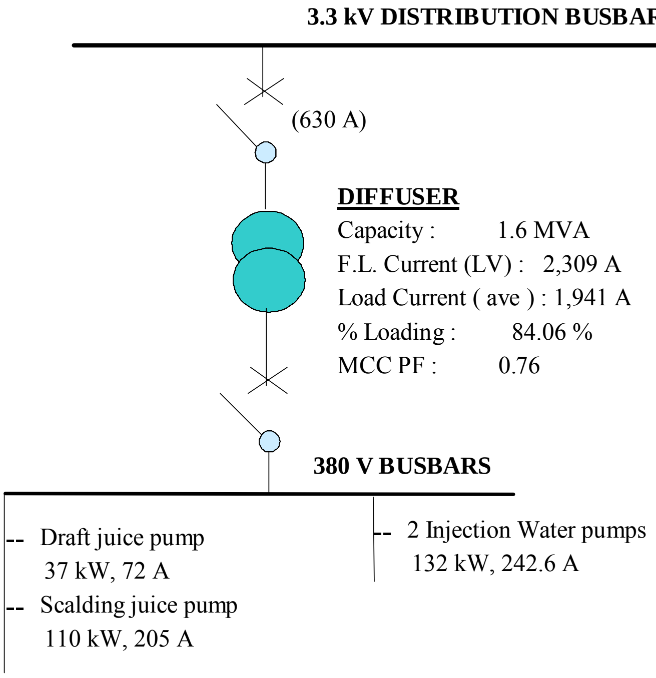

Figure 3. Single-line diagram format, using diffuser MCC as an example.

Discussion of results

Current and PF data analysis

From the measured data, it was seen that most of the transformers are operating at below half of their rated capacities, with most of the MCCs operating at PF values close to the factory's overall 0.80 lagging PF.

The two Central factory MCCs were found to have the poorest PFs, which placed them as the most likely candidates for PF correction. An investigation was done to ascertain the reason behind the poor power factor. The most probable reasons were the large motors on the MCCs or the supply transformers themselves operating well below their rated capacity. However, from measurement data, it was found that such motors operate at more than 50% of rated capacity. It was also noted that some of the least loaded transformers (see Figure 2) have better PF values. No conclusion was therefore reached as to the cause of such a scenario observed on the MCCs. Only the diffuser MCC was ear-marked for improvement because, as pointed out in the introduction, there was a proposal to move an injection water pump (132 kW, 242.6 A) to this MCC, and the installed capacitor panel would thus create extra capacity to accommodate the extra load. Despite the PFs for the two Central factory MCCs being the lowest, these were not considered for improvement because of their low percentage loading values, which gave no justification for such an investment.

Nchalo mill's single-line diagram

A study of the diagram showed that supplies to each item of critical mill equipment are all located on one MCC. For example, all the boiler feed water pump motor starters are located on Boiler 1-4 MCC. Such a scenario was seen to be hazardous in the event that this MCC tripped while the mill was running, as there would then be no water supply to the boilers. This would increase the risk of damage to the boiler tubes as a result of no water, and tube collapse due to the intense furnace heat. A similar scenario pertained to the kestner, where all the clear juice pumps that supply that vessel are on the Central factory #1 MCC.

Project recommendations

From the results obtained from this project, three recommendations were made for implementation.

First was to improve the PF on the diffuser MCC from the present 0.76 to 0.85 lagging, using a 250 kVAr capacitor bank with an automatic power factor controller to switch in/out capacitor blocks, depending on the difference between the set PF and the actual MCC PF value. The objective is to create extra capacity (kVA) for accommodating an extra injection water pump from Centrifuge #2 MCC. From Table 2, a 0.85 PF on the diffuser MCC gives a 206 A current reduction, which is enough capacity to accommodate the 132 kW, 243 A pump motor, considering that the motor normally runs at less than the rated current. Despite having two 75 kW SIMOVERT-type variable speed drives on the MCC, it was still considered acceptable to go ahead with implementing the recommendation, since results of a mill load survey conducted in the plant showed that the voltage and current total harmonic distortion on the MCC are within acceptable limits (V_{THD} less than 1.2%, I_{THD} less than 3.5%).

Secondly, all the strategic loads need be split between different MCCs to reduce the risk of damage to critical mill equipment, such as the boilers and the kestner vessel, that are fed by those particular loads. The objective is to make sure that, should either of the MCCs trip for any reason, the other pump would still be supplied from another MCC and maintain the water supply to the boilers, or the juice to the kestner, and so prevent damage to this equipment due to their tubes running dry.

The third recommendation was to create a load shedding system for the mill by carrying out a detailed study of the developed single-line diagram to determine which non-critical loads should be shifted to one or two MCCs, which could then be tripped as a load shedding strategy. The non-critical MCC will be loaded to get its percentage loading as high as about 80%, so as to provide a reasonable amount of load relief on the supply in the event of a load shed requirement. Other proposals on how such a system can be implemented will also be looked at, in order to come up with a more efficient and cost effective load shedding system.

Conclusions

This paper presented the assessment of the power reticulation system for Nchalo mill, with the main focus being on the capacities of the transformers being used and the PF at which each of the MCCs are operating.

The paper has brought into focus the need to design an economic and efficient load shedding system that will provide sufficient load relief on the remaining internal supply system (TAs), especially when TA #4, which is the largest TA at 4.0 MW, trips from the system. The shifting of the strategic loads between MCCs will greatly reduce the risk of damage to the boilers and the kestner, which are critical equipment for the mill, in the event of one of the MCCs tripping for any reason.

Although the results presented in this paper are applicable to Nchalo mill, the issues of risk reduction and equipment capacity limitations is applicable to most mills. Other raw sugar factories that have a situation similar to that of Nchalo mill, could benefit from a load flow study of their own plant to identify distribution constraints and possible risk areas.

In the 2006/2007 crushing season, the author will investigate in more detail the implementation of an effective and more economical load shedding system for Nchalo mill.

Acknowledgements

The author would like to acknowledge the efforts of Garry Rorich, Electrical Engineer at Nchalo mill, who was instrumental in sourcing the equipment that was used in the data collection, and also for providing support and guidance on the flow of the project. The author would also like to thank Stuart Watson, Factory Manager at Nchalo mill, for his constructive criticisms and suggestions throughout the study.

APPENDIX

Percentage Loading Calculation

Rated transformer current (LV) = 2,309 A
Actual load current (average) = 1,941 A
$$\% \text{ loading} = \frac{\underline{1{,}941}}{2{,}309} \times 100$$
$$= \underline{84.1\%}$$

Calculations for created extra capacity (kVA) and current reduction

Transformer vector group : Dyn 11
Present PF = 0.76 lagging
Actual load current (average) = 1,941 A
Line voltage (LV side) = 380 V

$$\therefore S = \sqrt{3} * VL * IL$$
$$= \sqrt{3} * (380V) * (1941A)$$
$$= \underline{1{,}278 \text{ kVA}}$$

$$\& \ P = S * \text{Cos}\varphi$$
$$= (1{,}277.53 * 10^3)\,(0.76)$$
$$= \underline{971 \text{ kW}}$$

For new PF = 0.85 lagging
$$S\ (\text{new}) = P \div PF\ (\text{new})$$
$$= (970.92) \div (0.85)$$
$$= \underline{1{,}142 \text{ kVA}}$$

$$\& \ IL\ (\text{new}) = S\ (\text{new}) \div [\sqrt{3} \times VL]$$
$$= (1{,}142.26 \times 10^3) \div [\sqrt{3} \times (380)]$$
$$= \underline{1{,}735 \text{ A}}$$

$$\text{Extra capacity} = S - S\ (\text{new})$$
$$= (1{,}277.53 - 1{,}142.26) \text{ kVA}$$
$$= \underline{135 \text{ kVA}}$$

$$\& \text{ Reduction in current} = IL - IL\ (\text{new})$$
$$= (1{,}941 - 1735.48) \text{ A}$$
$$= \underline{206 \text{ A}}$$

Capacitor rating (kVAr) calculations

$$\text{Initial kVAr} = P * \text{Tan } \varphi$$
$$= (971) * (\text{Tan } 40.54°)$$
$$= \underline{830 \text{ kVAr}}$$

$$\text{Final kVAr} = P * \text{Tan } \varphi(\text{new})$$
$$= (970.92) * (\text{Tan } 31.79°)$$
$$= \underline{602 \text{ kVAr}}$$

$$\therefore \text{Capacitor Rating} = \text{Initial kVAr} - \text{Final kVAr}$$
$$= (830.42 - 601.76) \text{ kVAr}$$
$$= \underline{229 \text{ kVAr}}$$